CoA NOTE M & P No. 23

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THE IMPROVEMENT OF MICRO-ELECTRONIC COMPONENT PRODUCTION OPERATIONS BY THE APPLICATION OF CRANFIELD DEVELOPED PRECISION ENGINEERING TECHNIQUES

by

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October, 1969

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SUMMARY

From an examination of the Cranfield Universal Measuring Machine certain features were selected. These features were linked together with some of the manufacturing and assembly operations used to make dual-in-line integrated circuits. The result was a group of design specifications for automatic machines to effect substantial improvements in productivity in those manufacturing operations.

The report describes the preliminary work which culminated in the preparation of specifications, discussions with manufacturers and changes which were made as a result of these discussions. The report concludes with a number of proposals for continuing the main work and suggests certain additional, separate, investigations which, it is thought, would produce information of value to the semi-conductor industry.

Contents

Acknowledgements

The author wishes to acknowledge the help received from discussions with staff of the Companies named in Section 9. Especially to Texas Instruments Ltd., for permission to take, in their works, the photographs which are the subject of illustrations numbers 33, 34, 35, 36, 37, 38, 42 and 43: to Emihus Microcomponents Ltd., for permission to use illustrations numbers 20 and 21; and to Packman Research Ltd., for illustration number 39.

It is also desired to express appreciation of the help, practical and otherwise, received from colleagues in several Departments of the College.

1. Initiation of project

Development work in the Department of Production Engineering at Cranfield takes place in a number of related disciplines. It was thought that it would be of value to make an investigation to determine if any advantage could be taken of any of this development work in the production processes of micro-electronic components.

Micro-electronic components were selected because, in general, production volume, starting with simple equipment, usually expands extremely rapidly and, frequently, at a rate which runs ahead of the development of semi-automatic, or automatic, assembly equipment.

2. Study of the Cranfield Universal Measuring Machine

The particular Cranfield project selected for study was the high precision universal measuring machine, see Figure 1. A good deal of work has been done on this machine and the stage of producing hardware for the prototype had been reached. Three of its features, especially, were studied to determine if use could be made of them in the manufacture of semi-conductor devices plus an overall feature. This overall feature of the machine is its ability to position the measuring head, within a few millionths of an inch, on a complete series of locations by pre-programmed tape control. The three individual features are as follows:

The main units of the machine are large and heavy and it is necessary that they can be moved with negligible friction or use of energy, and in exceedingly small increments of distance. This was achieved by the use of hydrostatic bearings to support the main moving parts.

The actuating mechanism to move the main moving parts was required to have a travel of up to 30", as nearly frictionless as possible, capable of fast or slow motion, movement in very small increments of distance, completely free from backlash and be readily controllable. These requirements were met by the development of a hydraulic actuator in which hydrostatic seals were used for the piston, and piston rod, sealing, see Figure 2.

Two of the requirements of the measuring machine were for rotation and angular movement of the measuring head. The movements were achieved by the use of stepping motors driven from controlled pulse generators.

3. Selection of features for exploitation

Study of the measuring machine had shown that there were four features of the machine which appeared to be attractive when related to the manufacture of semi-conductor components. These were its ability, according to a prepared programme, to position the head, successively, on a series of locations with very high precision; its ability to move large masses with negligible friction, no backlash and a high order of stiffness in all directions except that of desired movement; a near frictionless actuating mechanism which had extreme sensitivity and a stepping motion (used for angular motion operating in highly uniform increments.

In considering these features to determine which might be most suitable for exploitation in the manufacture of semi-conductor devices, regard had to be paid to the following facts. Because of the extremely small size of the components, any distances involved with respect to an individual component would be very small and not exceed on the average, about 0.250". In a similar way, any mass which may have to be moved will weigh grammes or ounces, and not pounds or hundredweights, and will be of small size.

Considering these features it was concluded that two features of the measuring machine could, with advantage, be used. These were the ability to programme the head to move to a series of co-ordinate positions and the highly uniform stepping fuction. The use of hydrostatic slides were 'discarded' as it was felt that, considering the small scale of size involved, their use would have resulted in an unjustified relative complexity and scaling them down would have involved a considerable amount of further development work, even if it were possible, effectively, to scale down the size sufficiently. It was thought, in all the circumstances, that a more practical solution would be to use linear ball or roller slides.

It was considered that the same objections applied, also, to the hydraulic actuator. In its place stepping motors driving fine pitched precision screws in nylon nuts were thought to be capable of producing the same effective results in the small scale involved in the manufacture of semi-conductor devices.

4. <u>Selection of processes/operations in semi-conductor manufacture</u>

Having selected the measuring machine feature of programmed movement to a series of positions, an examination was made of semi-conductor device manufacturing processes to select those to which this feature might be applied. One operation was outstanding in this respect:- that which applies connecting wires between the active elements in the silicon or germanium semi-conductor chip and the terminal posts or leads by means of which the active elements are connected to external electronic circuits. See Figure 3.

Although this is a basic operation there are a number of variations in detail according to the particular type of semi-conductor device concerned. The connecting wire may be of gold or of aluminium. The joint may be effected by a cold pressure weld or a hot pressure weld. Or ultra-sonic welding may be used. (Bonding is a rather more commonly used term than welding). Depending upon whether the device is a single or multiple transistor, or multiple diode, or integrated circuit, the number of connexions will range per device from two (four bonds) to fourteen (twenty-eight bonds) or even more.

This bonding operation is one in which a component is required to be positioned accurately, on a varying number of locations in succession, under and with respect to the bonding head, so that the required bonding of connecting wires can be affected. This operation was, therefore, considered to be suitable for further study.

Depending upon the particular semi-conductor device itself the approach to the problem was likely to differ, so that further consideration on this point took place. Four clearly separate variations could be identified.

These were: small signal transistors, power transistors, multiple diodes and integrated circuits. Small signal transistors are produced in large volume and a machine is being developed to semi-automate the wire bonding operation on this device. (There were certain difficulties which prevented the use of any fully automatic method). Power transistors are produced in relatively small volume. Multiple diodes are also produced in relatively small volume. Integrated circuits are produced in volume with every expectation of rapid and very substantial increases in the near future. These, also, are units which have not less than 10, usually 14 leads and with 20 and 50 lead versions looming ahead. (That is, 20, 28, 40 and 100 wire bonds respectively!).

The wire bonding operation on integrated circuits was therefore selected as that towards which the project would be turned.

A second function which was examined was that of the preparation of the photographic masters which are used in the early stages of manufacture of integrated circuits. (And diodes and transistors as well). This function is fairly complex and consists of a number of stages.

It starts, usually, with the preparation of a 250 x full size drawing of the circuit element patterns which will eventually be photographically printed on silicon slices for the etching and diffusion operations. See Figure 4. From this drawing a similar size photograph-master is prepared on highly stable two layer plastic film. (The top layer, transparent orange, is about 0.001" thick on the second, transparent clear, layer which is about 0.020" thick). The master is photo reduced in two stages to full size, and, at the same time, is multiple reproduced by a step and repeat photo process so that the glass plate contains uniform rows with a total of about 300/400 identical images. See Figures 5 and 6. These are then used for final reproduction on to the silicon slices.

Possibly the most particular and time consuming part of the entire process is the preparation of the 'Peelcoat' 250 x full size masters. These are prepared on hand operated co-ordinate draughting machines similar to that shown in Figure 7. This operation is one which is considered to be ideal for automatic production by numerical control techniques using programmed tapes. One manufacturer said that in about two years time he would be looking for such equipment. There is equipment available which, to a greater or lesser extent, could do the job. But, it costs upwards of £30,000. It is felt that a much more satisfactory solution would be a programme of modifications to existing hand operated machines which would cost a good deal less.

5. Selected processes. Review and discussion of associated problems

At present integrated circuits are usually made up into two encapsulations or packages. The 'flat pack' and the dual-in-line. See Figure 8. The former is very small and quite expensive. It was the second main form of encapulation to be used and is now required in projects where small volume is of primary importance and cost secondarily so. Its production volume is relatively small and will probably continue to be so. It would also raise some rather more difficult problems than is the case with the dual-in-line.

The dual-in-line package is much cheaper than the 'flat pack' although occupying considerably more volume. In commercial requirements generally, extreme small size is not of so great importance whereas low cost is of considerable importance. The volume of production of dual-in-line packages is already large and is expected to increase considerably.

Further discussion is therefore confirmed to the dual-in-line package device and continues describing the relevant and related operations.

At the first relevant stage the product is in the form of a slice of silicon about $1^1/_4''$ in diameter and about 0.010″ thick with about 300 to 400 complete integrated circuits formed into the silicon from one side and complete with a full interconnexion pattern on top of each individual integrated circuit. See Figure 9. The first significant operation is that of 'breaking' up the slice into its several hundred individual circuits by scribing with a diamond tool two sets of 'breaking' lines at right angles to each other.

The next operation requires that the individual bars are mounted on, and secured to, a kovar (Nilo-k) lead frame assembly. See Figure 10. The lead frame assemblies, for ease of handling, are in continuous strips of from 4 upwards. 8 is a common number, but they may also be in sheets like postage stamps. The bars, mounted on strips of lead frames, then pass to the bonding operation which is the heart of the entire project. At this operation the operator individually makes the 28 bonds on each bar and lead frame assembly on the strip and is expected to maintain an average time, for each individual bar and lead frame assembly, of approximately one minute.

After the bonding operation the strips are encapsulated in an epoxy material, the unwanted parts of the lead frame assemblies are cropped off and the individual units sawn from the strip. They are then ready for final electrical test. See Figure 8.

The individual operations relating to the project have been briefly described to give an outline of the field which is being studied. The next part of the discussion details the requirements which the operations must satisfy if the project is to be successful; the current state of the operations insofar as they are known; the improvements which will need to be made to meet the requirements of the project; proposals as to how these improvements could be effected.

The surface of the integrated circuit bar has an intricate pattern of deposited aluminium interconnexions which also include a number of square contact areas (.004″ or .005″ square), usually 14 in number, to which are bonded the gold wires which connect them to the lead frame terminals. It is these square contact pads which are of importance to the project. Depending upon the type of integrated circuit (electrical function) the pattern, or disposition, of these contact pads and their number will vary. In any one type of integrated circuit it is necessary that the positional relationships of the contact pads to one another and to the edges of the silicon bar should not exceed a maximum of, say, 0.0005″ in any one case.

The photographic process, referred to in Section 4, from which the master plates are produced results in repetitive production of silicon slices of extremely small variability, from the dimensional point of view, insofar as the deposited patterns are concerned. The result of this is that, for all practical purposes, for any individual type of integrated circuit there is no variability whatsoever in the relationships of the aluminium contact pads to one another in position or orientation. The only variation which must be considered is the variable position of the contact pads, as a set, with respect to the edges of the silicon bars. Scribing and breaking up of the slices into individual bars is normally done on automatic machines of reputed high accuracy and variations in size of the bars, in length and width, should be within 0.0005" which can be considered to be acceptable. This problem is dealt with in Section 6.

Mounting of the silicon bars upon the central platform of the lead frames is probably the most critical of the related operations. With respect to a datum, selected at a convenient location on the lead frame pattern, the variation in position and orientation of the silicon bar should not exceed, say, 0.001". Insofar as the lead frames themselves are concerned, there are two main methods of production. By press tool and by chemical etching. The normal tolerances of these methods of production, together with the relatively large contact areas on the terminal strips, compared to the contact pads on the silicon bars, are such that it is considered that variations in them can, for the time being at least, be ignored. Three individual tolerances contributing to overall variability have been given, two of 0.0005" and one of 0.001" giving a total of 0.002" with respect to the selected datum on the lead frame. The value of 0.002" has been arbitrarily selected on the following basis. The diameter of the gold wire used for making the connexions is likely to range from 0.0005" to 0.001". The diameter of the ball on the end of the gold wire just prior to bonding (the formation of the ball is described later) is approximately double the diameter of the wire. The contact pads are 0.004" or 0.005" square. It is considered that the bonding head (needle) in the proposed machine can be positioned with respect to the selected datum on the lead frame within a tolerance of 0.00005" which can be ignored. (The practicability of this tolerance is dealt with in Section 6).

Taking the foregoing into account, therefore, the maximum departure from the true position of any contact pad which can be accepted is 0.002" or 0.0025" according to the size of the pad. (This neglects the additional amount, extending to 0.00275" or 0.0035", which is available if the variation should be along a diagonal of the contact pad). On this basis, therefore, have the three allowances of 0.0005", 0.0005" and 0.001" been made. If they are achievable then the practicability of the project will have been demonstrated.

In considering the three relevant operations individually the first one, in sequence, is that of scribing and breaking the slices into individual bars. The operation is carried out using commercially obtained diamond tipped scribers in automatically indexing machines. See Figures 33 and 34. The method is described in Appendix 1.

The second operation to be considered is that in which the silicon bars are 'stuck' to the lead frames. There are at least two basic methods by means of which the bars are secured to the lead frame and a number of variations on the second method. Together with variations they are described in Appendix 2.

The third, and main, operation is that in which the gold, and occasionally aluminium, wire interconnexions between the silicon bar and the lead frame are made. The present method, which has been unchanged for several years, is manual with visual observation using a stereo microscope. It is described in Appendix 3.

In addition to the foregoing three processes in the assembly of dual-in-line integrated circuits some attention was paid to the preparation of photographic masters for integrated circuits and other semi-conductor devices. These photographic plates, from which the circuit patterns are reproduced on to silicon slices, are the end product of a complex process covering 8 stages which are as follows:-

1) Preparation of large scale master drawings.
2) Preparation of large scale 'Peelcoat' transparency masters.
3) First photographic reduction on to glass plate.
4) Plates mounted in kinematically supported holders.
5) Plates centred on the axis of holder and oriented to a datum.
6) Plate, in holder mounted in 'step and repeat' multiple reducing photo unit for reproduction of multiple images on glass master plate.
7) Final, actual, size glass master used to produce multiple images on silicon slice.
8) Step 7 repeated at intervals until entire circuit pattern is complete.

Step 2 is the important once insofar as the project is concerned but all eight steps have to be described in detail to obtain a full understanding of it. The steps are fully described in Appendix 4. The actual detail which is given refers to one manufacturer in particular but the whole procedure is basically similar throughout the entire industry.

6. <u>Feasibility Studies and Experiments</u>

Five studies and experiments have been carried out on various aspects of the project. Either to determine the current position with regard to the particular operation, or to determine whether a proposed line of action was reasonable or not. They are described in the following paragraphs:

1. Scribing of silicon slices.

Reference has already been made to the actual variations which can occur in the operations of scribing and breaking the silicon bars from slices. These were determined as described in Appendix 5.

A conclusion drawn from this experiment was that it was certainly possible to scribe and break silicon slices at this operation with a size variation small enough to be acceptable and, also, with an acceptably low loss of unusable bars caused by bad 'breaking'.

2. The alloying operation.

A feature of the present alloying operationg during which the individual bars are 'stuck' to the central platform of lead frames is the 'scrubbing' or horizontal vibratory motion which is applied to the bars as they contact the lead frame. This motion is applied in three distinct ways, by hand when the range of motion is, perhaps, about 0.015", at mains frequency via an electromagnetic system giving an amplitude of motion of about 0.005" and by an ultra-sonic generator with an amplitude of around 0.001". Figures 35 and 36 show a general view of an alloying machine and an operator 'scrubbing' a silicon bar. The alloying takes place at the applied temperature with light pressure and the scrubbing, or vibratory, motion is applied to break up any film of oxide which might be present on the under side of the silicon bar. However, the sequence of operations carried out on the silicon bar is such that there ought not to be any oxide film on the underside of the bar at this stage at all. It was, therefore, felt that it ought to be possible to effect the alloying operation without either the 'scrubbing' or vibratory movements. In the present operation the gold becomes plastic with the combined application of heat, pressure and 'scrubbing' but freezes as soon as the 'scrubbing' and pressure application cease. There is no control over, and it would be difficult to arrange in the mechanical methods and virtually impossible with the manual method, the point in the movement cycle at which motion stops. Therefore there is no control over the final position or orientation of the silicon bar on the central platform of the lead frame.

For programmed automatic bonding to be possible the silicon bar has to be accurately positioned and orientated on the lead frame platform consistently. This is clearly not possible with the present methods. The need of 'scrubbing' or vibratory movement is questioned.

The mechanics of the alloying process were discussed with the Materials Department of the College and it was learnt that, if the silicon was clean and the required minimum temperature reached, alloying by diffusion should take place on contact. If there were any particles of foreign matter on the underside of the silicon bar, the application of gentle pressure should overcome their effect and the alloying would take place, It was considered that only if there was a film of oxide on the underside of the silicon would it be necessary to use a 'scrubbing' or vibratory motion to break up the oxide film and allow the alloying to take place. The experiment carried out is described in Appendix 6.

The conclusion which was drawn from these tests was that it did seem to be the case that silicon bars could be satisfactorily alloyed to the lead frames without the application of 'scrubbing' or vibratory movement. Thus the task of preparing a specification for, and subsequent design of, an automatic position/alloying machine is considerably simplified.

3. In Section 3 of this report it was explained that one of the features of the Cranfield Measuring Machine which could be utilised on this project was the stepping motor system for angular positioning. In the case of the alloying machine the stepping motor drive would, through a precision screw, provide linear motion, it was also said in Section 3: that the moving parts would run on precision ball or roller slides. An example of a precision roller slide unit made by the Sigma Instrument Co. Ltd., shown in Figure 18, was available for examination and it was confirmed that it possessed the desired features of a high degree of stiffness in all directions except that of desired motion and almost frictionless in that direction.

It was considered to be necessary to demonstrate that a precision screw and stepping motor drive fed by pulses of current from a pulse generator, could be used to move and position a mechanism on a continuous and/or repetitive basis to an accuracy of better than 0.0001". The College had available a table on air hydrostatic slideways which had been used for work on the measuring machine project. The necessary additional parts were made for attachment to the table so that the stepping motor could be mounted and coupled to the precision screw and its nylon nut. The rig is shown in Figure 19 and details of the experiment are given in Appendix 7. From the tests it is clear that a mechanism actuated by a 50 t.p.i. precision screw, in turn driven by a stepping motor, can make incremental movements, and be positioned, with a degree of accuracy a good deal greater than is actually required for the project.

4. Need for heated anvils.

One problem associated with a multiple head, programmed, ball bonding machine such as is proposed later in this report arises from the need to provide a heated anvil under every bonding head. Quite apart from the need to provide temperature monitoring facilities for each anvil, the fact that each lead frame must be heated means that significant expansion and/or distortion of the strip, or individual frames on it, may cause positioning errors. Steps could be taken to negative these errors but they are a nuisance. If the heated anvils could be done away with altogether the problem would be solved. In addition, without the anvils, design and construction of the machines would be appreciably simpler. But, heat is necessary for the process.

Attention was drawn to a ball bonding machine, see Figure 20, described as a 'Micro Pulse Thermocompression Bonder', marketed by Emihus Micro-Components Ltd., of Glenrothes, Fifeshire. This machine requires no heated anvils as all the heat required is provided by pulses of low voltages at very high current levels which are applied to, and effectively short circuited by, the bonding needle itself. The generated heat is transmitted by conduction from the needle through the gold wire to the aluminium pad on which the bond is to be made. It is claimed that this method provides in a suitable manner all the heat that is required to make satisfactory bonds. Figure 21 shows the bonding needle and its current feeding conductors.

The possibility of using this principle was discussed with two semi-conductor manufacturers. In one case the use and effectiveness of this machine was dismissed out of hand as being not worth considering. In the other case doubts regarding its effectiveness were expressed, but for two stated reasons which seemed to be reasonable in the absence of further information. Firstly, because all the heat was applied to the bond from one side and through the gold ball. This, it was felt, was undesirable as it could lead to too much heat being applied to the gold ball, causing it to become too plastic and with the result that the ball would flatten too much and, in fact, might well finish up rather like a doughring with the gold wire coming up out of the centre of the ring and giving a ball/wire junction with little or no strength. Secondly, because, again, all the heat being applied from one side the actual bond between the gold and the aluminium would be negligible. It was, however, admitted that this was all supposition and that very little was really known about the mechanism of ball bonding.

A visit was made to Emihus works to see the machine and to discuss its performance. The machines are designed and built by the Electronics Division of Hughes Aircraft of California and have been used, it was stated, in various divisions of that company quite successfully. It was understood that these machines had been used on thick and thin film assemblies as well as on semi-conductors. Emihus were themselves proposing to put a machine to work on their own semi-conductor lines.

A number of samples were obtained of bonds on multi-diodes with the gold wires left sticking up so that they could be used for bond strength test purposes. The samples were bonded using a range of needle pressures from 80 grammes to 210 grammes. Figure 22 shows one of these samples. In no case did any of the bonds show the appearance which had been feared by one semi-conductor manufacturer, the doughring shape. All were more or less flattened balls as is normal although the degree of flattening varied according to the pressure which had been used. Examples of this variation are shown in Figure 23. One sample was bonded with a pressure of 80 grammes and the other with a pressure of 210 grammes. The testing of the samples and the results obtained are given in Appendix 8.

From these tests it may be concluded that the Hughes 'Micro-Pulse Thermocompression Bonder' will make satisfactory bonds between gold wire and deposited aluminium film on semi-conductor devices. Further, that the use of its basic micro-pulse principle would considerably reduce the complexity of the design of a multi-head automatic bonder provided that its additional cost could be borne. One complete single bond micro-pulse bonder would cost about £1,700 although it is possible that the cost, per head, on a multi-head machine would be a good deal less than this.

It is perhaps worthwhile pointing out another advantage claimed for these machines, in the light of a later comment (see Section 9). This is the ease and speed with which a needle can be changed. A change can be made in 2 or 3 seconds.

5. Tape-controlled Master Preparation

In considering the use of co-ordinate draughting or plotting machines and the possible future use of computor controlled equivalents there are a number of points which have to be borne in mind in relation to their use in the semi-conductor industry. With the existing manually operated machines the production of curves or diagonal lines is carried out by using special attachments. For example: if one wishes to draw a straight line followed by a curve and then a diagonal line the following steps have to be taken.

The straight line can be drawn normally by running the carriage along the appropriate axis. For the curve which follows the instrument has to be stopped and the pencil or pen holding adaptor removed from the precision sockets on the carriage. The adaptor is replaced by another specifically for drawing curves (there are a number of these depending upon the actual radius desired, see Figure 40) and the first adaptor with the pencil is replaced in a similar socket on the radius arm. One then draws the curve. Next follows the diagonal line. Once again the adaptor with the pencil is removed, then the radius adaptor is removed from the socket on the carriage and the carriage run out of the way. A separate straight edge unit with a carriage running along it and with a socket to carry the adaptor with the pencil is placed upon the table to suit the line which is to be drawn, see Figure 41, and the line is drawn by running the carriage along the straight edge. For further co-ordinate lines one has to remove the straight edge unit and switch the pencil carrying adaptor back to the main carriage of the machine. This procedure refers to draughting machines.

In the case of plotting machines which are usually tape controlled or the computer controlled draughting machines the production of curves or lines at any angle is quite simple. The programme used, tape or computer, is simply given the requisite series of co-ordinate positions for stepping round the curve or along the angled line. If the steps are small enough the curve or angled line will appear, to an ordinary visual inspection, to be smooth and regular. When sufficient magnification is used it will be seen to be a series of steps with the pencil or pen actually moving in the X and Y axes only.

This is perfectly satisfactory for producing drawings with pencil or pen. But it is not so when the preparation of peelcoat masters for semi-conductor device production is considered. It is not a pencil or pen which is used in this case but a knife. It is clearly not possible with a knife to produce a clean cut, which is absolutely essential, if a curve or angled line is to be produced by moving the knife in small increments on the X and Y axes successively. When curves or angled lines have to be produced they can only be satisfactorily done if the knife sweeps around the curve in a true radius or straight along the angled line.

As the plotting machines and computer controlled draughting machines do not have the facility for turning the 'writing' head so that one point on it is always facing the direction of motion, they are not satisfactory. In addition it would also be essential for the head to be retracted prior to the turn and extended again before resuming forward motion. Without this facility tearing of the film would almost certainly result when using a knife.

On the face of it these requirements would almost seem to rule out the possibility of using tape or computer controlled co-ordinateograph machines at all as curved or angled lines could not be cut without the use of separate adaptors which would have to be manually fitted and removed as required. There is an escape clause, fortunately. From enquiries which have been made of one semi-conductor manufacturer it would appear that it is only for the convenience of the draughtsman in preparing the 250 times full size drawings that curved and angled lines are used. Insofar as integrated circuits are concerned there is no particular reason why the entire pattern should not be entirely drawn using straight lines at right angles to one another. It must be pointed out, however, that this is not necessarily so in the case of patterns for individual diodes or transistors where the patterns may be circular, pear or star shaped and are required to be so for functional reasons. But as the production of integrated circuits, and developments thereof, are forming a rapidly increasing part of the output of the semi-conductor industry this last point can be put aside for the purposes of this project.

With the elimination of curves and angled lines it could be said that the arguments against the use of tape or computer controlled machines of the kind which exist now have been negatived. But there is still a need for retraction of the knife before each change in direction of travel and this is a function which existing tape controlled machines do not have. Further, it seems likely that the addition of the retraction facility would add significantly to their cost.

The present manually operated co-ordinatographs, whilst far, far, cheaper than the computer controlled machines, are still relatively expensive, i.e. from £800 to around £2,500. But the nature of their construction is such that it seems to be a quite feasible proposition to consider modifying existing machines so that they may be tape controlled and also have the retraction facility included. It is thought that this could be done for a sum that would make this a very attractive proposition as compared with the purchase of a computer controlled machine at £30,000.

7. Conclusions drawn from the feasibility studies and experiments

After the work on the studies and experiments had been completed, the information gained and that which was already available was reviewed so that the course of further action could be determined.

A number of uncertainties about the integrated circuit slice and bar operations had been resolved. They were as follows:-

1) Silicon slices could be scribed and broken with the required minimum variability in size of individual bars and in position of the interconnexion pattern with respect to the sides of the bars.

2) It should be possible to alloy silicon bars to lead frames without the need for 'scrubbing' or vibratory movement.

3) Positioning mechanism of simple construction could readily be constructed to make possible,

    a) positioning of bars on lead frames for alloying and,
    b) positioning of lead frame strips and alloyed bars under a bonding head for automatic bonding.

4) That a satisfactory bonding method, Hughes Micro-pulse, existed which obviated the need for heated anvils under the bars being wire bonded.

It was clear that a fruitful operation for improvement was that of wire bonding on the dual-in-line integrated circuits. It is currently a manual operation and requires a large amount of repetitive work. But, improvement of this operation, in the sense of making it automatic, meant that the two preceding operations had also to be considered as their performance had a major effect upon the prospect of improving the bonding operation. These preceding operations are the scribing and breaking of silicon slices into bars and the alloying of the bars to lead frames. Consideration had thus to be given to improving three operations in order to improve one.

Considering these operations separately the following conclusions were reached:

1. Scribing and breaking:-

The 'Tempress' machines currently used ought to be able to produce bars of sufficient uniformity in size and with the circuit patterns sufficiently uniformly positioned in order to meet the over requirements. The fact that variability of an unacceptable amount for this project occurs, although not for current process requirements, will require further investigation to determine and correct the causes of the variability.

2. Alloying of bars to lead frames:-

The variation in position and orientation of the silicon bars on the lead frames which occurs with the present operation is quite unacceptable. It will therefore be necessary to develop a new machine which will be capable of positioning, orientating and alloying bars to lead frames with the desired degree of uniformity. The machine should also have a production rate equal, at least approximately, to that of the present operation.

3. Wire bonding:-

Providing the necessary improvements to the two preceding operations were effected it became possible to design an automatic, programmed, bonding machine which would carry out the complete sequence of wire bonding operations on a dual-in-line integrated circuit bar from an initiate signal. It was not anticipated that the complete sequence would take significantly less time than the present manual operation but productivity improvement would be obtained by the use of multiple heads. The number of heads would be decided later but would be partly determined by the number of frames on a strip of lead frames.

Consideration was also given to the type of control system which should be used and this was discussed with the Instrumentation Laboratory of the College. As economy and simplicity were desirable features, it was decided that, in the first instance at least, the control system to be proposed should be multichannel punched tape.

From the examination which had been made of the present manual methods of producing peelcoat masters, the capabilities of the currently available computer controlled draughting machines and the tentative thinking about the possible future use of computer controlled machines for producing peelcoat photographic masters, the following conclusion was reached.

It was worth while considering the preparation of a design specification for modifications to one of the existing makes of co-ordinatographs to permit of the programmed, automatic, production of peelcoat photographic masters for integrated circuit devices for the following reasons:-

1) It saves having to discard the existing machines which have plenty of life still in them.
2) The design of existing machines seems to lend themselves to modification programmes.

3. The modifications can be tailored to suit the requirements of integrated circuit peelcoat masters which might present problems with the currently available computer controlled machines.

4. The cost of conversion by the proposed modifications would be expected to be very much less than the £30,000 plus of these currently available machines.

It was recognised that any specification prepared for one of the existing co-ordinatographs might have to be revised to suit either, or both, of the other available machines.

8. Development of basic design specifications

During this phase of the work three design specifications were evolved. They stemmed from what has been detailed in Sections 5, 6 and 7 of this report together with discussions with many people. The three specifications, not in order of importance or formulation, are as follows:

1) Modifications to the 'Aristo' co-ordinatograph for the application of tape control.
2) An automatic positioning/alloying machine for dual-in-line integrated circuits.
3) A programmed, automatic, multi-head wire bonder for dual-in-line integrated circuits.

Each is dealt with in turn in the following Sections:

1. The 'ARISTO' Co-ordinatograph.

The purpose of the specification is to define the design requirements of the 'Aristo' machine, modified to permit of the application of numerical control techniques to the automatic production of 'Peelcoat' large scale photograph masters for integrated circuits. The basic requirements, and the specification developed from them are given in Appendix 9.

2. Positioning/Alloying Machine.

Previous sections of this report have described how the existing methods were found to be unacceptable and how it was determined that a machine could be designed which would position silicon bars on lead frames to the desired standard of accuracy. The basic requirements were set down and from them a design specification was evolved. At the same time an 'artists impression' drawing was prepared to help with the preparation of the specification. See Figure 26. The machine was required to:

a) Pick silicon bars of varying size, only one size in a production run, from a target spot to which they had been delivered.
b) Transport them and deposit them on a precise location on the centre platform of a lead frame on a strip of lead frames.
c) Apply light pressure for a period of about one second and release the bar.
d) The lead frame must rest on a heated anvil for steps b) and c).

e) The lead frame strip is then to be indexed to bring the next frame into position and the cycle is repeated until all the lead frames in the strip have been done.

The design specification is given in Appendix 10.

3. Programmed, Automatic, Multi-Head Wire Bonder.

Preliminary considerations.

One of the conclusions reached, described in Section 7, was that stepping motor drive units on roller slides would be very satisfactory as the basis for the co-ordinate positioning unit. So as to guide preparation of the design specification a sketch was prepared of an outline co-ordinate positioning unit, on roller slides, driven by stepping motors and precision screws. It is shown in Figure 28. When this had been done another simple sketch was prepared to show the form which a single head automatic wire bonder might take. This is shown in Figure 29. It was then decided that the proposed specification should take into account, as far as possible, a number of the features of the existing manually operated machines. These machines had been studied and a set of requirements was drawn up which, it was felt, the automatic machine would have to meet as a minimum. On these, amongst other things, the specification would be based. These requirements are given in Appendix 11.

From the information obtained about the existing manual operation, and especially the average time of $1^1/_4$ minute to complete the bonding of one lead frame unit, it had been concluded that not much benefit would result from the use of a single head automatic machine, other than improved consistency of bonding. (Even this was not of too great advantage as the yield of good bonds from the existing operation is high and the eventual reliability of the completed devices is also good). It was for these reasons that prime consideration was given to a multi-head machine with 8 heads and with the provision that any lesser number of head units could be provided in a single machine.

As was done in the case of the positioning/alloying machine, an 'artists impression' drawing of a multi-head bonder was prepared to assist in the preparation of the design specification. It is shown in Figure 30.

The machine is required, from a pre-prepared tape programme, to carry out the entire sequence of operations involved in wire bonding dual-in-line integrated circuit bars on lead frames in strips of 8. The operations include the wire bonding of the gold wire, making the interconnexions between the bar and the terminal strips on the lead frame, flame cutting the wire and detailing, positioning the bonding heads for the bonding operations, all necessary co-ordinate movements and positionings, provision of a warning signal if a wire jam occurs in any head unit and an 'end of programme' signal when the last operation has been completed and the machine is ready to be reloaded for the next complete cycle to commence. The specification is given in Appendix 12.

9. Industry discussions and specifications resulting therefrom

Apart from a considerable number of informal discussions with individuals, visits were made to, and more formal discussions took place with, a number of manufacturers of integrated circuits and with two additional companies who, for the purposes of this discussion, could be classed as equipment manufacturers. The main reason for these discussions was to obtain the views of the principal manufacturers in this field about the problems which they experience in the operations under review and the additional problems which they might anticipate if machines such as are proposed were built. The discussions are summarised and the principal points raised are discussed below.

The companies were:-

Marconi Micro-electronics Ltd., Witham, Essex.
Associated Semi-conductors Ltd., Southampton.
Ferranti, Semi-conductors Division, Oldham.
Texas Instruments Ltd., Bedford.
Plessey Co. Ltd., Semi-conductor Division, Swindon.
Emihus Micro-components Ltd., Glenrothes.
Packman Research Ltd., Twyford.

The first five were selected as being principal manufacturers of micro-electronic circuits in the United Kingdom of whom the 1st, 3rd and the 5th are wholly British and the 2nd and 4th are foreign owned. The last two became known during the course of investigations as equipment manufacturers who were likely to be interested in different parts of the project. Emihus in the multi-bonding machine and Packman in the co-ordinatograph proposals.

In considering the points which were discussed with the component manufacturers it is worth noting that 2 of the 5 are large manufacturers of semi-conductor components and the remaining 3 are relatively small manufacturers. This division has, apparently, an effect upon the 'state of the art' in that points which appeared to be troublesome to the 'small' manufacturer were not so to the 'large' manufacturers. However, size of the firm had no particular effect upon the individual interest shown in the project. Most interest was expressed by one of the small firms and one of the two large ones with, possibly, the smaller firm rather more so.

In considering the many points made, and objections raised during these discussions it is difficult to put them in any order of importance. In any case, one man's order of importance is likely to differ from that of the next and so no particular attempt has been made to put them into any order. They are dealt with as they come.

There was a fairly general agreement that, for the concept of an automatic bonding machine, the critical operation was that of positioning and alloying the silicon bar to the lead frame. Insofar as current methods of manufacture are concerned this is not an operation which is in any way critical for positioning of the silicon bar. No company had any idea of the actual variability experienced in positioning because it was unimportant but guesses put it as high as 0.015". There were varying views as to the possibility of accurate positioning and alloying but all thought that some sort of vibratory or scrubbing movement would be essential to break up the oxide film on the underside of the silicon bar to allow the alloying to take place. It is interesting to note that, a factor generally ignored, at the alloying operation there ought not to be any oxide on the back of the silicon bar at all. A simple experiment, described in Appendix 6, suggested that heat and light pressure alone, without any vibratory or scrubbing movement, should be sufficient. One manufacturer undertook to carry out some tests to confirm, or deny, this theory. To date they have not been carried out.

Like the alloying operation, not much attention has been devoted to the diamond scribing of silicon slices in the 'Tempress' automatic indexing machines which appear to be in general use. Largely because there is, up to a point, no interest in the actual size of the bar nor in the variations of size which may occur from bar to bar. There is a spacing of about 0.004" between individual patterns on a slice and, so long as the break does not penetrate into or beyond the edge of a pattern, it is immaterial where it lies. Nor does it matter if the break is a clean break or is serrated, subject, of course, to the edge of the pattern not being touched. It is known that the shape of the diamond scriber and the depth of the scribed line have an effect upon the cleanness or otherwise of the break but not too much appears to have been done, or known, about this operation except for simple adjustments to the depth of cut. The diamond scribers are proprietary items which are bought as such and used without further ado. There was some disagreement about the yield of well broken bars from a slice. In some cases there did not appear to be any concern at all and in others concern was expressed about the proportion of unusuable bars. That is to say bars in which the line of break 'invaded' the pattern. This proportion could be as high as 10 to 15% it was suggested. It was also suggested that bars which would be perfectly suitable for current operational requirements would not be so for the proposed new automatic alloying/positioning machine. That is to say, bars with serrated edges which can be used without any trouble at present could not be used in the new machine, especially if some form of vacuum pickup is used. Thus, it was said, the yield of 'good' bars could fall to an unacceptable level. This point is referred to in the first experiment described in Section 6 of this report. It is suggested that this is not such a problem as has been said by some. All in all it is concluded that the scribing breaking operation, like many others, could usefully have time devoted to a thorough examination of it so that a better understanding of the physical processes involved could be gained. This could not fail to be of benefit to semi-conductor manufacturers but it is one of the many comparatively minor problems for which they cannot spare effort.

Some effort may well have to be devoted to the scribing operation in order to reduce the size variability which appears to be experienced. The operating mechanism of the machine is such as to suggest that it ought to produce bars with negligible size variation between them. It has a stepping motor drive to a screw and pulse generators to supply the motor. Furthermore, and not surprisingly, the U.K. agents for the 'Tempress' machine are quite categorical in their claims for its repetitive uniformity.

At least one manufacturer has been experimenting with another method of cutting out the individual bars from a slice. Not particularly from the point of view of reducing size variability but to reduce the loss from broken bars. This experimental method uses saws. It is a good deal slower and also requires that the slices must be stuck down. The slowness is overcome by ganging three saws and cutting three slices in parallel at one time. But the 'unsticking' of the individual bars and cleaning their backs so that alloying can take place presents a number of problems. It is not known what degree of success has been achieved with this method.

There are a number of ideas which might work but a separate programme on this operation would have to be drawn up and worked upon if a satisfactory automatic processes is to be developed. It is fortunate that an automatic process for this operation is not essential to the use of automatic positioning/alloying and bonding machines.

Most of the discussions centred around the bonding operation itself. Although the project has been mainly concerned with the gold wire bonding process which is used by the majority of manufacturers, at least one company of those visited is using an alternative process in two forms. Aluminium wire is used and the two methods, neither of which require the application of heat, are wedge bonding which is being phased out, and ultra-sonic which is being brought into general use.

It was, perhaps, a little surprising to get the impression that the small manufacturers experience significantly more problems, or the same problem more frequently, than the large manufacturers although all are using basically the same processes. There were also divergences in views about various aspects of the processes. One manufacturer said that his wire bonding operation was low cost and trouble free. Other manufacturers were prepared to say that there were problems of greater or lesser degree. And it was in this context that it was noticed that the small problem of one large manufacturer was a more serious problem to the small manufacturers.

A further example of difference in emphasis concerns the frequency with which the gold wire jams in the bonding needle and the trouble which is experienced in clearing the jams and putting the machine back into service. The same basic process is used by all but there was a certain reluctance on the part of some manufacturers to be too specific about the extent of their troubles. This tends to inhibit discussion about them. However, the incidence of jamming on any one machine can vary from once per day to a number of times. It may be partly the operator's fault or partly due to circumstances beyond her control. It may take a minute or two, or less, or a good deal more to clear the jam. In one case which was actually observed the operator tried for several minutes to clear a jam without success and then called her supervisor. He did not appear to have any greater success and after 15 minutes had elapsed, when the observation had to cease, the jam appeared to be no nearer clearing. This problem stems from the following facts. Gold wire of about 0.001" in diameter is used which has to pass through a hole about 0.0015" diameter in a needle heated to about 150°C. The wire is neither easy to see or handle and breaks at a load of about $^1/_4$ ounce. It must not be 'fingered' because of the risks of contamination.

One manufacturer was sure that the incidence of jams was related to the speed at which the operators worked together with their normal, inbuilt, human variability. He fell between two stools. He wanted higher production rates so the operator was encouraged to work faster. At the same time it was admitted that this would increase the frequency of jams because of the operator's greater speed and variability in her actions, which also influence the frequency of jams. It was also admitted that by increasing the speed of the operator the theoretical increase in productivity so obtained could well be more than negatived by the greater down time on the machine caused by more frequent jams. It was further admitted that no-one knew what the relationship might be between the two factors. A promise was made to carry out some simple tests to determine if there was a direct relationship between operator speed and frequency of wire jams. To date, no information has been received about the result of the tests.

It was clear that the frequency of jams and the time needed to clear them was a major factor influencing the interest shown by manufacturers in the project proposals. Especially that this problem would be multiplied by the number of heads in a multi-head machine. Nevertheless it was apparent that an automatic machine ought to have a significant and beneficial effect on two main aspects of the jamming problem. These are the variability in rate of descent of the head, due to variability in the operator, and the use of replacement heads when jams occur.

In an automatic machine it will be possible to control the rate of descent of the head, and of course, the variation in impact load of the needle/ball combination on to the bar. Because it is controllable there will be consistency and it is suggested that consistency in this case will reduce the frequency of jams. It is also proposed that the bonding heads should be unit assemblies with suitable location points. In the event, then, of a jam the head would be changed immediately for a fresh one, losing no time in attempting to clear the jam. The jam on the head can then be cleared <u>off</u> the production line and the head prepared for re-use. It is possible that a further reduction in the frequency of jams might result from off-line clearance because of the absence of production pressure which is always present when clearance of jams is carried out on-line.

As it was clear that only a multi-head automatic bonder would be economically acceptable the foregoing discussion is particularly relevant. Clearly, the rate of jamming on a single head machine would be multiplied by the number of heads on a multi-head machine, so that it is important that a low rate of jamming is achieved together with a speedy clearance when jams do occur. The experience of individual manufacturers is variable in this respect. In the best case the multi-head machine could be expected to operate with an acceptably low rate of jamming. In the worst case the machine would seem likely to be out of service for most of the time. But it is also true to say that the worst case of jamming on the existing types of manually operated machines would be quite unacceptable to the best case manufacturer. It seems, therefore, that the worst case manufacturer could do a good deal with his equipment and operators to reduce the frequency of jamming and greatly improve his productivity. Such an improvement would be likely to reduce, if not remove altogether, his objections to the use of an automatic multi-head machine.

A cost examination was made by one manufacturer to determine the maximum cost for an automatic multi-head bonder which would be acceptable from a depreciation/pay-off point of view. Several assumptions were made which included the following:-

1. Same hours of operation per year as existing machines.
2. 18% allowance for down time on complete machine as compared with 4% on existing machines.
3. No increase in throughout per head as compared with existing machines.
4. Same labour cost per machine as compared with existing machines.
5. Cost recovered in 12 months.
6. An 8 head machine used.

On this basis a machine costing about £21,000 would pay-off in 12 months. In considering possible costs it must not be forgotten that a second machine for positioning and alloying is also necessary. No cost exercise has yet been carried for this machine but it is considered that its cost would be far less than that of the bonder. However, its user is not likely to get any cost benefit out of it when used on its own on the wire bonding process. (The position will be different when the day of the flip chip arrives). Thus its cost must be bulked with that of the bonder in determining the economic justification of the proposed system. From some of the discussions which have taken place it is felt that there is every possibility that an automatic multi-head bonder could be built for substantially less than the £21,000 which would be considered acceptable for such a machine by one of the manufacturers. If the cost of the positioning/alloying machine is bulked in with the cost of the bonder there is a good prospect that both machines could be built within the limit of £21,000 already given.

One point which arose during the discussions with manufacturers is a most important once when the economics of the project are being considered. It is the length of 'life' remaining to the wire-bonding technique of making internal connexions on semi-conductor devices. In explaining this point one must first say that in this industry few methods or processes remain unchanged for very long. There is always a great pressure for improvements and in the case of wire bonded connexions it is considered to be a compromise. In a relative sense it is considered to be costly and prone to reliability problems. For some years a search has been going on for a replacement method which would be more reliable and cost less, or at least, no more. Such a method has been conceived and it is known as the 'flip chip' technique.

This method is already beginning to appear in volume transistor production. Its introduction to the manufacture of integrated circuits presents a number of additional major problems. It is believed that some manufacturers have found solutions to these problems, although they have still to be proved in practice and engineered for production volume. On the basis of this work forecasts have been made to the effect that the wire bonding process will be completely superceded by the 'flip chip' process in from one to three years. Thus any proposals for improving the wire bonding process must be made with this time scale in mind. Not forgetting the possibility of any part of the process improvement also proving to be useful for the 'flip chips'. All that need be said here about the detail of the 'flip chip' method is that the chip, or bar, is mounted upside down and that all connexions are made simultaneously. A description of the process is given in Appendix 13.

It must also be said that one manufacturer expressed little faith in the imminent use of the 'flip chip' method for integrated circuits. Whilst agreeing that it would be satisfactory for transistors it was their view that there were a number of problems associated with its use for integrated circuits for which solutions were not likely to be found in the near future.

One major manufacturer, who believes that solutions have been found to the 'flip chip' integrated circuit problems, recommended that account should be taken of the expected change to the 'flip chip' process in any proposals which were put forward. This proposal was made with a view to ensuring that when the change in process is made as much as possible of the proposed system can still be used and as little as possible discarded.

In examining this proposition there are two basic operations, and their associated machines, to be taken into account. The position/alloying and the wire bonding. The second of these becomes completely redundant and any machine developed for use with it would have to be discarded. In the case of the former operation, a machine would be required for 'flip chips' which would be almost identical to that which is proposed to make possible automatic wire bonding. The only difference is that for wire bonding the silicon bar is used with the circuit pattern side facing upwards and for 'flip chips' the circuit pattern is facing downwards. This difference is of no consequence to the functioning of the machine and, in fact, the same machine could be used without alteration.

It was suggested that to minimise the loss when the machine for ball bonding was discarded, one machine should be designed to carry out both functions. This was considered and a number of limitations became apparent:

1. Bonding could not take place simultaneously with alloying because the lead frame strip must be stationary for alloying and, of course, the converse is also true.

2. Bonding one complete circuit is a much slower operation than alloying one circuit so that the rate of alloying is reduced to approximately that of ball-bonding.

3. As the operations must be consecutive, the operating rate is further reduced. Alloying by about 20 times and bonding by about 1/10th.

4. Only a single bonding head could be used.

Nevertheless, because of the source of the proposal, an 'artists impression' drawing of a combined machine was prepared. It is shown in Figure 32.

It was further suggested that, contrary to the original intention (from the point of view of system simplicy) of having the 'broken' bars hand sorted by an operator who would also position and orientate them ready for pick up by the positioning/alloying machine, consideration should be given to the development of a machine which would accept 'broken' slices with the individual bars still in their original relative positions, sort out the mechanical and electrical rejects and then transport the good ones right side up and correctly orientated to the target spot on the positioning machine ready for pick-up for alloying. Although practically no work has been done to determine likely solutions to the problems arising from this suggestion a design specification, setting out the requirements which would have to be met, has been prepared and it has been incorporated with that for a combined positioning/alloying and bonding machine to form a comprehensive design specification for a complete automatic assembly system for dual-in-line integrated circuits. This specification is given in Appendix 14.

The approach to Packman Research Ltd., to determine their interest in the Co-ordinatograph proposal was made at a rather interesting time. The company, which is a small one, undertakes research and development projects for customers and also manufacturers its own design of co-ordinate draughting machines, see Figure 39, and teaching machines. It also makes scale relief models, produced on a modified version of its co-ordinate draughting machines, from ordnance survey maps. A number of the co-ordinate draughting machines have been sold to semi-conductor manufacturers for the preparation of Peelcoat masters. In the month prior to the College approach two of Packman's customers had asked if any thought had been given to the possibility of modifying these machines to permit of tape control. The answer given was 'No'.

The College approach was thus most appropriate and of considerable interest. It is true that the design specification for modifications to a co-ordinatograph was written around the German 'Aristo' and that the British machine does not possess several of the features of the 'Aristo'. Particularly the precision racks and pinions. The specification would have to be revised to suit the British machine and an equivalent to the precision racks such as, for example, steel tape would have to be added to the measurement system. This is not considered to be a difficult problem. It was the opinion of the writer, and also of Mr. Packman, that the probable cost of design and manufacture of a prototype set of parts for modification of one of these machines would be of the order of £5,000 and would take about one year in time. At the time of writing Packman Research is considering its attitude with regard to a possible joint programme with the College in pursuing the development.

10. Conclusions and proposals for the continuation of the project

A. Conclusions.

From the work which has been described in this report certain conclusions have been reached. These are described and dealt with in the following paragraphs:

1. A machine can be constructed for the automatic ball bonding of the internal gold wire connexions in dual-in-line integrated circuits. To be economical the machine needs to be a multi-head machine capable of working upon a number of integrated circuits simultaneously. This

machine also requires another machine to locate precisely silicon bars for alloying to the lead frames and this machine can also be constructed. In order to locate precisely silicon bars in the second machine, very consistent sizing of the silicon bars is required and a machine exists which is capable of this sizing consistency.

2. Machines developed for wire bonding as in 1, above, are likely to have a relatively short life, variously estimated as from 1 to 3 years before the ball bonding process is replaced by the 'flip chip' technique. Nevertheless, if speedy action is taken, it is considered that a reasonable life and financial gain could still be achieved.

3. The machine which is required for positioning/alloying, and which is also necessary for the operation of an automatic ball bonding machine, will be essential for the 'flip chip' process.

4. Proposals.

From the foregoing conclusions the following proposals for further action are made. It is clear that there will be differing views upon them and that there will be difficulty in selecting a preferred one to go forward to the design and hardware stage. 9 proposals are put forward which represent 8 phases in the development of the project plus one further proposal dealing with the development of low price, tape controlled, co-ordinate draughting machines. For economic gain to be realised any one of the first 5 selected will have to proceed with all speed. The next three are not likely to be required for production use for a year, at least, which time could usefully be used for design and development. For them time is available. For the first five time is running out. In the case of the last proposal interest in the industry is just beginning to appear so that, here also, time is available for design and development. If work on it goes ahead it is likely that the modifications would be just about ready for industry when it wants them.

1. Design and build two machines. A position/alloying machine and an automatic, programmed, mutli-head ball bonding machine according to the specifications in Appendices 10 and 12.

2. Design and build three machines. A machine for automatically sorting silicon bars, from the 'broken' slice, orientating them and delivering them to a target spot on the positioning/alloying machine. Plus the two machines already referred to in Proposal Number 1.

3. Design and build a bar sorting and orientating machine as in Proposal Number 2 and a combined automatic, programmed machine for positioning/ alloying and ball bonding on a single head.

4. A single integrated, automatic system incorporating the essential features of the three machines in Proposal Number 2.

5. A single integrated, automatic system incorporating the essential features of the two machines in Proposal Number 3 and as described in the specification in Appendix 13.

6. Design and build a positioning/alloying machine, generally according to the specification in Appendix 10, but specifically for 'flip chips'.

7. Design and build a bar sorting and orientating machine, generally similar to the first machine described in Proposal Number 2, and the machine described in Proposal Number 6.

8. Design and build a single machine incorporating the essential features of the two machines described in Proposal Number 7.

9. Design and build a modification set for the Packman 'Micro-marker'.

Insofar as the writer has any preference he would choose Proposal Number 1 out of the first 8 as being that most likely to prove economically viable in the time available. In this case the first machine in the proposal would be used as the machine for Proposal Number 6.

If it should be held that there is not time enough available for any of the first 5 Proposals to be economically viable, then he would plump for Number 6.

In any case, whatever choice is made from the first 8, it would also be recommended that Proposal Number 9 is proceeded with in parallel.

11. Recommended additional programmes

As a result of the investigations described in this report, a number of problems were thrown up which are directly related to the main project. Not too much is known about them in industry and it is suggested that they should be the basis for separate additional programmes of investigation. They would be of benefit to the main work in this report and could be expected to be of considerable use to the semi-conductor (including micro-electronics) industry. The first two would be of immediate interest to the industry whilst the last two are more directly associated with the development of automatic machines such as are dealt with in this report. These proposed further programmes are as follows:

1. A detailed investigation into the mechanism of the operations of scribing and breaking silicon slices using the Tempress machine for scribing. Amongst the factors which would have to be taken into account are the following:

    a) Form, angle, etc., of diamond scriber.
    b) Speed of scribe stroke.
    c) Depth of cut.
    d) Thickness of silicon slice.
    e) Presence or absence of oxide film on the slice, and its thickness.
    f) The method used to break slices after scribing.

    The results would be judged by the yield of good (i.e. 'well-broken' bars from a slice) bars and by the uniformity of breaking on the scribe lines and consistency in size.

2. An examination into the metallurgical factors involved in the formation of a silicon/gold eutectic at the alloying operation on integrated circuit production to determine if the operation can be be carried out satisfactorily without any of the vibratory motions currently being applied. Factors which will have to be considered in assessing the results are:-

   a) Thickness of the gold film
   b) Method of application of the gold. (There are at least 4 methods).
   c) Presence of any particles of foreign matter on the alloyed face.

   The results would be judged by the degree of adhesion and uniformity of contact at the interfaces silicon/gold/base material, with freedom from cavities, voids, etc. at the interface.

3. An investigation to determine if a method can be found which will hold separated silicon bars in place in their relative positions (as before breaking) during handling and which will not hinder any subsequent automatic sort or present any obstacle to the alloying operation.

4. The development of a method of automatically transporting and sorting of silicon bars as a follow on to 3. above, and which will deliver good bars, right way up and correctly orientated, on to a target spot on a positioning/alloying machine ready for pick-up.

Appendix 1

Description of scribe and break operation

The indexing increment on the machine is adjustable to take into account varying widths and lengths of integrated circuit bars. The slice being scribed is held by suction on a small circular table which can separately be given an angular indexing of 90° so that scribing can take place in the two necessary planes.

The initial positioning of the scriber midway between two rows of integrated circuit patterns is determined by manual adjustment on the part of the operator who uses a stereo microscope to view. This adjustment determines the positional variation of the set of contact pads with respect to the edges of the bars. The row spacing of the patterns on the slices is about 0.004" so that variability of thus amount could be expected. In practice the visual adjustment is easy and the operator should be able to position the scriber midway between two rows of patterns within about 0.0002". The method of indexing used on the machine, stepping motor drive, is such that incremental errors should be well within the 0.0002" tolerance already mentioned. The accuracy of stepping motor drives is dealt with in one of the feasibility studies in Section 6.

Samples taken have shown, however, that if the machine is left to run automatically, incremental errors of up to 0.005" can occur. Other samples have shown that if the machine's incremental errors are corrected on a visual basis by the operator just prior to the commencement of each individual stroke, the incremental variations are held to within about 0.001". In fact, with care, the variations may be held down in this way to under 0.0005". No investigation of the reasons for these variations has been made but, from a brief discussion with the manufacturer's representative and general consideration of the incremental mechanism, it is thought that the most likely cause is insufficient maintenance of the machine. It should also be noted that, insofar as the present methods of production are concerned, variation of bar size within the limits permitted by the row separation on slices is not of any particular importance. It should not be surprising, therefore, if little attention is paid to these variations or their causes.

Whilst more work will have to be done to obtain positive confirmation, it does seem that these 'Tempress' machines should have the necessary capability to produce bars of the required uniformity of size. The breaking operation which follows the scribing is quite simply carried out. At least two methods are used. The first of these requires that the scribed slice is placed on a very slightly convex anvil and a rubber roller or squeegee is run firmly over it. In the second method the slice is placed on a 'bed' of several filter papers with several more placed on top of it. It is then run firmly over by a metal roller.

In both cases a certain amount of care is required to ensure that the slice breaks along the scribe lines and not randomly. This is also affected by the scribing itself. An additional refinement which has been used is to place the slice upon a thin film disc of clear plastic before breaking. This ensures that the broken bars remain in their relative positions after breaking. This can help later sorting.

The sorting operation which follows breaking is required for two main reasons. The first is to sort out misshapen bars. They may be due to two causes. Random breaking across the scribe lines and, secondly, to sort out the 'incomplete' bars. These result from the fact that the slice is round whilst the group of patterns is approximately square. A number of bars will have no circuit pattern at all and some will be incomplete rectangles from the edge of the disc.

The second reason is to sort out electrical rejects. Immediately prior to scribing the bars on a slice are electrically tested on an automatic machine. Those which do not meet the electrical test requirements are marked with a spot of coloured ink. They are then sorted out.

Appendix 2

Description of alloying operation

In the first method, with the lead frames in strips of at least four, small blobs of an epoxy resin adhesive are deposited on the central platform of the lead frame. The operator picks up a silicon bar with tweezers and, with the aid of a stereo microscope, deposits it on the film of adhesive, approximately central to the platform. When all the frames on a strip have been dealt with in the same way it is put on one side for the adhesive to dry which takes a minute or so. The bars are positioned on a visual inspection basis only and, although there is no factual information available about positional variation, it is thought that this might extend to about 0.015" at least. In addition it is thought that some float, at least until the adhesive sets, may take place.

The second method depends upon a metallurgical phenomenon. That at a temperature well below that of the melting points of the materials involved a diffusion takes place when gold and silicon are brought into contact to form a gold silicon eutectic. A similar diffusion takes place between the gold and silver plated kovar lead frames.

The alloying operation requires the interpolation of a layer of gold between the silicon bar and the central platform of the lead frame. This is applied in one of several ways which are described below. The temperature of the lead frame platform, by resting upon a heated anvil, is raised to about 480°C. At this temperature, which is well below the melting points of the materials concerned, an alloying by diffusion takes place between the gold and the silicon and between the gold and the silver plated kovar.

The variation include the following: The gold is applied in the form of a very thin wafer; by gold plating the whole lead frame; by vacuum deposition of gold on the back of the silicon slice before scribing and breaking; selective plating of the central platform of the lead frame only. The bar is positioned by hand or by machine. A to and fro (vibratory) motion is applied to the bar whilst being positioned by hand or by machine at mains or ultra-sonic frequencies. The amplitudes of these vibratory movements vary from about 0.001" in the case of the ultra-sonic to perhaps 0.015 or more in the case of hand 'scrubbing'. (The hand operation is sometimes called 'scrubbing'). See figures 35 and 36.

No factual information is available about the amount of these amplitudes as its amount is not considered to be of importance. The motion itself is considered to be of importance to break up any oxide film which there may be on the back of the silicon bar and which would prevent the formation of the gold silicon eutectic. It may also be noted that, at this stage of production, there ought not to be any oxide film of the back of the bar at all.

Appendix 3

Description of bonding operation

A lead frame strip, in a suitable carrier, is positioned so that the central platform of one lead frame with a silicon bar alloyed to it rests on a heated anvil. It is necessary for heat to be applied so that the bond will 'take'. Most of the heat is applied from underneath through the anvil and the remainder through the bonding needle/wire guide and the wire itself. See figure 37.

With a micro-manipulator mechanism operated by one hand, the operator positions the whole unit so that the first contact pad is directly under the gold wire, protruding through the needle, on the end of which has been formed a ball. When satisfied that the ball is centred over the contact pad the operator, by hand or foot control, brings the whole bonding head assembly down until the gold ball touches the aluminium contact pad. At this stage an overtravel mechanism takes over so that only a controllable weight presses the gold ball, through the needle, to make the thermocompression bond. After about one second, the bond effective, the operator allows the head assembly to return upwards and, at the same time, with the micro-manipulator repositions the lead frame so that the appropriate terminal of the lead frame is under the needle. This done, the head is again brought down to pressure bond the gold wire to the terminal. Again after about one second the operator allows the head to return to its normal 'up' position, paying out gold wire as it goes up. To complete the cycle the operator cuts the wire with a tiny hydrogen flame which leaves a ball on each end of the severed wire. The gas flame is followed by a notched 'de-tailing' blade which hooks on to the wire under the ball and pulls the wire tail away from the second bond. This may be seen in figure 38.

This sequence is repeated for every pair of bonds and, on the average, takes a little over one minute to complete 14 cycles, or 28 bonds, on one integrated circuit.

There is no location problem with this manual method as, regardless of the position or orientation of the silicon bar on the central platform of the lead frame, the operator visually positions the entire assembly with respect to the position of the bonding needle for the various bond points.

Appendix 4

Description of photo mask preparation

Step 1: A 250 times full size drawing is prepared on transluecent 1" x 1/10" graph paper where each 1/10" represents 0.0004". This drawing contains all the diffusion patterns for an integrated circuit, or any other semi-conductor device. The patterns are for emmitters, bases, collectors of transistors, anodes and cathodes for diodes, etc. One blue print is taken from the master for each pattern of a set and the particular pattern in each case is colour washed in. See figure 4. This procedure of multiple prints simplifies registration at step 2. No special accuracy is required at this stage except that the pattern is drawn in multiples of the 1/10" squares representing multiples of 10 microns in the final pattern size. These actual sizes being determined by the functional requirements of the circuit.

Step 2: A two layer, highly stable plastic material, 'Peelcoat', is used for this stage. (This material is also used for the manufacture of fluid logic components in the Department of Production Engineering at the College). The upper layer, approximately 0.001" thick, is a transparent orange colour, photographically opaque, and adheres by surface adhesion to the 0.020" thick transparent clear main layer. The 250 times full size Peelcoat masters, prepared from the colour washed prints already mentioned, are 'drawn' on German 'Aristo' co-ordinate draughting machines. Other machines available are the Swisss 'Koradi' and the British, Packman, 'Micromarker'. The carriage runs on rollers on a vee and flat on each axis. See figure 7.

The carriage has a precision socket in which can be mounted a range of interchangeable units with cutting knives, etc. (Surgical scalpels are used). The setting dials which register the movements of the carriage are graduated according to the scale of magnification of the drawing which is being prepared. In the case of the 250 times full size, the scale graduations are in microns.

If, therefore, the original co-ordinate references for each pattern are in microns, the carriage can be moved the required distance in microns directly from the scales. The positioning accuracy is ± 0.0012". This error amount is, however, totally masked by variables occurring at other operations.

As indicated, co-ordinate references are prepared from the pattern and from a standard datum on the original drawing and are used on the 'co-ordinatograph' to cut the pattern on the Peelcoat film, in the 0.001" top layer. The 'windows' thus cut are peeled off leaving the required pattern 'clear' in the otherwise orange master. The first master cut is left on the table and the remainder of the set are cut on top of it. This simplifies determination of co-ordinate references for later patterns.

On the original drawing, on a convenient location at one side of the pattern there is usually drawn a registration target. This is usually in the form of a series of concentric circles. They are cut out, one by one, on successive peelcoat masters in a set in the order in which they must be used. The largest circle on the first master and each succeeding master taking the next smaller circle.

Step 3: At the first photographic reduction from the peelcoat master, 25 times to 10 times full size, a single image about 2 cm square is reproduced on a glass plate. The optical system used at this stage has a distortion factor of less than 0.01% at the fringes of the field. As no part of the lense anywhere near the fringe is used, however, it is considered that, for all practical purposes, there is no distortion. At this stage no special care is taken to ensure that the image is central or correctly orientated on the glass plate although, of course, it is very near the correct position.

Step 4: The glass plate is mounted in a special holder with three kinematic locations.

Step 5: The holder, with glass plate, is positioned on its kinematic locations in an optical unit. The image on the plate is then lined up with the optical centre of the unit, and orientated, with respect to a datum which was added underneath the pattern at step 3. The plate is then locked in position in the holder and stays that way, at least until step 6 has been completed.

Step 6: Up to a maximum of eight plates in kinematic holders, and normally including all the patterns which would be required for one type of integrated circuit or other semi-conductor device, are mounted in the eight cells of a 'Step and Repeat' machine. This photographic machine is used for the final reduction to actual size and for the production of the multiple images on the final glass photo mask. The eight plates produce of course, eight photo masks.

The cells containing the plates are mounted on a carriage which is moved along the X axis at a constant rate by a motor driven precision leadscrew. Exposure, is by means of a high intensity, high speed, photo flash lamp, one per cell. The flashing of the lamp is timed by a photoelectric counter which counts the lines on a line standard as they pass a slit on the carriage. The flash time is so short with respect to the speed of the carriage that no blurring of the image occurs. The positional accuracy in the X axis is of the order of ± 10 micro-inches. As each row of images is completed the carriage returns to the start position and indexed, in the Y axis, to the next row by a manually operated leadscrew. Measurement of movement is similar to the method used for the X axis except that a vibrating slit is used and adjustment made to a null on a meter. Positional accuracy in the Y axis is of the order of ±20 micro-inches.

It is standard practice to omit one image altogether from the approximate centre of the set of multiple image to assist registration during steps 7 and 8.

Steps 7 and 8: In the photographing of successive multiple images on to silicon slices registration of them is of prime importance. It is normally done by visual observation of the circular targets which appear on every individual image in each pattern. The alignment errors at this operation are expected not to exceed ± 40 micro-inches ≈ ± 1 micron. As a unit of 5 microns is used for element size, spacing, etc., an error of up to 1 micron is considered to be quite acceptable for the bulk of the work. For the small proportion of the work in which greater accuracy in registration is required, for example, very high frequency devices where element size and spacing in units of 2 microns are necessary, much greater care is taken in the visual registration. The photographic reproduction of images on to the silicon slice is repeated until all the photo masks for that type of device have been used. In between each photographic stage there are, of course, developing, etching, diffusing, oxidizing and application of photo resist, operations.

It will be realised that the errors at step 6 mask those occurring in the preparation of the peelcoat masters by from 2 to 4 times. Whilst those errors at steps 7 and 8 mask them by up to 8 times. It has been stated that these errors from true position are perfectly acceptable for most cases in the present state of the art and that there is little point in trying to reduce the error of up to 0.0012 which can occur at step 2.

Appendix 5

Silicon bar size study

It had been understood, from enquiries, that the scribing operation could be carried out in two ways. a) with the indexing movements between strokes carried out automatically by the machine on the basis of a pre-set adjustment for the actual spacing required, or b) by manual control on the part of the operator who closely watches the operation through a stereo microscope and advances the scribing head during the return stroke by visual observation. The spacing between the rows of patterns is approximately 0.004" and the scribe line should be in the centre of this band.

Accordingly, a request was made for two electrically scrap slices to be scribed and broken, one by each method, so that they could be measured and the extent of the variability determined. A quantity of about 260 individual bars was obtained from each slice from the two methods. Measurement of the lengths and widths of the bars was made with the aid of a metric toolmaker's microscope. Taking the measurements was a slow job and, therefore, not all the bars were measured in either case. In fact, it was judged after 82 of those obtained by automatic indexing and 86 of those obtained by hand indexing, that enough information had been obtained for a reasonable assessment of the variability to be made. The actual plots are shown in the graph in Figure 11.

The automatically indexed sample showed a variation of 0.13 mm in both the short dimension (1.3 mm nominal) and the long dimension (1.5 mm nominal). The manually indexed sample showed a variation of 0.11 mm in the short dimension (1.25 mm nominal) and 0.08 mm in the long dimension (2.25 mm nominal).

The results of the manually indexed sample are better than at first appears to be the case from the figures quoted. In the short dimension all but four of the sample of 86 were within a range of 0.04 mm and in the long dimension all but one were within a range of 0.04 mm and all but seven were within a range of 0.02 mm. (that is to say, within 0.0008″). It was also noted that, for reasons unknown, the automatically indexed sample appeared to show three quite separate distributions in the short dimension and two in the long dimension.

A further point which was noted concerned the evenness of 'breaking' along the scribed lines. In the manually indexed sample six had serrated or chipped edges which might make them unsuitable for vacuum pickup, although not for manual handling, and one was totally useless. In the automatically indexed sample, for some strange reason, these figures were approximately doubled. Thirteen with serrated or chipped edges and three were totally useless. See Figure 12 which shows examples of bars with chipped or serrated edges.

Appendix 6

Alloying with 'scrubbing'

A simple fixture was designed and built to determine whether silicon bars could be satisfactorily alloyed with heat and gentle pressure only. No 'scrubbing' movement. The fixture, shown in figure 13, used a low voltage electric soldering iron supplied via a variable voltage (variac) transformer with a voltage sufficiently above its rated voltage for the flat end of the bit to reach the desired temperature of 480°C. The temperature was measured with the aid of a miniature indicating thermocouple unit. Gold was applied in the shape of 'preforms' about 0.050″ square and about 0.003″ thick. See figure 14.

After ensuring that the requisite temperature had been reached, a lead frame was placed in position, as shown in figure 15, and then, using a vacuum pencil a gold preform was positioned approximately centrally on the lead frame platform. Again with the vacuum pencil a silicon bar was placed on top of the gold preform and light pressure applied to the top of the bar as shown in figure 16. Of the half dozen or so which were alloyed in this way the majority appeared to have a satisfactory degree of adhesion when tested with a pair of tweezers. An example is shown in Figure 17.

It should be pointed out that there are two main reasons for alloying, or otherwise attaching, silicon bars to the lead frames. Firstly to hold them in position for the subsequent operations of wire bonding and encapsulation and secondly, to ensure a good uniform contact with the lead frame platform for thermal conductivity purposes.

Appendix 7

Positioning with a stepping motor drive

The stepping motor rotates in steps of 1.8°. That is to say, in steps of one two hundredth of a revolution. The precision screw had a pitch of 50 t.p.i. so that one turn of the screw would advance the table by 0.020″. Thus, one step of the motor turning the screw would advance the table by 0.0001″. It was hoped to secure a continuing and repetitive accuracy of at least that order. The movement of the table was sensed by an electronic transducer head and indicated on the scale of a calibrated meter. The system magnification was such that one division on the meter scale represented one one-hundredth-thousandth part of an inch (0.00001"). The stepping motor was fed from a suitable power supply, pulse generator, and an amplifier. The generator could be arranged to supply pulses continuously at any frequency from 1 per second up to several thousands per second, or single pulses of millesecond length up to hundreds of millisecond length.

After a number of tests it was found that the movement of the table in forward or reverse in response to a specific number of pulses in each direction was extremely consistent and highly repeatable. The forward and return distances were the same within an estimated one fifth of a division on the indicating instrument scale. This corresponds to 0.000002" and is much more accurate than is absolutely necessary. In movements due to a single step of the motor, a nominal 0.0001", the variations between individual steps did not exceed an estimated 0.000005".

Further tests were made to determine if variation of the pulse length would affect the previous results in any way. Various pulse lengths throughout the range provided by the pulse generator were used for specific numbers of pulses and for single pulse steps. But, so far as could be determined, it made no difference to the functioning of the stepping motor or to the accuracies previously reported. This is attributed to the fact that into the amplifier was built a flip-flop circuit to drive the power stage. In this case the length of the pulse is of little consequence. Its 'front' is all that the flip flop requires to be triggered.

Appendix 8

Micro-pulse bonding tests

Full tests were carried out with the co-operation of the Materials Department of the College. The Department possesses a very sensitive tensile testing machine with a full scale of 10 grammes on its lowest range. The machine clamps could grip the bunched leads of the header of the sample but a special adapter had to be made to hook under the ball on the end of the 0.001" diameter gold wire so that the pull could be applied. A drawing of the adapter is shown in Figure 24. It was expected that, if the bonds were good, the wire itself would break at around 6 to 8 grammes, the approximate breaking load of 0.001 diameter gold wire.

The tensile test machine also produces a chart record showing the load applied against extension of the specimen so that it was easy to determine the load at which the wire broke. Figure 25 shows one of the chart records. Four pulls were made on specimen No. 3, which had been bonded with the highest needle loading of 210 grammes, and consequently showed the greatest amount of flattening. A further two pulls were made on specimen No. 6 which had been bonded at 80 grammes, the lowest bonding pressure used, and thus showed the least flattening. See these examples shown in Figure 23.

In all but one of the tests the wire broke in about the middle of its length. The exception broke just under the ball and it was considered that it had broken there because the upper and lower grips of the testing machine had not been correctly lined up and there had thus been some bending as well. The remaining three pulls on specimen No. 3 broke at 5.1, 5.3 and 5.9 grammes respectively. The two pulls on specimen No. 6 broke at 4.5 and 5.7 grammes. These results have been discussed with the second of the two manufacturers previously referred to, and who expressed the view that the results were entirely satisfactory and said that the bonds were of adequate strength. He was pleasantly surprised.

Appendix 9

Specification for modifications to the co-ordinatograoh for tape control

Requirements:

a) The depth of penetration of the knife into the plastic material must not be less than, say, 0.0015″ nor more than, say, 0.002″. This is to ensure that the 0.001″ thick top layer is fully cut.

b) The unit carrying the knife must be capable of retraction. The amount is not important so long as it is at least 0.010″ to clear the plastic completely.

c) The unit carrying the knife must be capable of rotation in, say, 90° steps but only when the unit has been fully retracted.

d) The measuring system shall be capable of measurement from a selectable datum and hold the co-ordinates of the actual position with respect to the datum continuously.

e) The control system must be capable of dimensional discrimination down to at least the error amount of the original machine. That is to say, 0.0012″.

From these requirements a detailed design specification was prepared which is as follows:

1. The 'Aristo' co-ordinatograph is the basis of this specification and the following requirements are additional to those of the basic machine.

2. X and Y axes.

   a) The traverse movements will be driven by stepping motors fed from the control unit.
   b) Traverse speeds on functional (cutting) movements to have a maximum speed of not less than, say, 3″ per second.
   c) Functional movements may be in either direction on each axis.
   d) Where return traverse is required on non-functional movements, the maximum reasonable speed possible will be used.
   e) The maximum distance of traverse, in each axes, is 36″.

3. Measuring system.

   a) The measuring system shall, if possible, use the existing precision racks.

b) It is to have an inherent accuracy of not less than the 0.0012" of the existing machine.
c) Provision is to be made for setting up of a basic datum, for both axes, which will be the reference point for each programme.
d) There should be a digital read out for the position in each axis.
e) The system must be able to count down towards, as well as up and away from the selected datum.
f) Counting in the measuring system must be effective at either of the two speeds referred to in paragraph 2 above.
g) Counting must also be effective if the drives are disconnected and the carriages traversed by hand.
h) Once a datum has been set, the true position of the head, in the X and Y axes with respect to the datum, must be displayed and available continuously for control purposes.

4. Z Axis. (Interchangeable heads which carry cutting knives, etc.)

a) Measurement in the Z axis is not required.
b) Provision is to be made for retraction of the knife.
c) The amount of extension of the knife is to be adjustable so as to permit of a penetration of not more than, say, 0.0015" into the plastic film.
d) When retracted, only, provision is to be made for indexing the head in increments of 90° (see paragraph 5b) so that the cutting edge of the knife is always facing the direction of travel in a functional traverse. (This assumes that reverse, non-functional, traverses are not normal during the cutting of any one continuous part of a pattern except to the limited extent, and for the purpose, described in paragraph 5i, following.
e) The angular positions to which the head is indexed in the 90° increments will lie along the X and Y axes.
f) Suitable adjustment is to be available to ensure that the vertical cutting edge of the knife is on the centreline of the head, or alternate provision to the same effect.
g) After indexing to the desired new angular position the knife is to be extended to penetrate the plastic film to the cutting depth before commencement of a functional traverse.

5. Control System.

a) The system is to be designed for, and receive instructions from, a punched or magnetic tape depending upon the degree of sophistication required and chosen.
b) The system is to be based upon point to point instructions in the X and Y axes only. (Assuming, as seems possible, that integrated circuit patterns can be drawn without the use of curved or angular lines.
c) Whilst cutting traverses are being made in one continuous part of the pattern, movement in the X and Y axes simultaneously shall not be possible. (See assumption in paragraph 5b, above). However, after completion of one continuous part of the pattern, and after retraction of the knife, movement in the two axes simultaneously is permissible in traversing to the start position for the next cutting sequence.

d) From signalling of the 'START' signal the sequence of operations is as follows:

1. Identify the position of the head with respect to the selected datum.
2. Move head along X and Y axes as necessary to the co-ordinate position fixing the start of the cutting sequence of the first continuous pattern on the programme.
3. Index the head until the cutting edge of the knife faces the direction of the first cutting traverse.
4. Extend the knife to cutting position.
5. Traverse the head along the chosen axis to the next co-ordinate position at which a change of direction is to take place, and stop.
6. Retract knife.
7. Index the head until the cutting edge of the knife is facing in the direction of the next cutting traverse.
8. Repeat steps 4, 5, 6 and 7 until the pattern has been completely cut.
9. Move head as necessary along the X and Y axes to the co-ordinate position fixing the start of the next pattern.
10. Repeat steps 4 to 9 inclusive until the programme finishes the last continuous pattern and finishes on step 6.

e) Once the initial datum has been set the control system must receive continuous signals from the measuring system which indicate the position of the head and relate them to the input instructions from the programme tape.

f) If the motor drives to the carriage are disengaged and the carriages are traversed by hand, the control unit will continue to indicate the true position of the head with respect to the selected datum and operate the motors as required when they are re-engaged to the carriage. See 3g and 5e.

g) Any backlash, electronic, mechanical or any other, in the loop system-measuring, control, drive, measuring - must be contained within the limit of ± 0.0012 given in paragraph 3b.

h) There must not be any hunting in the system, or over-travel except as provided in the following paragraph.

i) To ensure square, clean cut corners and to obviate the risk of tearing the plastic film when the 'windows' are subsequently stripped off, the following facility should be provided for use as required. With respect to each cutting traverse, and before extending the knife to the cutting position for the start, and before retracting it at the end, under and over travel to the programmed distance of a selectable amount up to, say 0.005" can be applied automatically. The amount of overtravel must, however, be negatived before applying undertravel prior to the commencement of the next cutting traverse.

j) Fail safe features must be built in so that, in the event of any mechanical, electric or electronic fault the machine will stop immediately and operate an alarm signal.

k) The control system must accept 'upcount' and 'downcount' signals from the measuring system, according to the direction of travel of the head along the X or the Y axes and act accordingly. Signals will normally be positive in both axes with respect to the datum referred to in paragraph 3c.

Appendix 10

Specification for a positioning/alloying machine

Design specification for an automatic positioning/alloying machine for dual-in-line integrated circuits.

This machine is one of three inter-related machines in a system for the production of dual-in-line integrated circuits in which machines 1 and 2 are required to make possible the operation of machine 3. Machine number 1 is the 'Tempress' automatic indexing diamond scribing machine whose function is to 'mark' silicon slices so that they can be broken up into individual bars. It already exists. Machine number 2, the subject of this specification, is an automatic machine whose function is to mount silicon bars for alloying ('sticking') on a precise location on the central platform of the lead frame. Machine number 3 is a tape programmed and controlled, multi-head, wire bonder for making the wire connexions between the silicon bar and the terminal strips on the lead frame.

1. The machine is to be of unit type construction consisting of 4 units as follows:

   A. A carrier and positioning unit for silicon bars.
   B. A carrier, positioning and heating unit for lead frame strips.
   C. A pick-up and transfer mechanism to take silicon bars from Unit A, to the alloying operation on Unit B and physically initiate the alloying operation.
   D. A control unit which will provide the necessary co-ordinated drives to units A, B and C consistent with ease of access and visual observations of the functions.

2. Unit A.

   A. The silicon bars are to be pre-positioned, circuit pattern side up and correctly orientated, on a spot location ready for pick-up by Unit C.
   B. The silicon bars are to be placed in position on the target spot by an operator using a stereo microscope with a suitable graticule in the optical system.

3. Unit B.

   A. The unit is to accept lead frames, generally of the shape size and construction shown in Figure 27 in strips of, say 8 and locked in a suitable carrier. It is to have a means of indexing them, one by one, to the operating position where they are to be located from a pre-determined datum ready for positioning and alloying of a silicon bar to the frame.

B. In the operating position the central platform of the lead frame is to be positioned over, and rest upon, a heated anvil maintained at a temperature of approximately 480°C.

C. Visual indication of the anvil temperature is to be provided.

D. Entry and exit supports are to be provided to take the full length of a lead frame strip in its transport carrier. The entry support is also to guide the carrier so that the indexing and locating mechanism can take over and complete the positioning.

E. The unit is to be designed in such a way that alternative guides, carriers and/or indexing and locating mechanisms for other patterns and strip length of lead frames can readily be substituted. It is not intended that any one individual machine, once built to take one particular length of lead frame strip, should have to be notified to take any other length of strip. It may be required, however, to modify it to accept another pattern of lead frame.

4. Unit C.

A. When a silicon bar and lead frame are located in their operating positions a carrier and transfer mechanism will carry out the following functions:

1. Pick up silicon bar.
2. Transfer silicon bar to desired position above lead frame central platform.
3. Lower silicon bar to make contact with platform.
4. Apply a load of, say, 50 grammes for a time of, say, 1 second for the alloying process to be carried through and completed.
5. Release silicon bar, lift and transfer back to start position ready to pick up next silicon bar.

B. The unit must accept as required any one of a range of sizes of silicon bars from, say, 0.040" square to 0.050" x 0.100". Adjustment for change of size may be by interchange of pick-up probe. Only one size during each production run, of course. No mixing of sizes.

C. The actual mechanics of pickup should preferably be by suction, to prevent damage to the surface of the bars, and the heads for different sizes of bars should be changeable easily and quickly.

D. With respect to the selected datum on the lead frame in its carrier, the silicon bar is to be mounted centrally on the mounting platform with a maximum deviation of, say, 0.0005" in any horizontal direction.

E. The pickup mechanism must allow for slight vertical angular positioning variations so that the under face of the bar makes full face contact with the mounting platform so as to prevent the formation of voids in the alloyed structure.

F. As the lead frame datum is transferred to the carrier for positioning, a means of adjustment is to be provided in the transfer mechanism for each horizontal plane.

G. The downward vertical movement of the pickup mechanism is to have an overtravel device to allow for variation in bar thickness and the relative vertical heights of silicon bars and lead frames, and to prevent damage to bars.

H. The pickup mechanism is to have sufficient vertical travel to give adequate clearance over the indexing and positioning mechanism of other units and to permit of visual observation of the operation with a stereo microscope.

I. An adjustment is to be provided so that the alloying load, referred to in paragraph 4.a.4., can be varied within the range of, say, 25 to 200 grammes.

J. The pickup and transfer mechanisms are to have a high degree of stiffness in all directions except those of desired movement.

K. The pickup and transfer mechanisms are to be designed so that ultrasonic vibrations, of a suitable amplitude and frequency can be applied in the horizontal plane to the silicon bar during the actual alloying part of the operation. This is to break down oxide films on the under side of the bar so that the alloying can take place, if this should prove to be necessary.

Appendix 11

Basic requirements for multi-head wire bonder

1. Suitable provision must be provided so that both sides of each bond are heated to the required temperature at the moment of bonding.

2. Co-ordinate movements should be possible over an area of, say, $^3/_4$" square.

3. Needle pressure must be adjustable within a range of, say, 25 to 300 grammes

4. No side movement of the bonding needle is permissible once contact has been made with the silicon bar. A rolling action may, however, take place.

5. Co-ordinate movements may occur simultaneously with vertical travel of the bonding needle after the first bond, only, in each pair of bonds.

6. Suitable 'looping' of the gold wire must occur between each bond in a pair.

7. After the second bond in each pair, bonding needle vertical travel, flame cutting and the de-tailing operations must be complete before co-ordinate movements to the next position take place.

8. The flame cutting and de-tailing operations occur after the second bond only in each pair of bonds.

9. The de-tailing operation occurs almost simultaneously with, but fractionally after, the flame cutting operation.

10. Provision must be made for stereo microscope examination of any unit in the machine.

11. The machine should be designed so that up to 8 bonding heads can be fitted for simultaneous operation. It is not intended that any one individual machine should be expected to have the number of heads on it varied.

12. There must be provision for fine adjustments of the spacing of heads to the precise pitch required.

13. There must be provision for fine adjustment of the vertical heights of individual heads.

14. There should be availability of master location points for lead frame strips in carriers in lengths of up to 8 frames.

15. Consideration should be given to the possibility of the use of other methods of application of the desired bonding heat.

It should be noted that the 15 requirements include some which stem from conclusions reached and described in sections 6 and 7 of this report.

One integrated circuit manufacturer uses lead frames in strips of 8. It is known that other manufacturers used other lengths of strip. One, for example, uses strips of 4.

Appendix 12

Design specification for a programmed, automatic, wire bonder for dual-in-line integrated circuits

This machine is one of three inter-related machines in a system for certain of the assembly operations for dual-in-line integrated circuits in which machines number 1 and 2 are required to make possible the operation of machine number 3.

Machine number 1 is the 'Tempress' automatic indexing diamond scribing machine to 'mark' silicon slices so that they can be broken up into individual bars. It already exists.

Machine number 2 is an automatic positioning/alloying machine the function of which is to mount silicon bars on a precise position on a lead frame for alloying to the lead frame.

Machine number 3, the subject of this specification, is a tape programmed and controlled multi-head wire bonding machine for making the interconnections between the contact pads on the silicon bars and the terminal strips on lead frames, and on a number of units simultaneously.

1. The programme will consist of a number of bonding sequences, normally at least 14, which will be similar and of the following content. The lead frames are positioned by the co-ordinate unit for the first bonding of the gold interconnection wire to a contact pad on the silicon

bar. The bonding head retracts and the lead frames are re-positioned for the second bonding of the wire to the appropriate terminal strip on the lead frame. (See figure 31, which is an enlarged view of the centre part of a lead frame with a silicon bar shown in position). The bonding head retracts and the gas flame cuts the wire and the de-tailing blade pulls the wire tail away from the bond.

2. The machine is to be of unit type construction consisting of 3 main units which are to be assembled in a compact manner consistent with ease of access and visual observation of the functions. The units are as follows:

A. A co-ordinate positioning unit.
B. A multi-head bonding unit.
C. A control unit with tape reader.

3. Unit A - Co-ordinate positioning unit.

The unit shall be capable of movement in each axis in the horizontal plane of up to, say, $^3/_4''$ with a positional accuracy in each case of not less than 0.0005″. It will run on precision roller slides.

b. The rate of movement in each axis shall have a maximum of not less than 0.200″ per second.

c. The mechanism is to have a high degree of stiffness in all directions except those of desired movements.

d. The unit shall have support guides to accept a strip of 8 lead frames of the type, construction and size shown in figure 10.

e. The guides must have locators which will ensure that the lead frames in a strip are located from the selected datums.

f. The unit must incorporate electrically heated anvils for each lead frame, maintained at a temperature of approximately 350°C, and so positioned under the guides that, when the lead frames are located in position, the central platform of the lead frame is positioned directly above and in contact with an anvil.

g. A visual means of monitoring the temperature of the anvils must be provided.

h. The unit is to be designed in such a way that alternative guides and locators for other patterns of lead frames and in shorter strips can readily be fitted. It is not intended that any one individual machine, having been designed for one pattern and length of strip should be converted for any other length of lead strip. It may have to accommodate other patterns, however.

4. Unit B - Multi-head bonding unit.

a. The unit should have 8 bonding heads for simultaneous use and also provision for its use with any lesser number. It is not intended that any one individual machine having been designed for, say, 8 heads should be converted to use any other number of heads.

b. Each bonding head with gold wire feed, gas flame for wire cutting and de-tailing blade, may be basically similar to existing heads on manually operated bonders but must be unitized and easily detachable to assist in clearing wire jams, etc.

c. The following features in existing heads are particularly important and must be retained:

1. Over-travel movement in the downward stroke of the bonding head after bonding contact has been made.
2. Once bonding contact has been made between the aluminium contact pad and the gold wire, the only relative movement permissible is a rolling action.
3. Adjustment of the bonding pressure.

d. Positive locations must be provided for the unitized bonding heads so that removal and replacement will not affect the positional relationship of that particular station with respect to the co-ordinate positioning unit described in paragraph 2.

e. As the basic datum is on the lead frame in its carrier, provision must be made for adjusting the position of individual bonding heads in both axes of the horizontal plane with a movement discrimination of, say, 0.0001" and also for vertical adjustment.

f. The mechanism of the bonding head itself is to have a high degree of stiffness in directions other than the required one.

g. Provision must be made for stereo microscope examination of any bonding position to assist set-up and for general visual observation.

h. A unit is to be fitted to each bonding head assembly which will sense if the gold wire jams in a needle and pass a signal to the control unit for action.
N.B. The gas flame is required to produce balls on the severed ends of the gold wire for (1) the bonding joint on the contact pad on the silicon bar and (2) so that the de-tailing blade can locate on the wire tail, left after the wire has been flame cut, and pull it off.

5. Unit C - Control unit.

a. The programme input is to be by way of a multi-channel tape with one channel for each motion.

b. The motions which have to be controlled are:

1. Movement of the co-ordinate unit in either axis on the

horizontal plane and in both directions.
2. Down and up movements of the bonding head. ('Up' is the normal, or at rest position)
3. Feed in and out of the cutting flame and de-tailing blade.

c. The motions of Units A and B are to be co-ordinated as follows:

1. Positioning movements of unit A may take place simultaneously with upward movements of the bonding heads on unit B after the first bond only in each sequence of two bonds.
2. Positioning movements of unit A in each axes may take place simultaneously.
3. After the second bond in each sequence of two bonds, positioning movements of unit A must not take place until after the flame cutting and de-tailing operations have taken place.
4. The flame cutting and de-tailing operations must only take place after the second bond in each sequence of two have been completed and the bonding heads have returned to the normal, up, position.
5. Movement of unit A and the heads on unit B are to be so arranged that suitable looping of the connecting wire between the two bonds will result.
6. Provision must be made for the acceptance of a manually given 'STOP' signal if operations have to stop in the middle of work on a lead frame strip for any reason and restart at the same point on the cycle at which the stop was given when a 'RESTART' signal is given.
7. Upon receipt of a signal from any one of the wire jam sensing units on unit B the control unit will immediately halt operations, as in 6 above, and give a visual/audio signal so that immediate corrective action can be taken.
8. The tape must feed in a 'STOP' signal after completion of the last operation on a strip of lead frames so that a new strip can be loaded ready for a 'START' signal to initiate a new cycle.

Appendix 13

Detail of flip chip technique

The flip chip technique is already in use for transistors and much work is going on to 'tame' it for use on integrated circuits. In effect it is a complete reversal of existing methods of making the connections between the silicon wafer or bar and the external terminals.

For transistors the wafer is formed with three 'bumps' protruding above the surface and corresponding to the emitter, base and collector elements on which they are formed. They are in triangular formation and their height is of the order of 0.005" to 0.010". There is no special need for great care to ensure that they are all the same height within close tolerances. Like a three leg stool they will accommodate themselves to quite a wide discrepancy in their own heights, or in the mounting surface, when they are inverted and bonded to a suitable substrate.

The substrate has tracks deposited upon it with contact areas for the 'bumps'. The other ends of the tracks have preformed connections to the external leads. The bonding operation is basically similar to the existing wire bonding operation except that all three bonds are formed simultaneously. This is its great attraction. But it must also be said that this method of connection is considered to have much greater reliability than the wire bonding method.

In applying this method to integrated circuits the problem is that they have many more than three connections. They will not behave like a three leg stool. It has proved to be very difficult to develop a method of producing 14, or more, 'bumps' whose height is the same within a very small tolerance. The order of tolerance which is being sought is about 0.0001". With variations much greater than this there is a considerable risk that the bar will be cracked during the multiple bonding operation.

Although at least one manufacturer has expressed the opinion that there will not be a solution to this problem for integrated circuits in the near future, one other manufacturer is satisfied that he has found a very satisfactory answer and that it only requires engineering to bring it into production.

There are two principal advantages which are expected from the flip chip technique. All bonds are made at the same time and the elimination of the bonded wire connections substantially increases the reliability of the interconnection system of the device. A further advantage, from the point of view of automatic assembly, is that it may be necessary to use a single bar size regardless of circuit requirements.

Appendix 14

Specification for an automatic assembly system for dual-in-line integrated circuits

The system will deal with the assembly of D.I.L. i/c's from the stage at which they are scribed and broken, through sorting and orientating, positioning on, and alloying to, the lead frame, to the bonding of the interconnecting wires between the silicon bars and the lead frame. The mechanism for sorting and orientating may be separate from, or incorporated in, the main machine and is described in another specification. This specification describes the rest of the system.

The machine which is the subject of this specification is tape programmed and controlled and carries out the following functions. It picks up silicon bars, delivered by the mechanism described in the associated specification, positions them on lead frames, alloys them in position and finally makes all the wire connections between the bar and the lead frame.

1. The machine is to be of unit type construction consisting of 6 main units which are to be assembled in a compact manner consistent with ease of access and visual observation of the functions. The units are as follows:-

a. A carrier, positioning and heating unit for lead frame strips.
b. A pick up and transfer mechanism to pick up bars from the machine described in the associated specification and transfer the bar to the alloying position on a lead frame in unit A and physically initiate the alloying operation.
c. A single wire bonding head
d. A co-ordinate positioning unit.
e. A base unit on which units A, B, C and D will be mounted.
f. A control unit with tape reader which will provide the necessary co-ordinated drives to units A, B, C and D.

N.B. Units B and C will be mounted on unit D.

2. Unit A.

i. The unit is to accept lead frames, generally of the construction shape and size shown in figure 27, in strips of, say, 8, locked in suitable transport carriers and have a means of indexing them, one by one, to the operating position where they are to be located from a predetermined datum on the transport carrier ready for positioning and alloying of a silicon bar to the frame. The full length of the lead frame transport carrier is to be supported.

ii. In the operating position, the centre platform of the lead frame is to be positioned over, and rest upon, a heated anvil maintained at a temperature of approximately 480°C.

iii. Visual indication of the anvil temperature is to be provided.

iv. The unit is to be designed in such a way that alternative transport carriers and/or indexing and locating mechanisms for other patterns of lead frames can readily be substituted.

v. The entire mechanism to have an additional X axis movement over a distance of say $^3/_8$" increments of not more than 0.0001" and positional accuracy of the same order. To be complementary to the Y axis movements of unit D.

3. Unit B.

i. When a silicon bar and a lead frame are located in their operating positions a carrier and transfer mechanism will perform the following functions:

   a. Pick up silicon bar.
   b. Transfer silicon bar to desired position above centre platform of lead frame.
   c. Lower silicon bar to make contact with platform.
   d. Apply a load, of, say, 50 grammes for a time of, say, 1 second for alloying process to carry through and be completed.
   e. Release silicon bar, lift and transfer back to start position ready to pick up next silicon bar.

ii. With respect to the selected datum on the transport carrier, the silicon bar is to be positioned centrally on the mounting platform of the lead frame within a maximum deviation of, say, 0.0005" in any horizontal direction.

iii. The pickup method will be such as to allow for slight vertical angular positioning variations so that the under side of the silicon bar makes full face contact with the mounting platform to prevent the formation of voids in the alloyed structure.

iv. The pickup device will be capable of adjustment so as to cover the range of silicon bar sizes given in paragraph 4.5B in Appendix 10.

v. As the lead frame transport carrier is the datum for positioning, a means of adjustment is to be provided in the transfer mechanism for each horizontal plane.

vi. The vertical movement of the pickup mechanism is to have an over-run device to allow for variation in bar thickness and relative vertical heights of silicon bars and lead frames.

vii. The pickup mechanism is to have sufficient vertical travel to give adequate clearance for the indexing and positioning mechanisms of other units, for the burn-off flame and de-tailing blade and to permit of visual observation of the operations.

viii. An adjustment is to be provided so that the alloying load, referred to in paragraph 3.i(d), can be varied within a range of from, say, 25 to 200 grammes.

ix. The pickup and transfer mechanisms are to have a high degree of stiffness in all directions except those of required motions.

x. The pickup and transfer mechanisms to be designed so that ultra-sonic vibrations, of a suitable amplitude and frequency, in the horizontal plane can be applied to the silicon bar (to break down oxide films) during the alloying part of the cycle, if this should prove to be necessary.

4. Unit C.

The programme will consist of a number of bonding sequences, normally at least 14, which will be similar and of the following content. The lead frames, in transport carriers are positioned by the co-ordinate unit for the first bonding of the gold connecting wire to a contact pad on the silicon bar. The bonding head retracts and the transport carriers are repositioned for the second bonding of the connecting wire to the appropriate terminal strip on the lead frame. (See figure 31 which is an enlarged view of the centre part of the lead frame in figure 27 and with a silicon bar shown in position). The bonding head retracts, the gas flame cuts the wire and the de-tailing blade pulls the wire tail away from the bond.

i. The bonding head, complete with gold wire feed, gas flame for wire cutting and de-tailing blade, may be basically similar to existing heads on hand operated bonders but must be unitized and made easily detachable to assist in clearing wire jams, etc.

ii. Positive locations must be provided for the unitized bonding heads so that removal and replacement of a head will not affect its positional relationship with respect to the co-ordinate positioning units described in paragraphs 2(v) and 5.

iii. Of the features in the existing heads the following are particularly important and must be retained:

a. Overtravel movement in the downward stroke on the bonding head mechanism after bonding contact has been made.

b. Once bonding contact has been made between the gold ball (formed on the end of the wire by the gas flame) and the silicon bar, the only relative movement permissible is a rolling action.

c. Adjustment of the bonding pressure.

d. In addition there should be some control over the rate of downward movement of the bonding head.

iv. As the basic datum is on the lead frame transport carrier, provision must be made for adjusting the position of the bonding head in both axes of the horizontal plane in increments of, say, 0.0001″ and also for individual vertical adjustment.

v. The mechanism of the bonding head itself is to have a high degree of stiffness in directions other than the required vertical movement.

vi. Provision must be made for binoccular microscope examination of the bonding position to assist set-up and for general visual observation.

5. Unit D.

i. The unit will support units B and C.

ii. The unit shall be capable of movement in the Y axis of the horizontal plane of up to, say, 2″ and with a positional accuracy of not less than 0.00005″. (A fast and a relatively slow rate of travel with long and short distance are required, respectively, for the heads of units B and C).

iii. The rate of movement shall have a maximum of not less than 0.200″ per second.

iv. The mechanism is to have a high rate of stiffness in all directions except those of the required motions.

v. An electrically heated anvil maintained at a temperature of approximately 350° is included and positioned so that it heats by conduction the lead frame central platform which is directly under the bonding needle. (If possible, micro-pulse bonding is to be used which will obviate the need for the heated anvil and visual temperature indication called up in this and the following paragraph).

vi. A visual means of monitoring the anvil temperatures must be provided.

6. Unit E.

This unit will be suitably designed so as to accept units A, B, C and D on a unitary basis. Attachments to be such that the units, and parts of units especially in the case of unit C, can be easily and quickly replaced without upsetting previously set positional accuracies.

7. Unit F.

i. The programme input to be via a multi-channel tape.

ii. Two completely separate cycles of movement have to be controlled and interlinked.

a. The movements required for positioning and alloying silicon bars on lead frames.

b. The movements required for bonding the gold wire connections between the silicon bar and the lead frame.

iii. The various movements, and their order, are as follows:

a. Position unit A so that first lead frame in the transport carrier is positioned with central platform in centre zero position.
b. Advance unit D so that pick-up arm on unit B is above target position for silicon bar.
c. Extend pickup arm to pick up silicon bar.
d. Retract pickup arm with silicon bar.
e. Reverse movement of unit D so that pickup arm with silicon bar is above lead frame platform in centre zero position.
f. Extend pickup arm so that silicon bar contacts platform and a load of up to, say, 50 grammes, is applied for, say, 1 second to initiate and complete alloying operation.
g. Release silicon bar and retract pickup arm.
h. Index unit A along X axis so that 2nd lead frame is positioned with central platform in centre zero position.
i. Repeat movements (b) and (g) inclusive.
j. With respect to the datum for the bonding programme: by co-ordinate movements of units A and D position bonding head so that needle is above first connection pad on silicon bar on first lead frame.
k. Extend bonding head to make ball bond on silicon bar.
l. Retract bonding head and simultaneously, by co-ordinate movements of units A and D move to position for second bond on terminal strip on load frame, extend bonding lead and complete bond.
m. Retract bonding head.
n. Operate flame cutter and de-tailing blade.
o. Repeat (j) so that needle is above second or next connection pad in the sequence.
p. Repeat (k) to (o) inclusive.
q. Repeat (j) to (o) until bonding programme for complete integrated circuit is finished.
r. Repeat (a) to (q) until silicon bars have been alloyed to all lead frames in the strip and bonding connection programmes have been completed for all the silicon bars.
s. Stop. Ready for removal of completed lead frame strip in transport carrier and insertion of new one ready for start of complete programme once again.

N.B. The movements in steps (a) and (h) are constant, relatively large movements, whilst those in steps (j) and (l) are small and variable co-ordinate movements.

iv. Co-ordinate positioning movements of units A and D may take place simultaneously.

v. Co-ordinate positioning movements of units A and D will take place simultaneously with upward movements of bonding head after the first bond, <u>only</u>, in each sequence of two bonds on each connection wire.

vi. After the second bond in each sequence of two bonds, co-ordinate positioning movements must not take place until after the flame cutting and de-tailing operations have been completed.

vii. The flame cutting and de-tailing operations must only occur after the second bond, in each sequence of two, has been completed and the bonding head has returned to the normal, 'up', position.

viii. Movements of A, C and D are to be arranged so that suitable looping of the connecting wire occurs between each bond in a sequence of two.

ix. Provision must be made for the acceptance of a manually given 'suspend' signal if operations have to be stopped for, say, a wire blockage and for a manually given 'restart' signal, after clearance, at the point in the cycle at which the 'suspend' signal was given.

x. The tape must feed in a STOP signal after completion of the last operation on a strip of lead frames so that a new strip can be loaded ready for a START signal to initiate a new cycle.

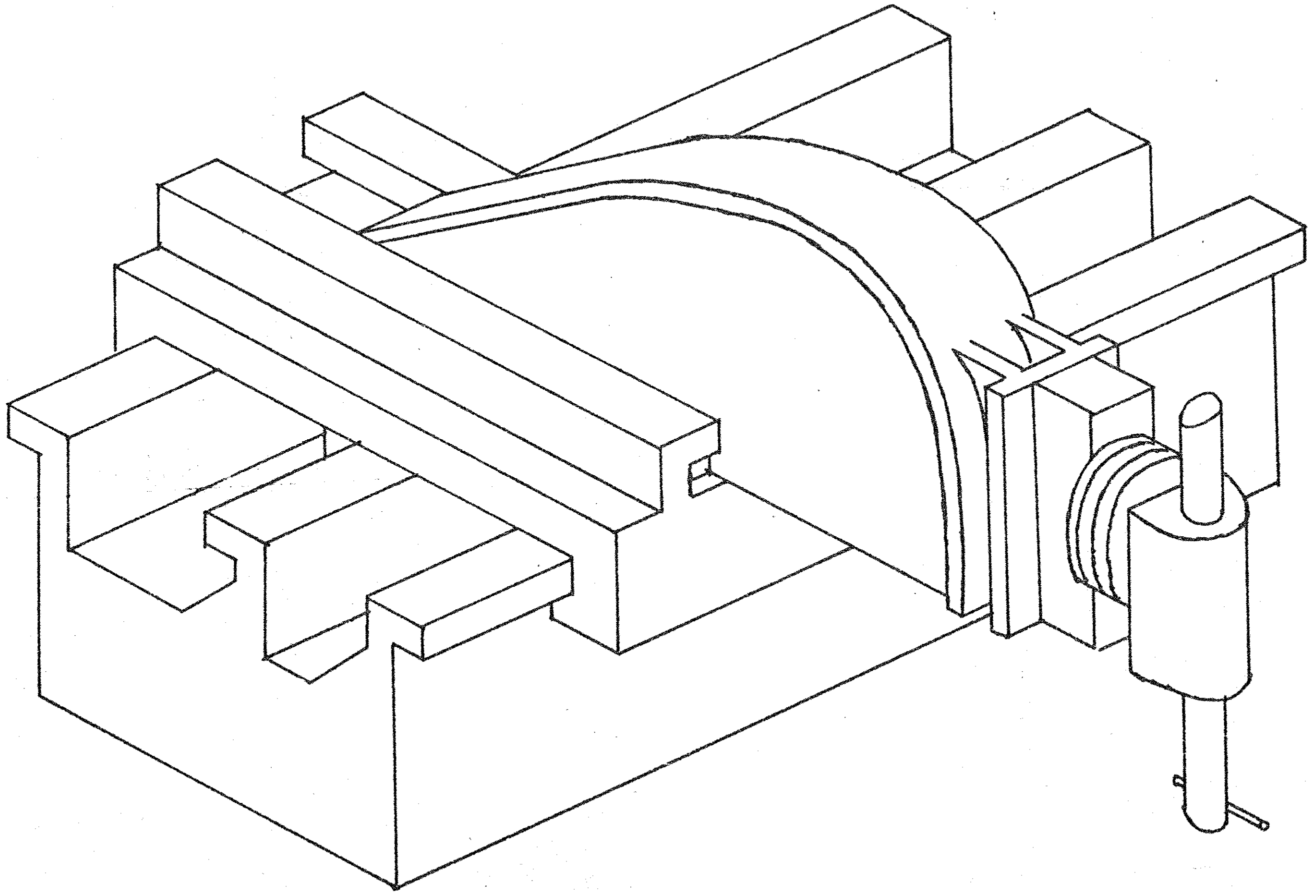


FIG. 1 DIAGRAM OF THE CRANFIELD MEASURING MACHINE

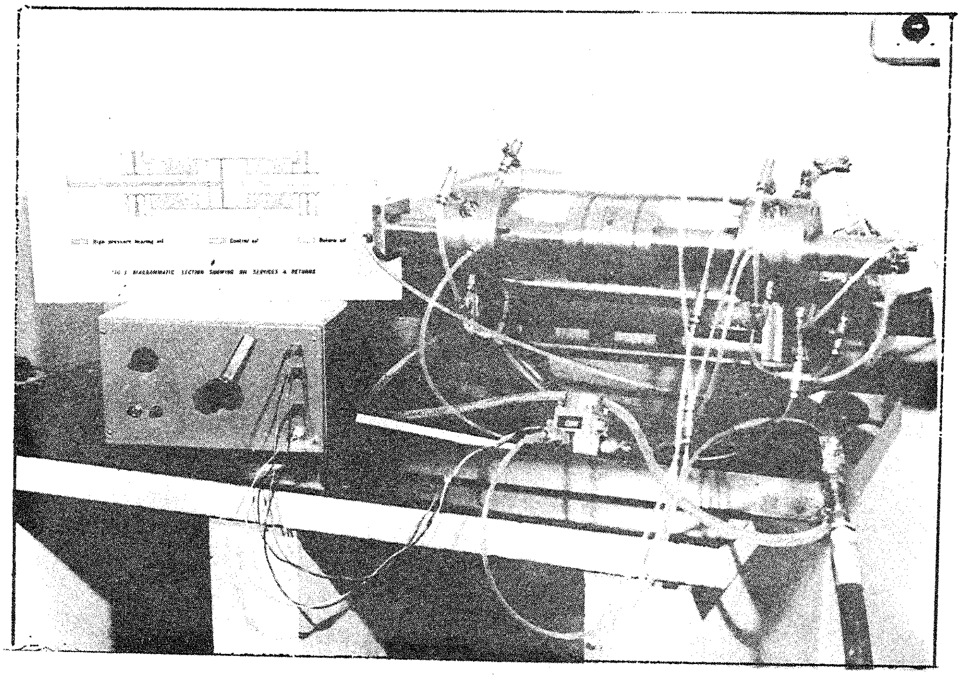


FIG. 2 THE HYDRAULIC/HYDROSTATIC ACTUATOR

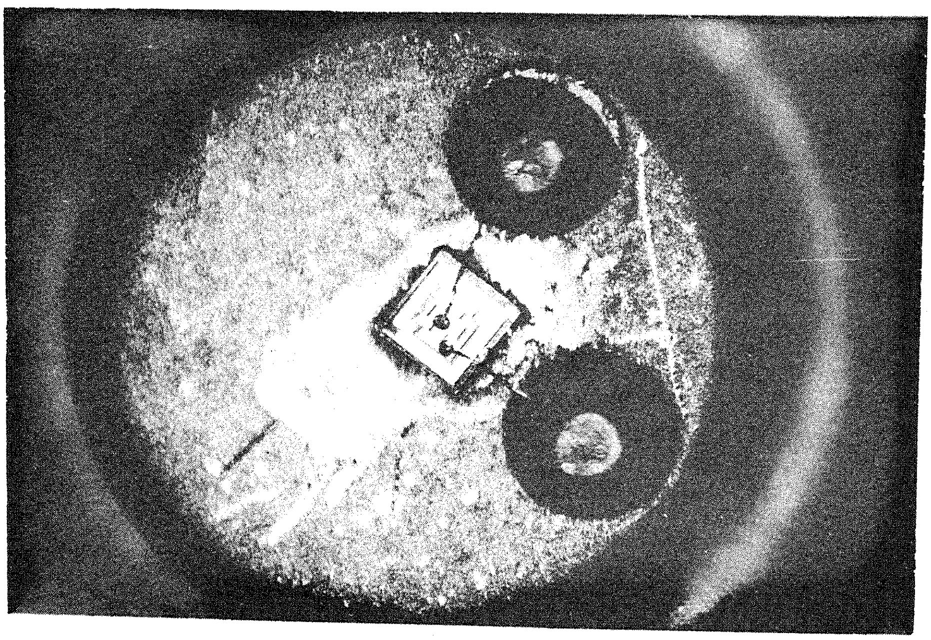


FIG. 3 UNCANNED SEMI-CONDUCTOR DEVICE SHOWING GOLD WIRE-BONDED CONNEXIONS

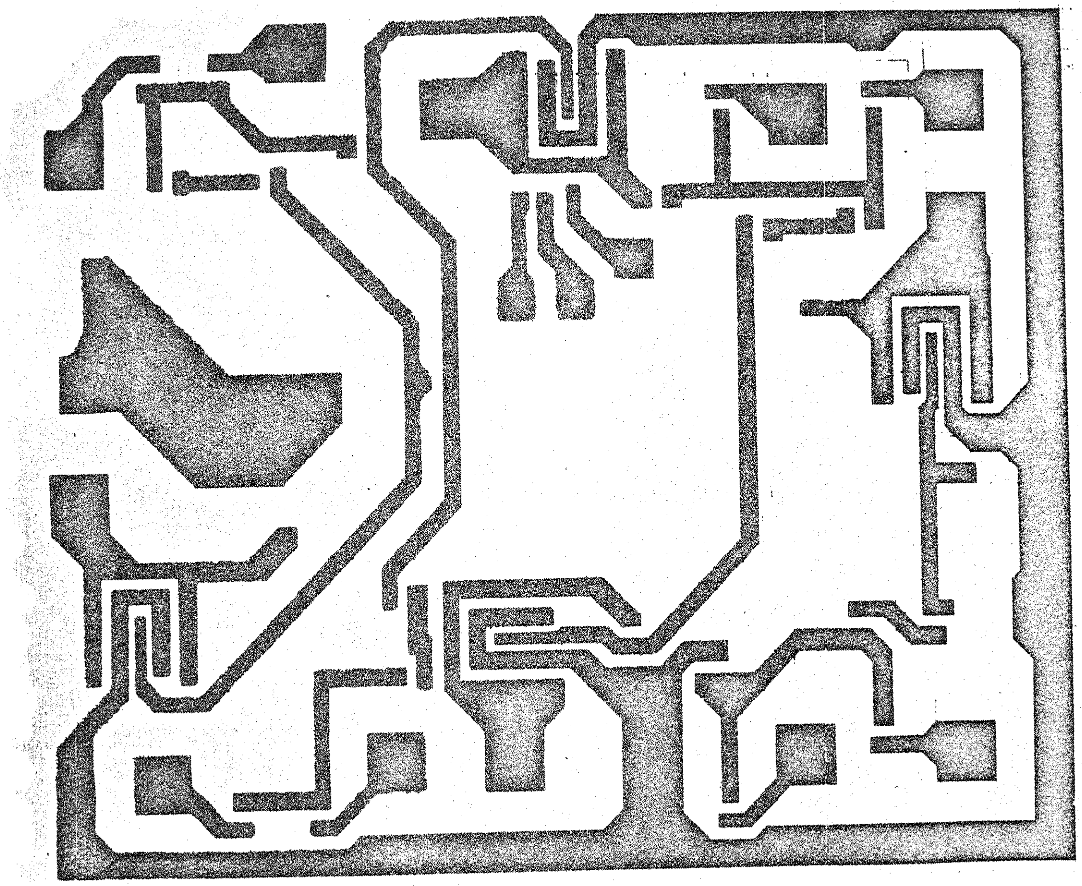


FIG. 4 MASTER INTERCONNEXION DRAWING FOR AN INTEGRATED CIRCUIT

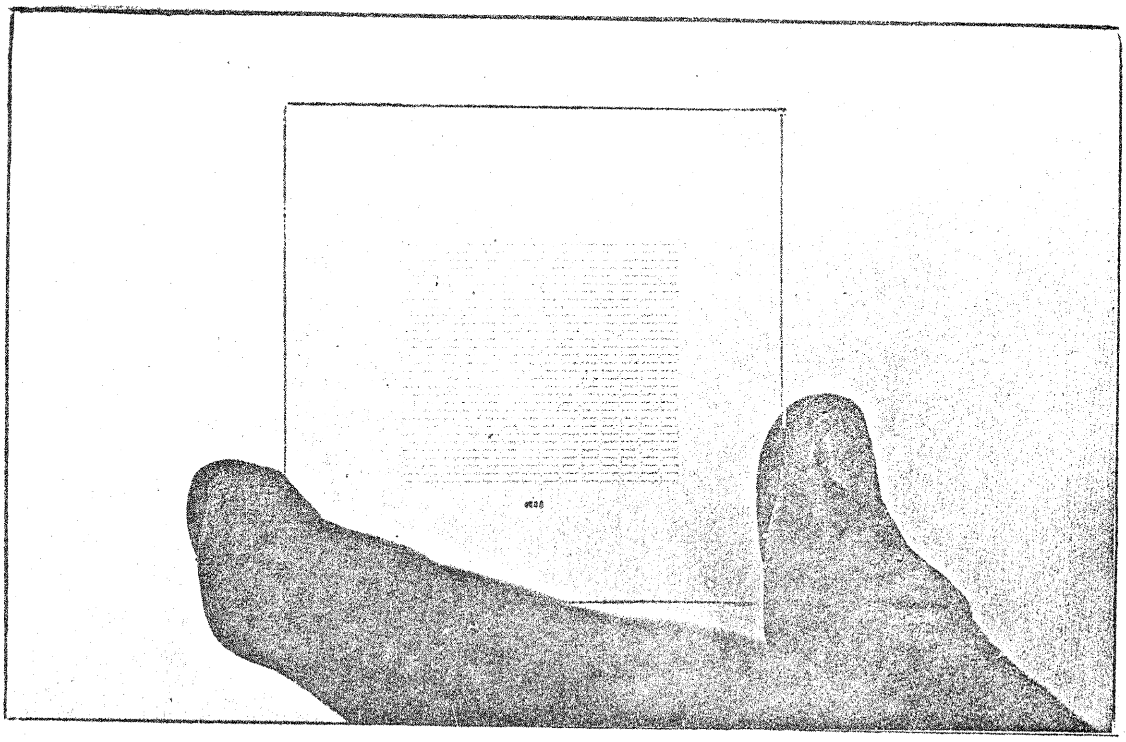


FIG. 5 FULL SIZE GLASS METER

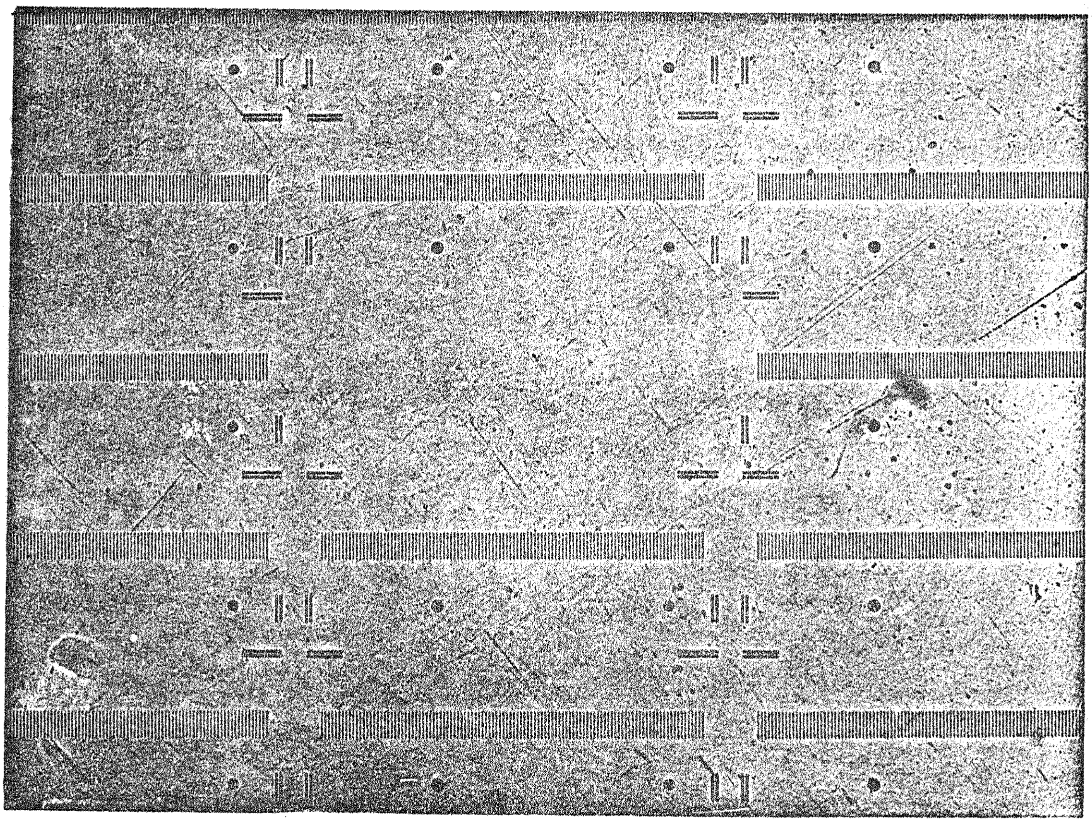


FIG. 6 ENLARGED VIEW OF THE CENTRE OF FIG. 5

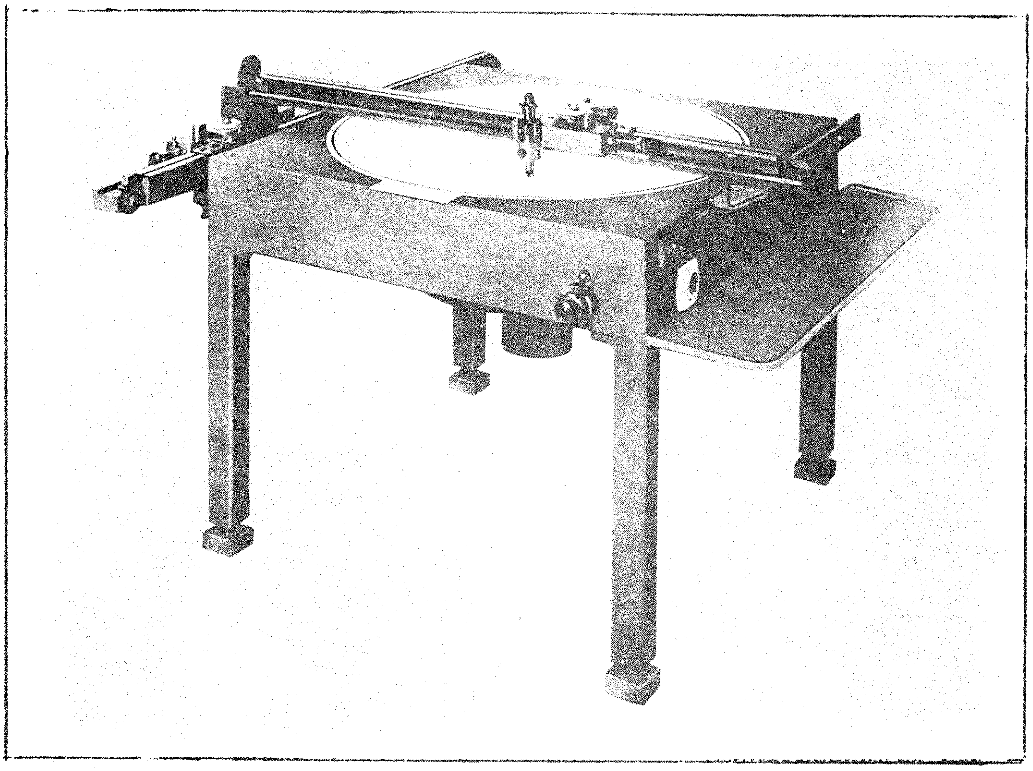


FIG. 7 THE "ARISTO" CO-ORDINATOGRAPH

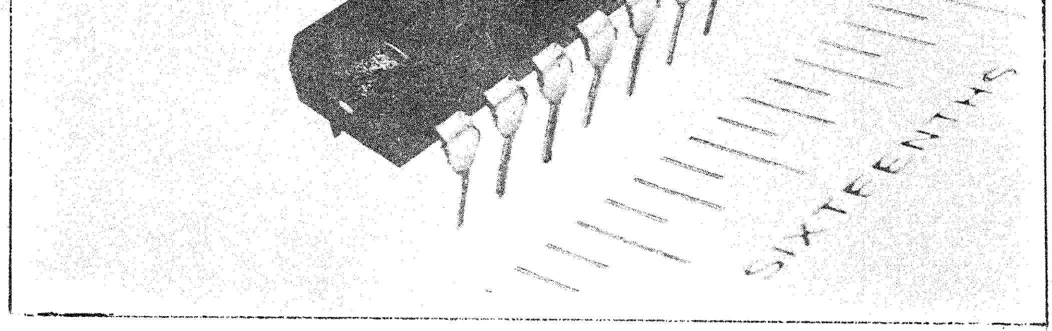


FIG. 8 A DUAL-IN-LINE INTEGRATED CIRCUIT

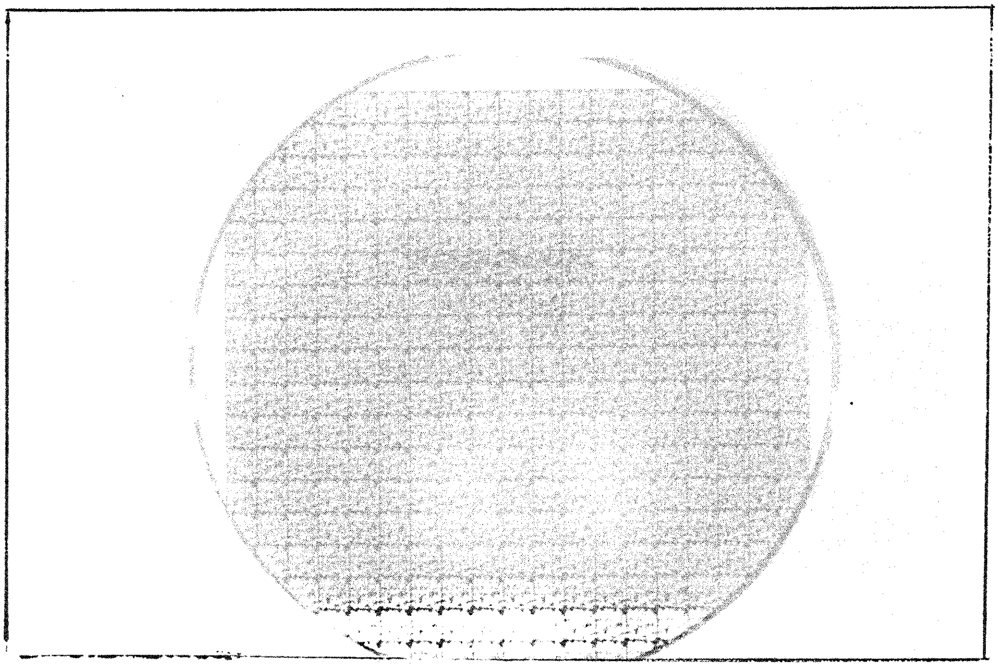


FIG. 9 AN INTEGRATED CIRCUIT SLICE

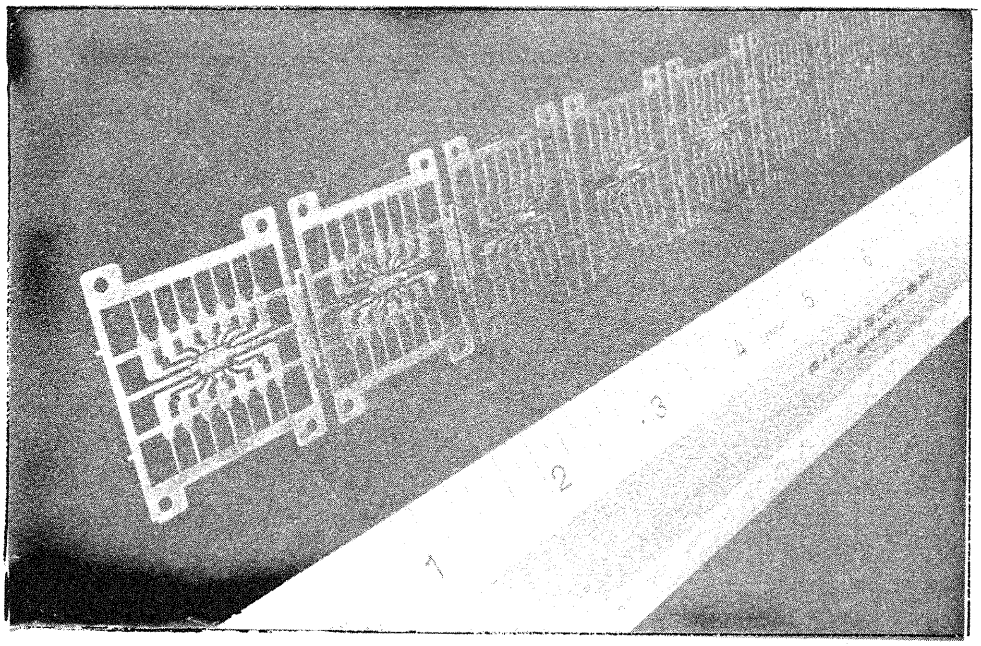


FIG. 10 AN 8 UNIT LEAD FRAME STRIP

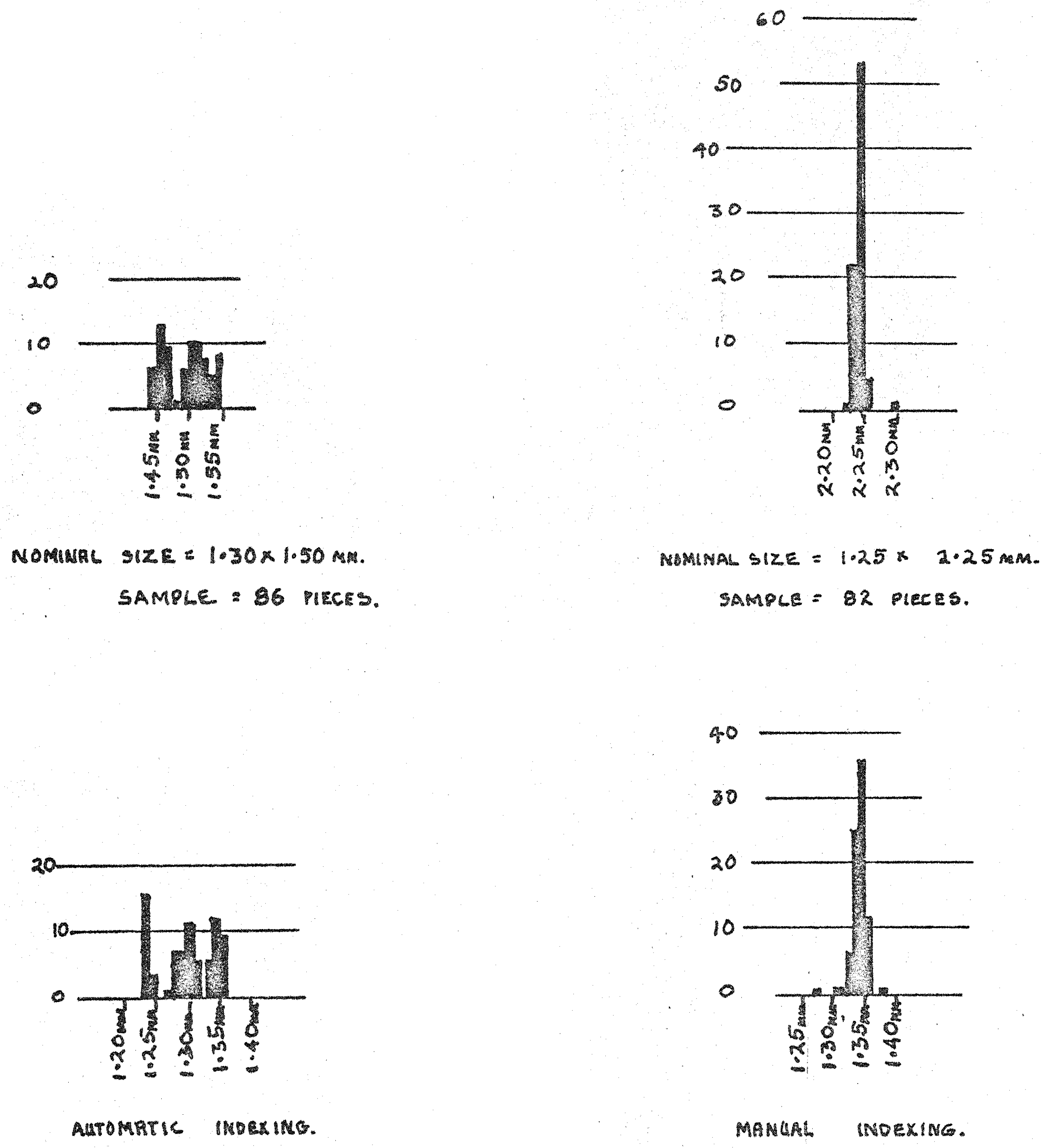


FIG. 11 SILICON BAR SIZES

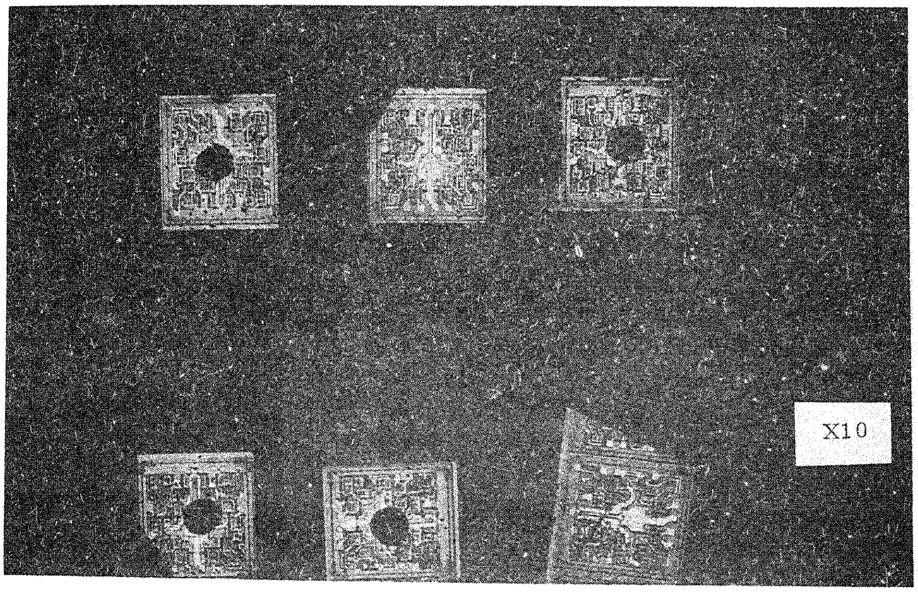


FIG. 12 SILICON BARS WITH CHIPPED EDGES AND ALSO BROKEN ACROSS CIRCUIT PATTERN

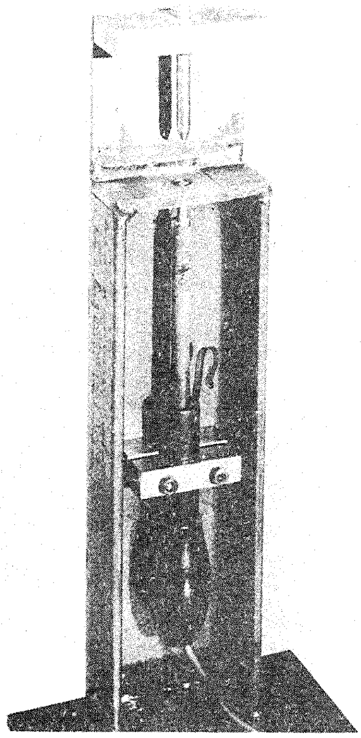


FIG. 13 SOLDERING IRON FIXTURE FOR ALLOYING EXPERIMENT

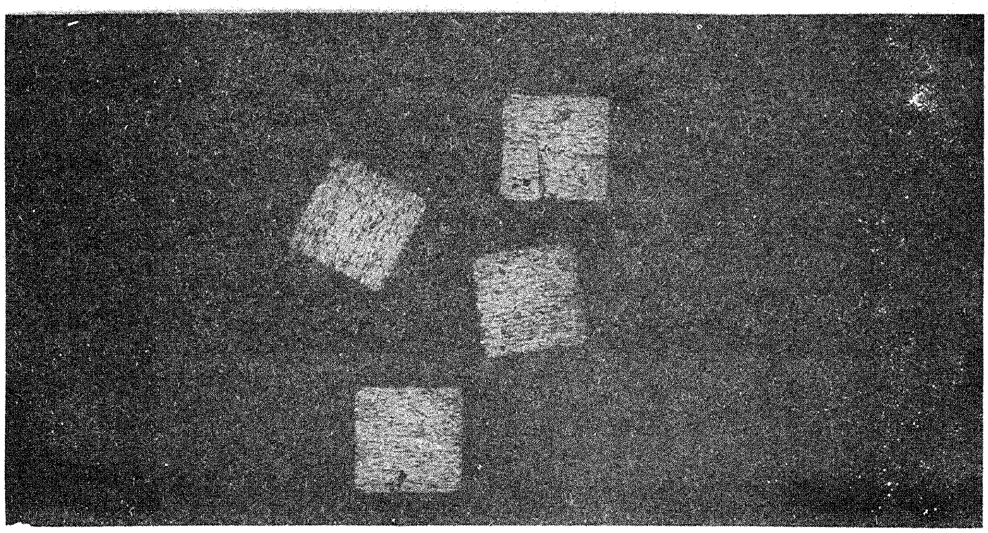


FIG. 14 GOLD PRE-FORMS

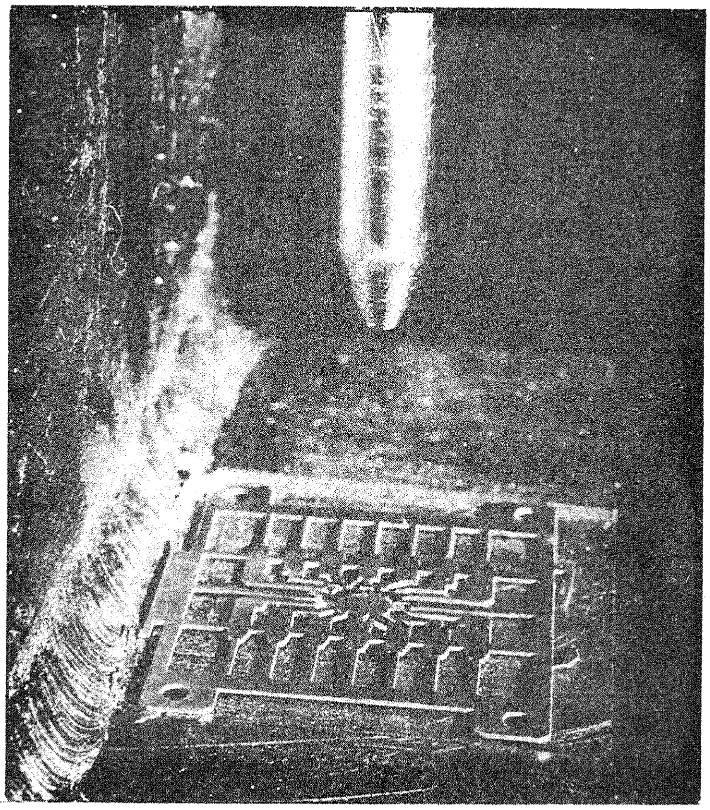


FIG. 15 ALLOY TEST FIXTURE WITH LEAD FRAME IN POSITION

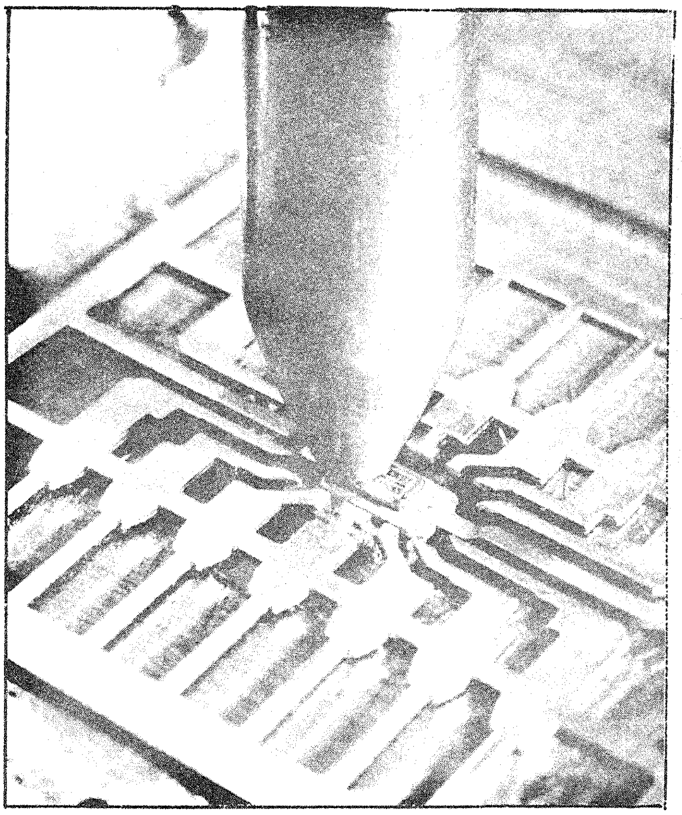


FIG. 16 ALLOYING UNDER PRESSURE ONLY

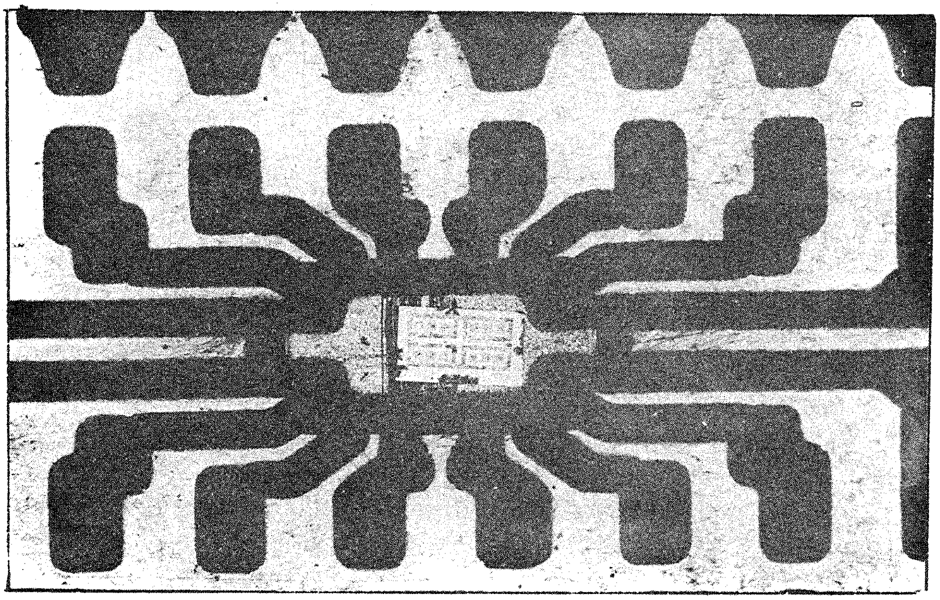


FIG. 17 SILICON BAR ALLOYED TO LEAD FRAME WITHOUT "SCRUBBING"

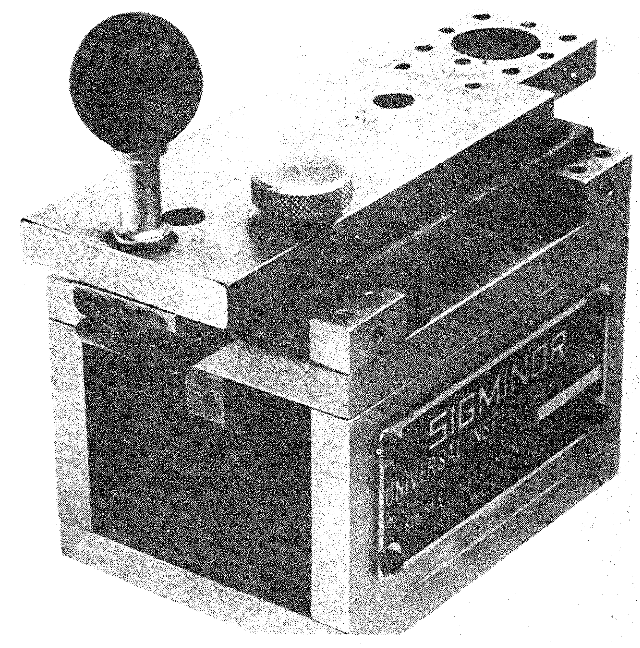


FIG. 18 ROLLER SLIDE UNIT

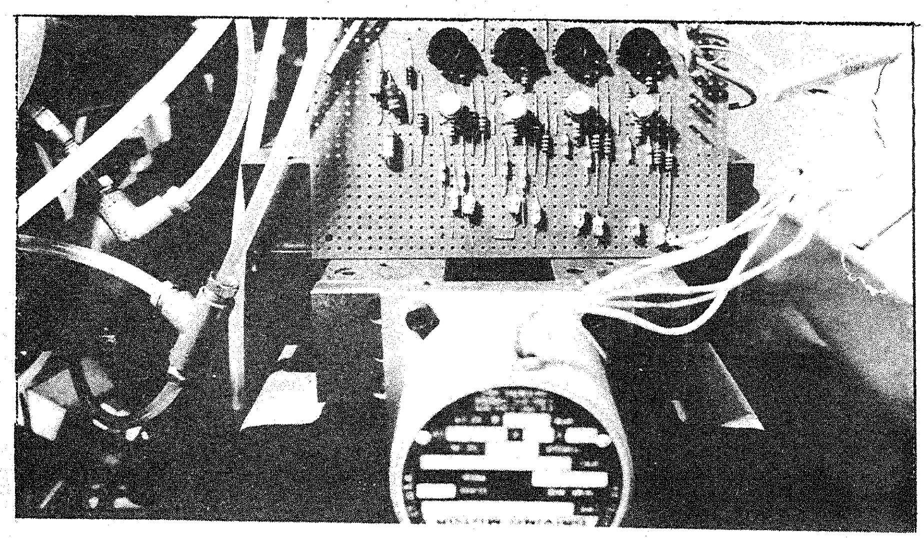


FIG. 19 SET UP FOR TESTING STEPPING MOTOR DRIVE TO PRECISION SCREW

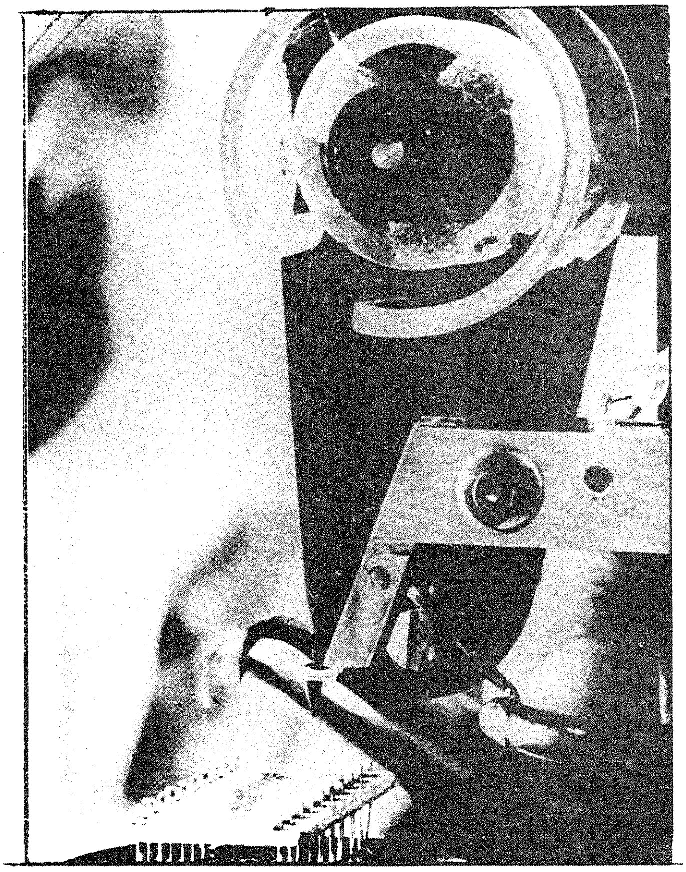


FIG. 20 HUGHES' MICRO-PULSE BONDING MACHINE HEAD

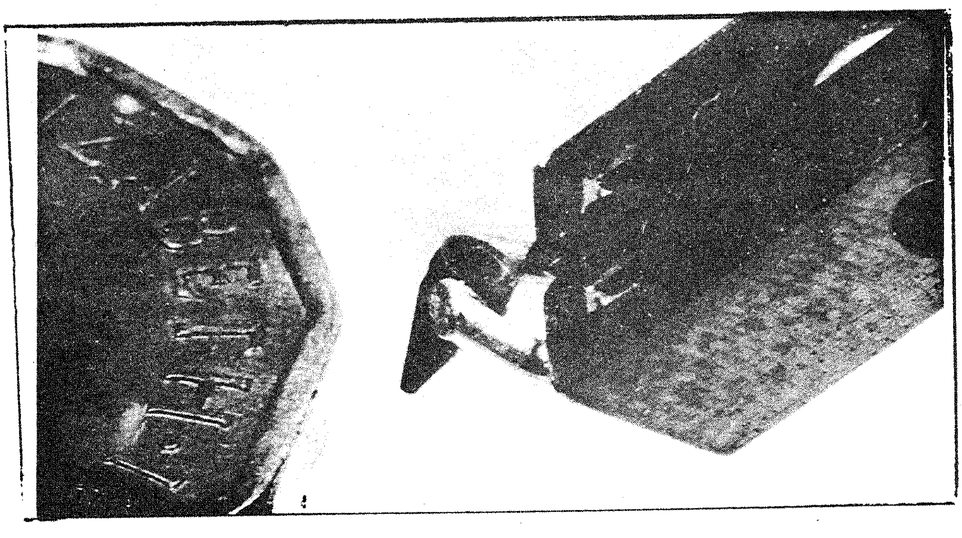


FIG. 21 MICRO-PULSE BONDING NEEDLE

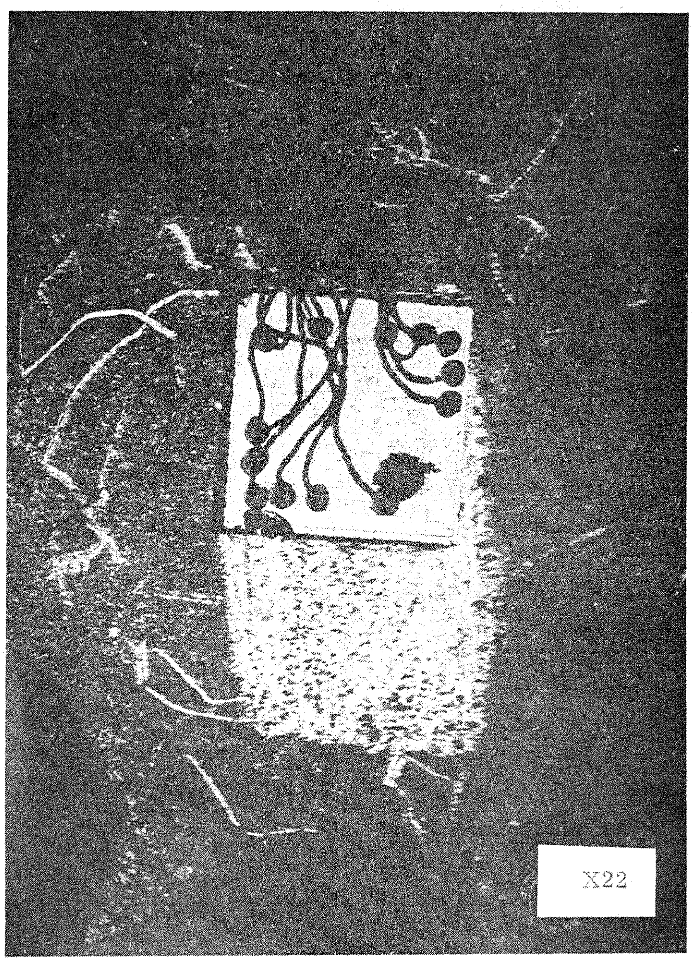


FIG. 22 MICRO PULSE BONDING SAMPLE

FIG. 23a MICRO-PULSE BONDS DONE AT 210 GRAMMES NEEDLE LOAD

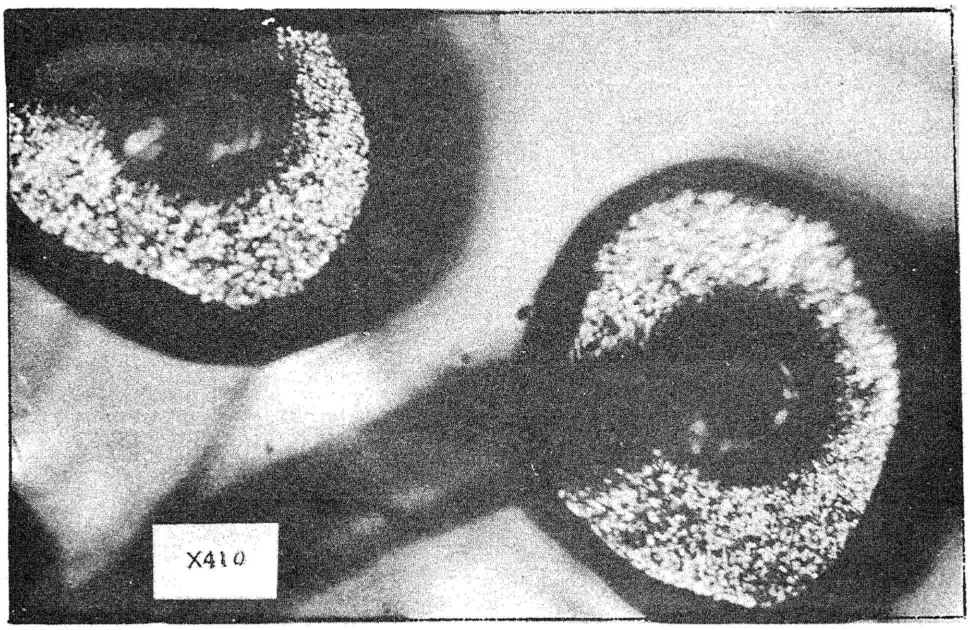


FIG. 23b MICRO-PULSE BONDS DONE AT 80 GRAMMES NEEDLE LOAD

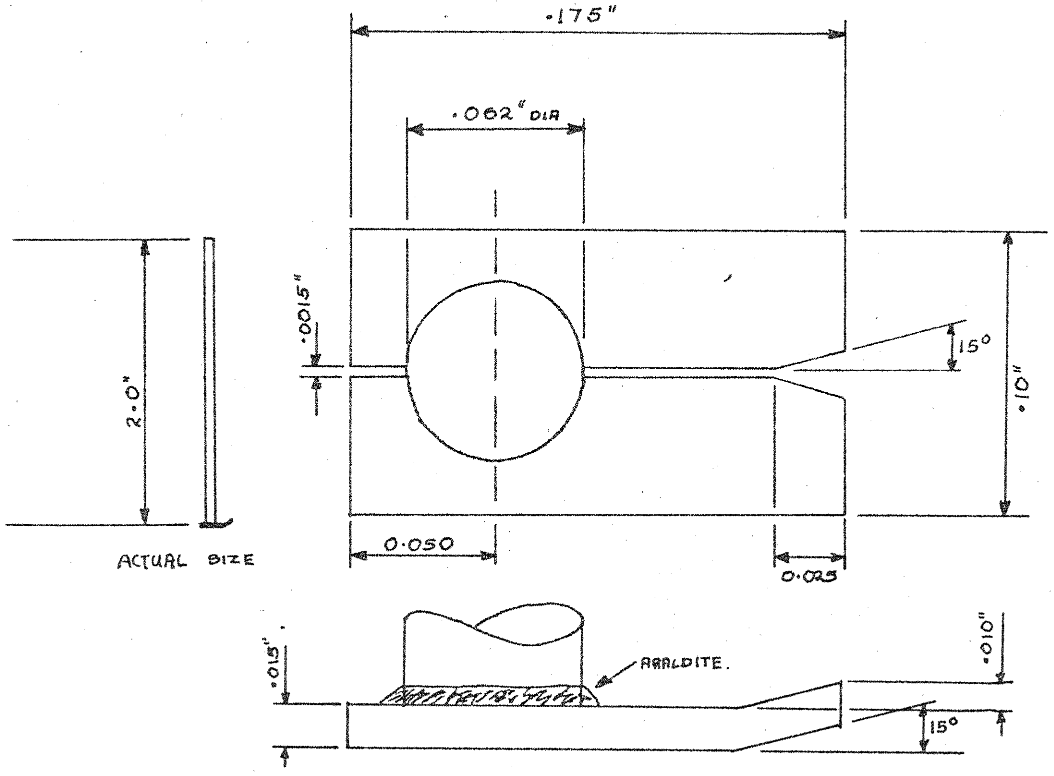


FIG. 24 DRAWING OF THE PULL TEST ADAPTOR FOR MICRO-PULSE BOND TESTS

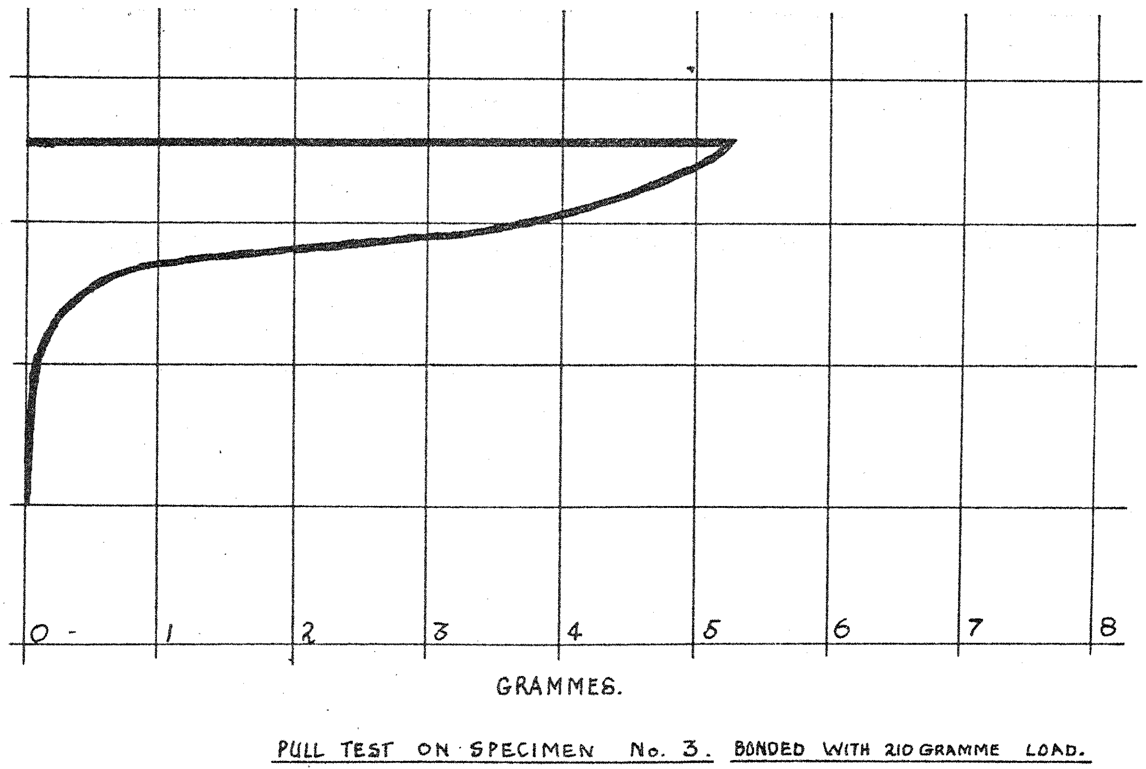


FIG. 25 MICRO-PULSE BOND PULL TEST RESULT CHART

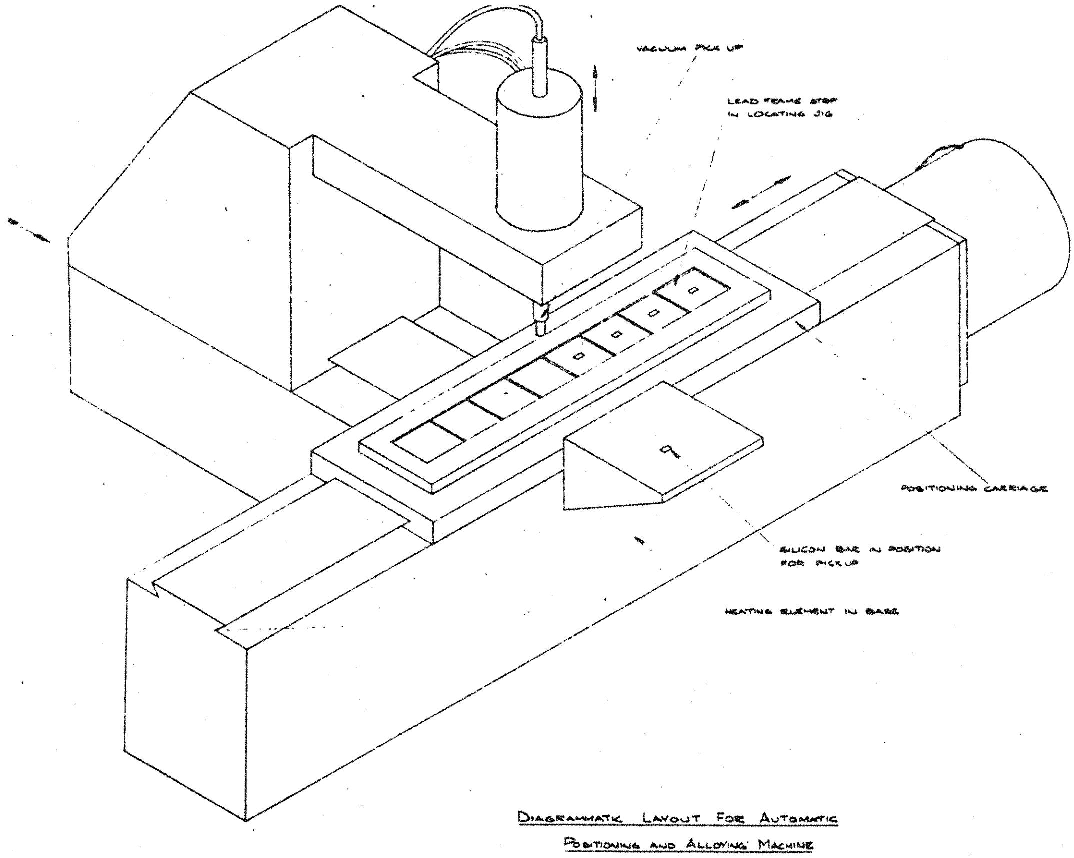


FIG. 26 DRAWING OF POSITIONING/ALLOYING MACHINE

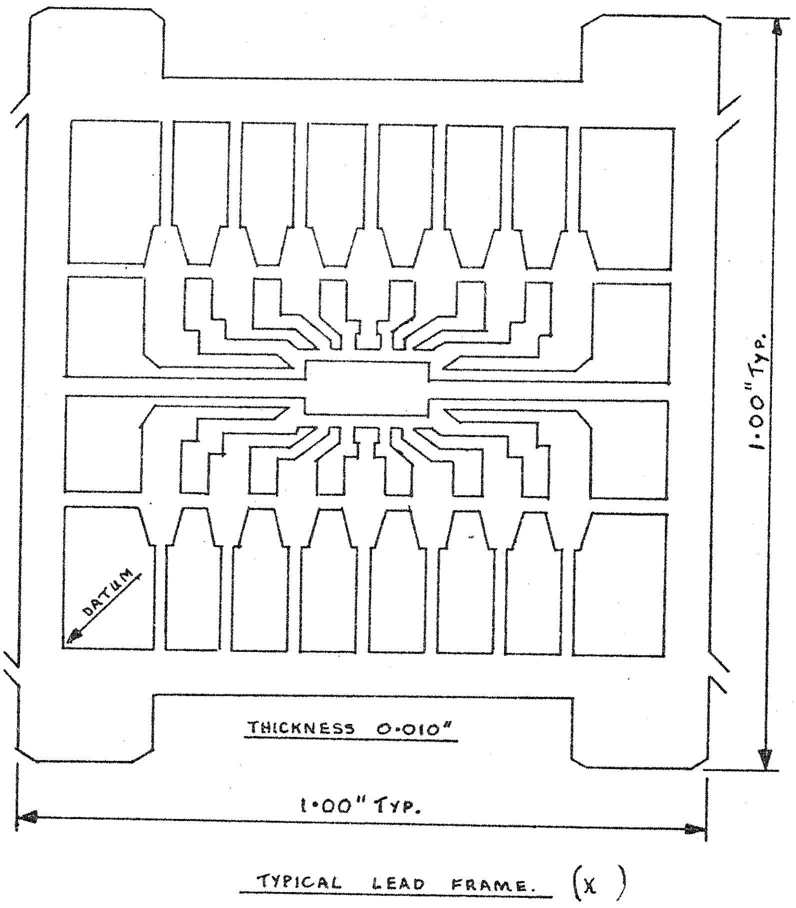


FIG. 27 DRAWING OF DETAIL OF LEAD FRAME

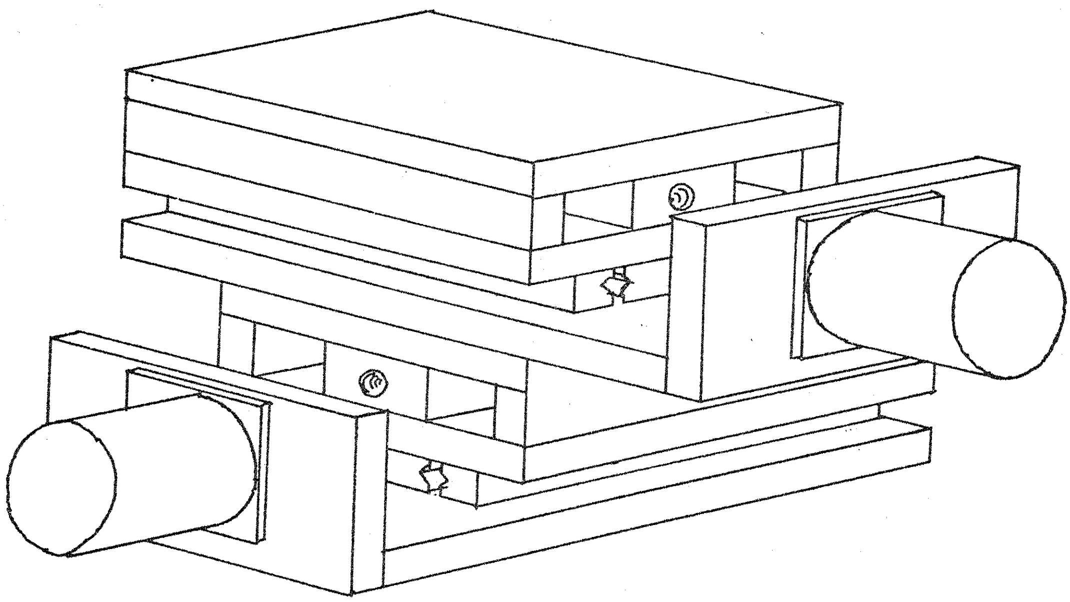


FIG. 28 DRAWING OF PROPOSED CO-ORDINATE UNIT

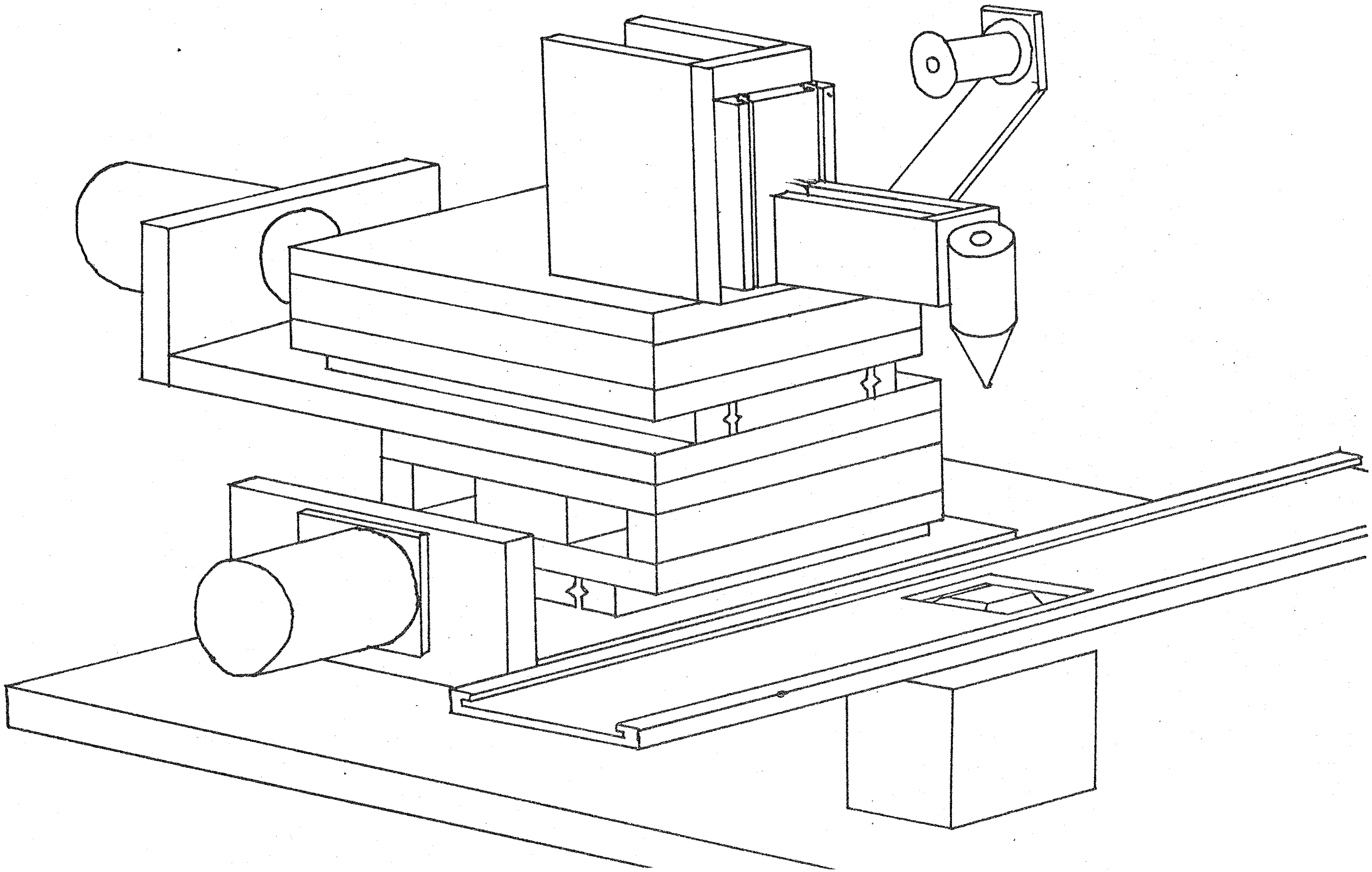
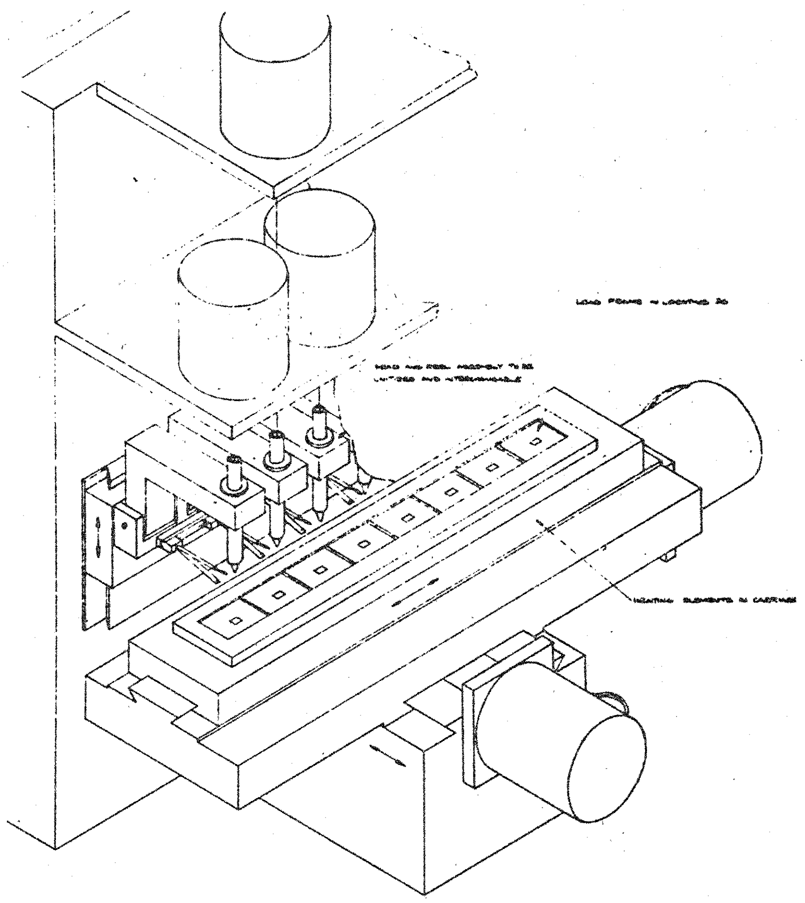
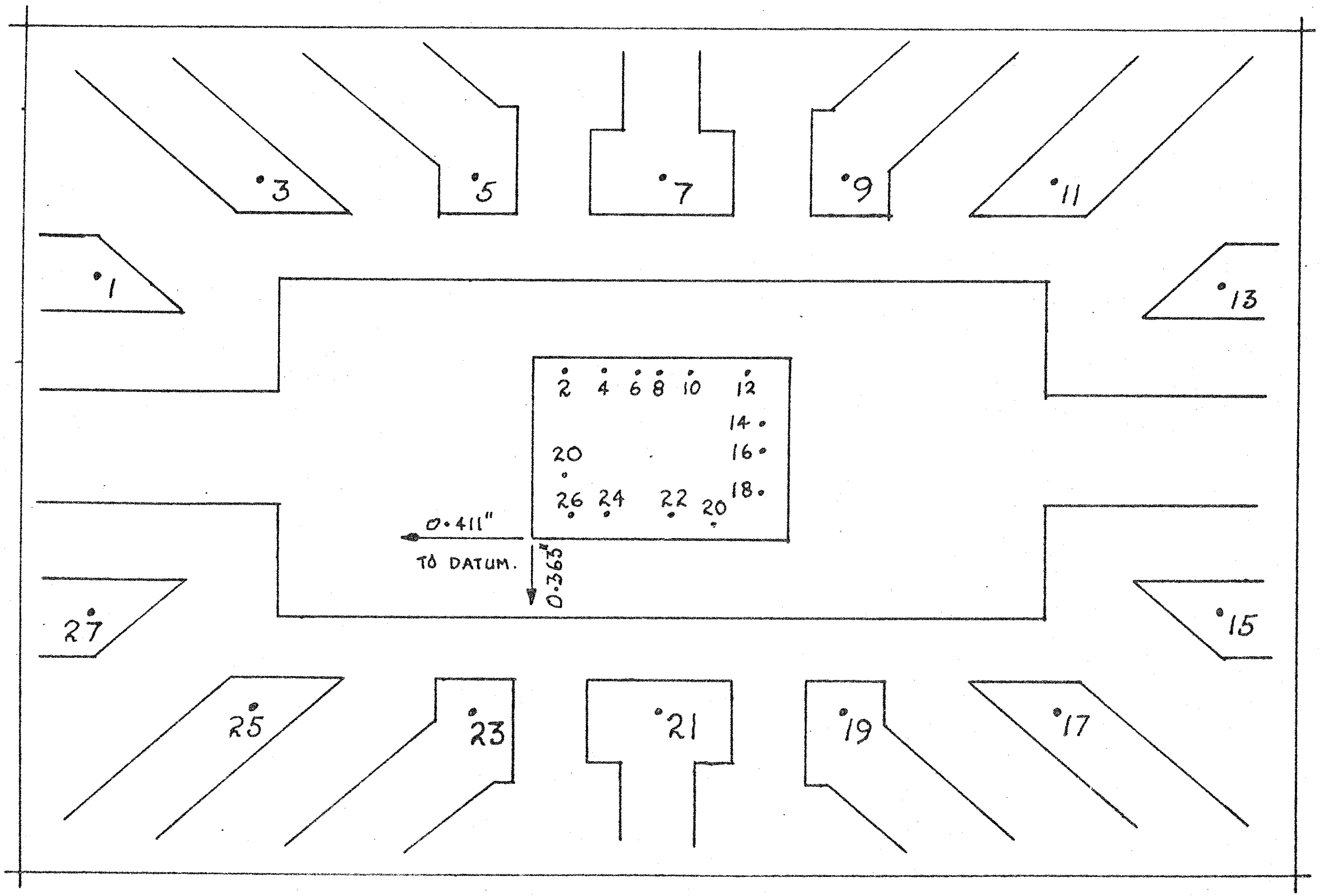


FIG 29 DRAWING OF PROPOSED SINGLE HEAD BONDER



DIAGRAMMATIC IMPRESSION OF LAYOUT FOR
AUTOMATIC MULTI-HEAD WIRE BONDING MACHINE

FIG. 30 DRAWING OF PROPOSED MULTI-HEAD BONDING MACHINE



WIRE CONNEXION SEQUENCE :- 2 TO 1. 4 TO 3. 6 TO 5 -------- 28 TO 27.

FIG 31 DRAWING OF CENTRE OF LEAD FRAME WITH SILICON BAR IN POSITION AND SHOWING ORDER OF BONDS

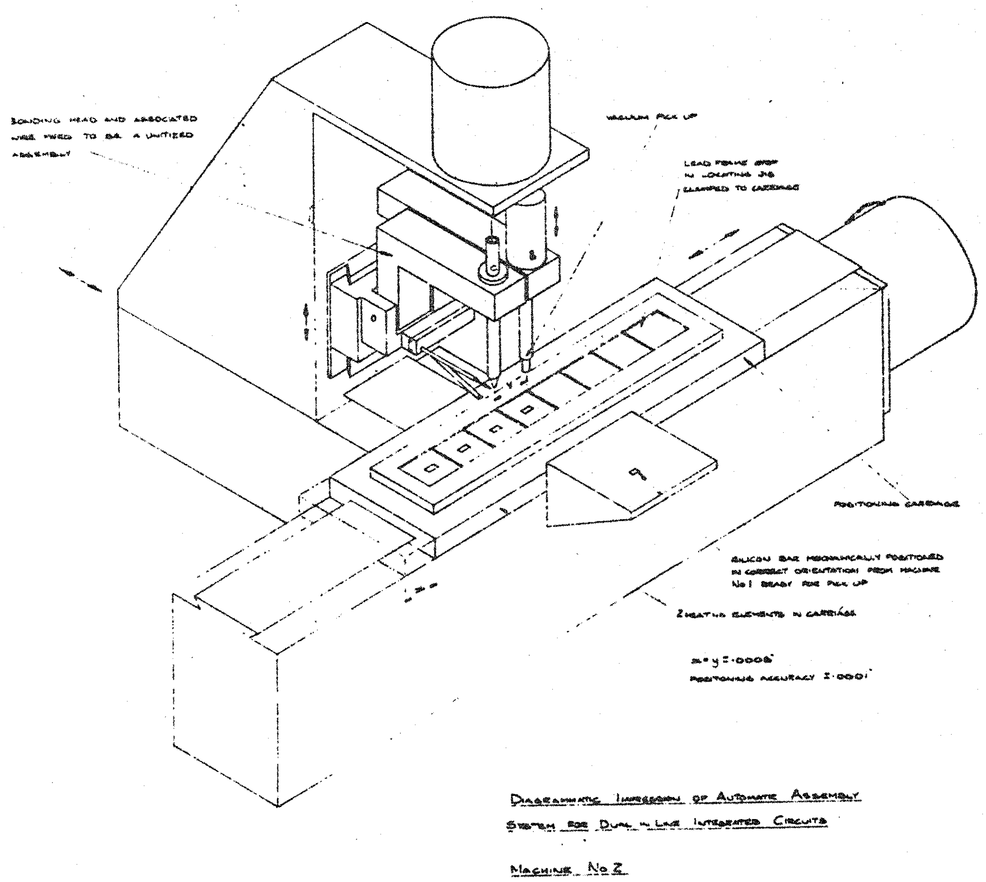


FIG. 32 DRAWING OF PROPOSED POSITIONING/ALLOYING/ BONDING MACHINE

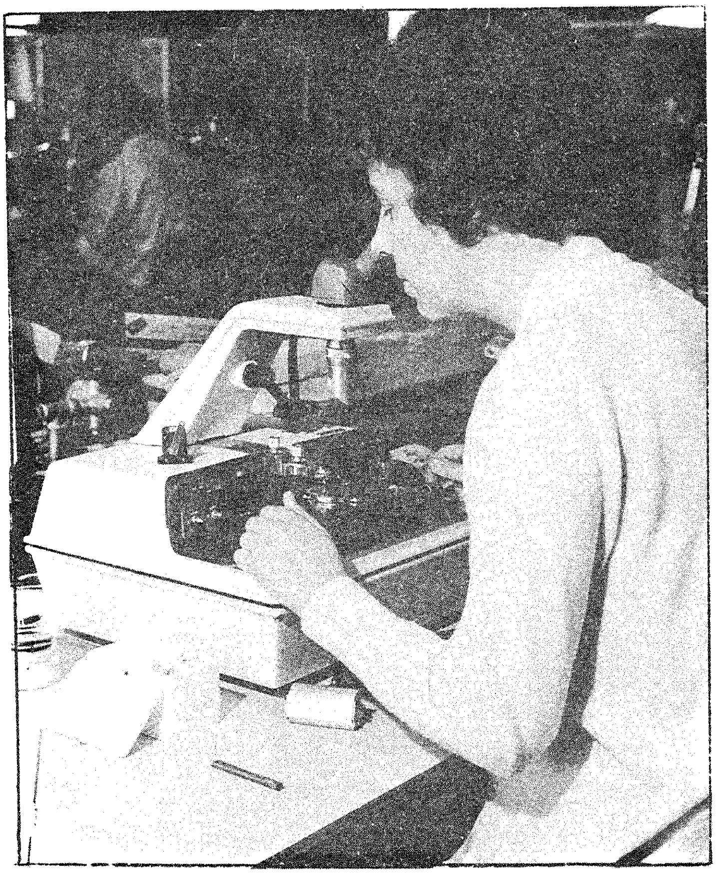


FIG 33 THE "TEMPRESS" SCRIBING MACHINE

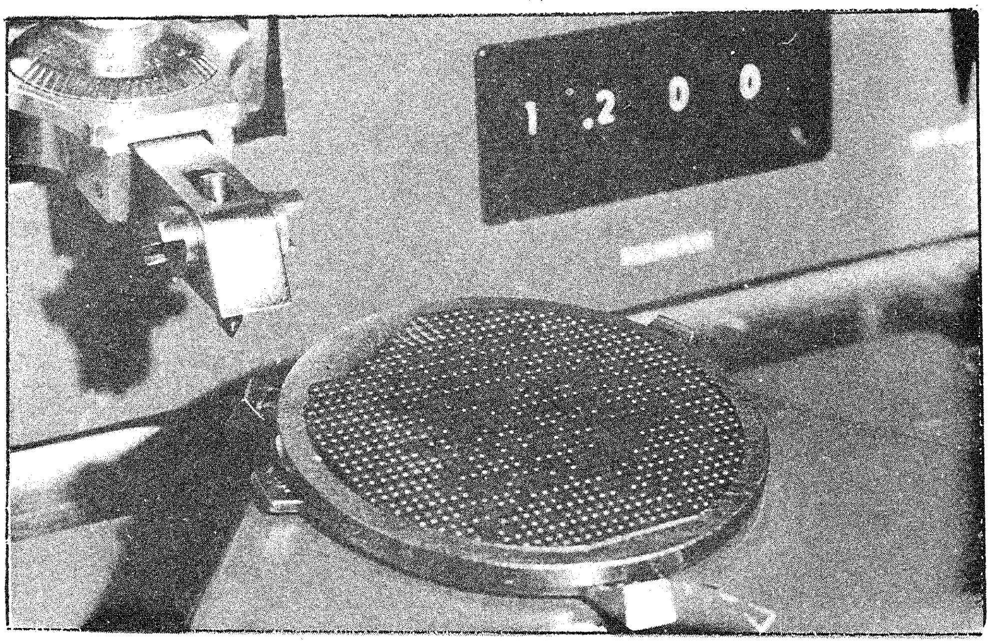


FIG. 34 SCRIBING A SILICON SLICE

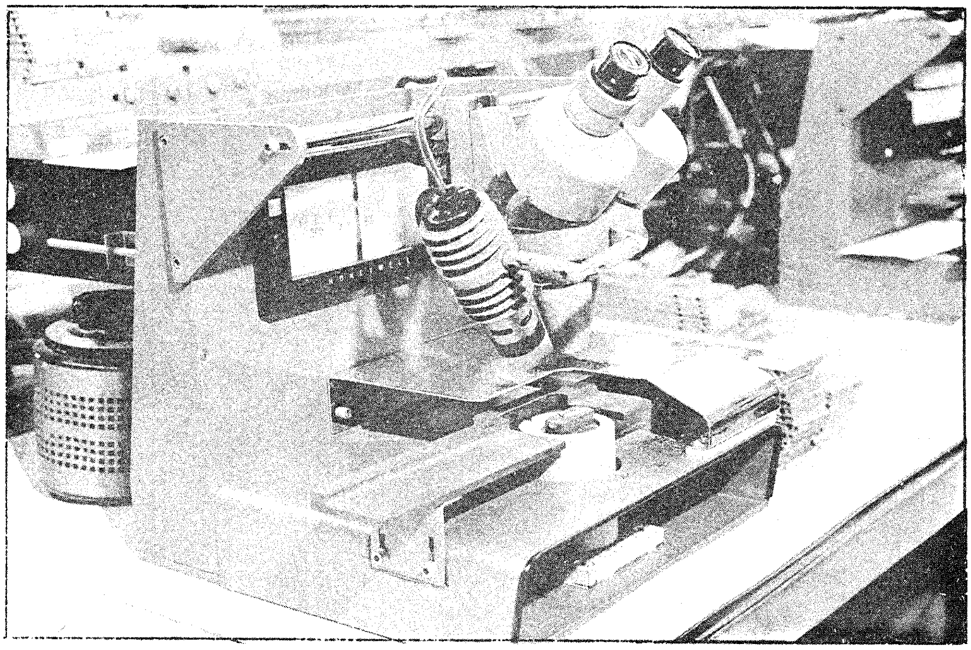


FIG. 35 DUAL-IN-LINE INTEGRATED CIRCUIT ALLOYING MACHINE

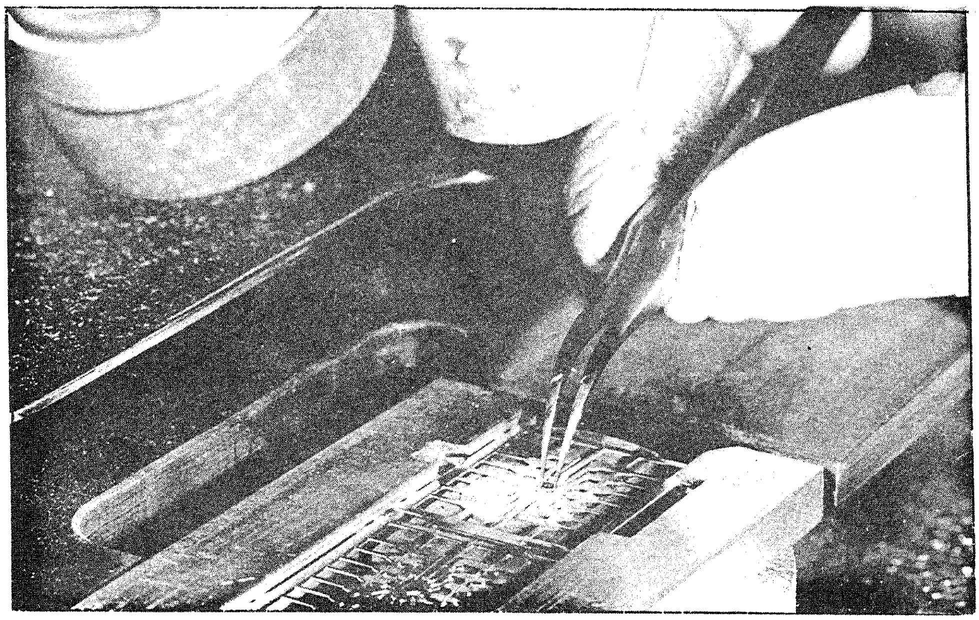


FIG. 36 THE "SCRUBBING" OPERATION

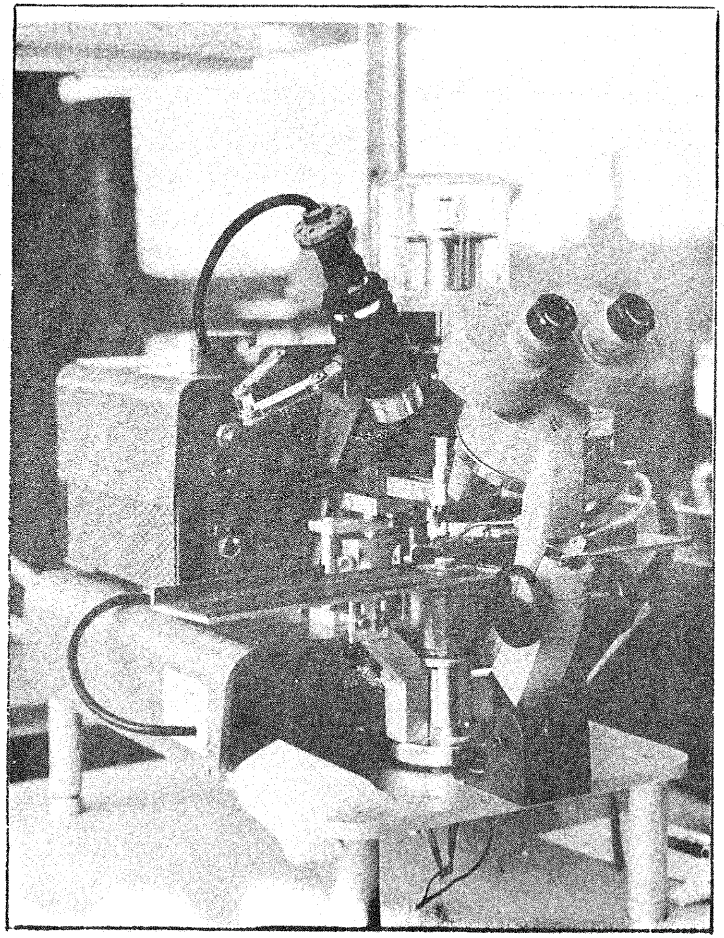


FIG. 37 DUAL-IN-LINE INTEGRATED CIRCUIT BONDING MACHINE

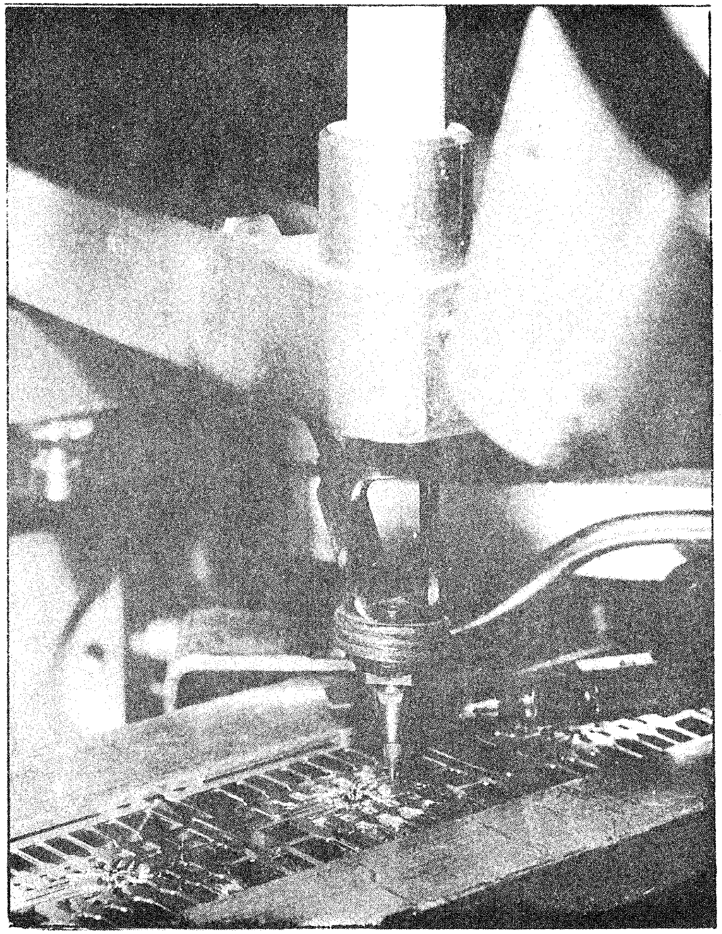


FIG. 38 THE BONDING OPERATION

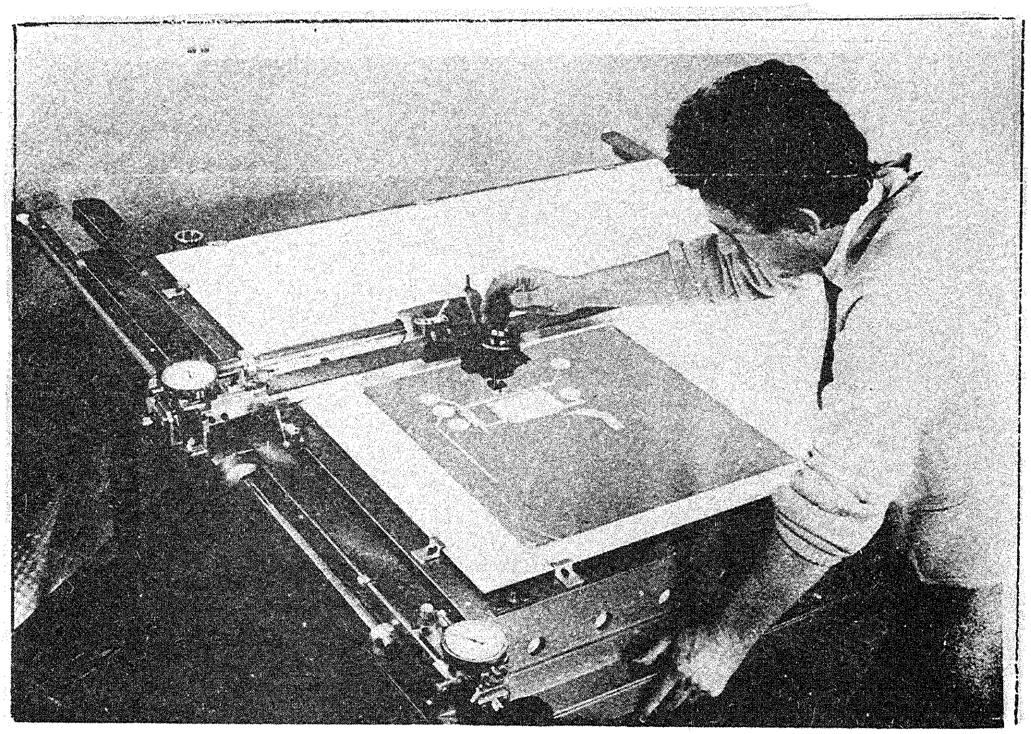


FIG. 39 THE PACKMAN "MICROMARKER"

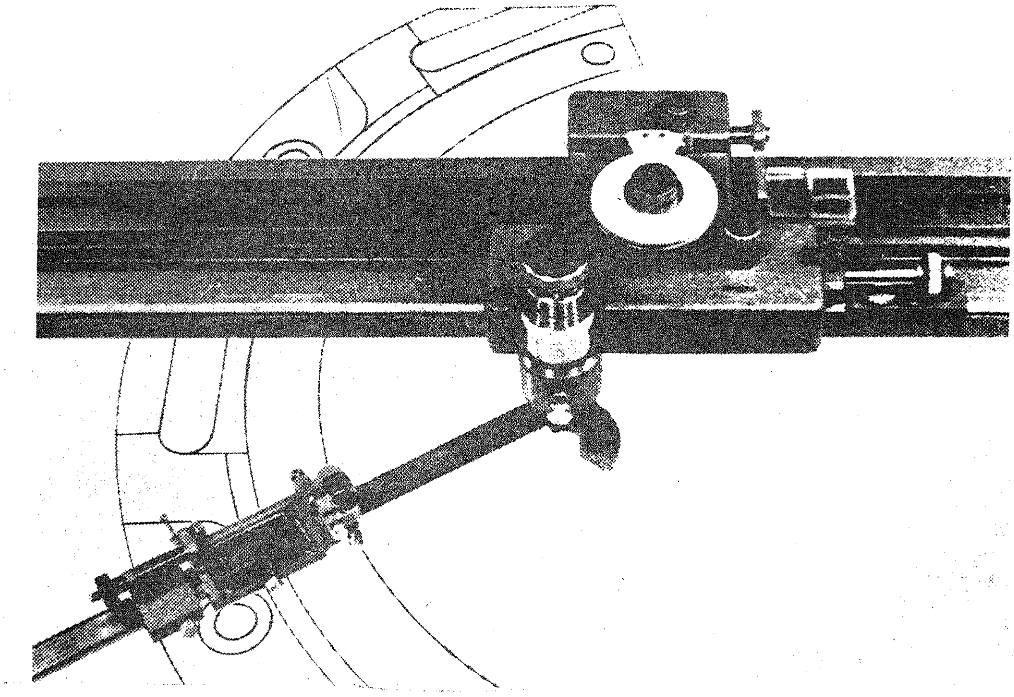


FIG. 40   THE "ARISTO" BEAM COMPASS

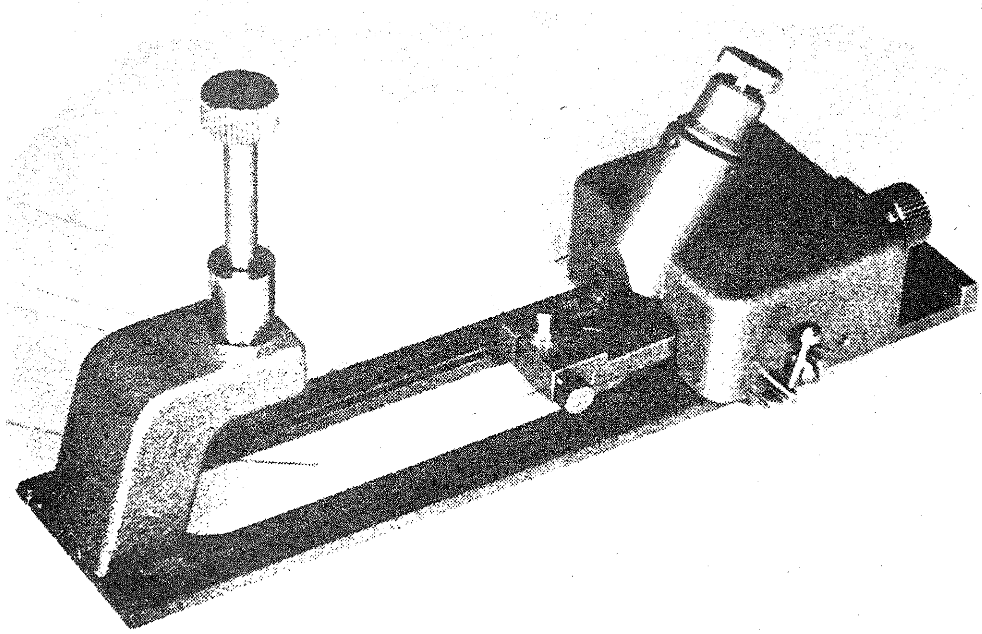


FIG. 41   THE "ARISTO" STRAIGHT EDGE

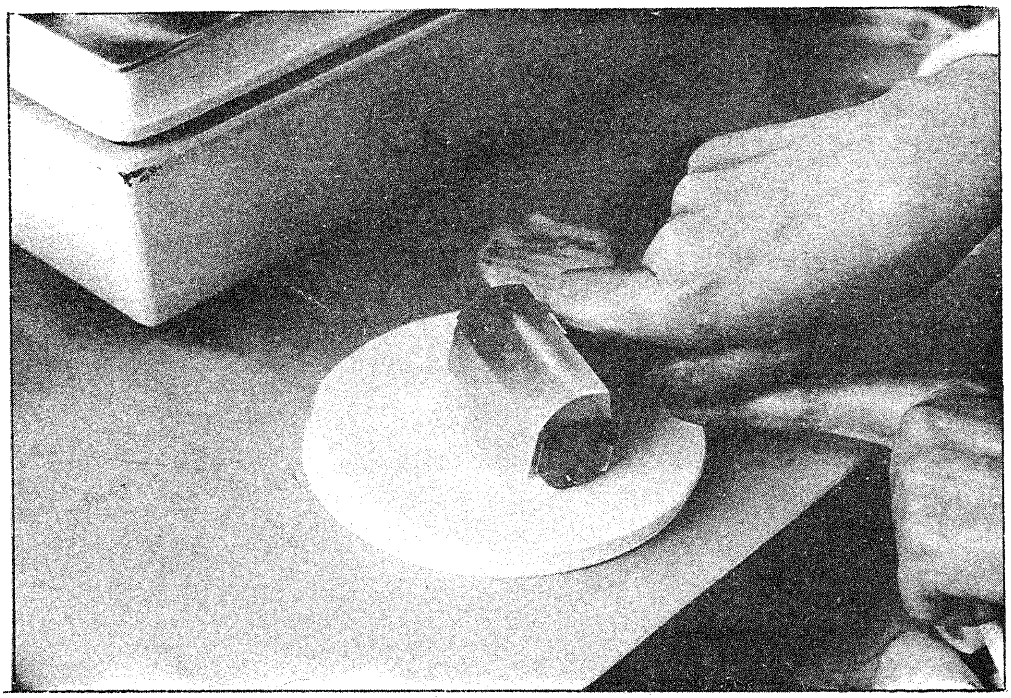


FIG. 42 ROLLER BREAKING A SCRIBED SILICON SLICE

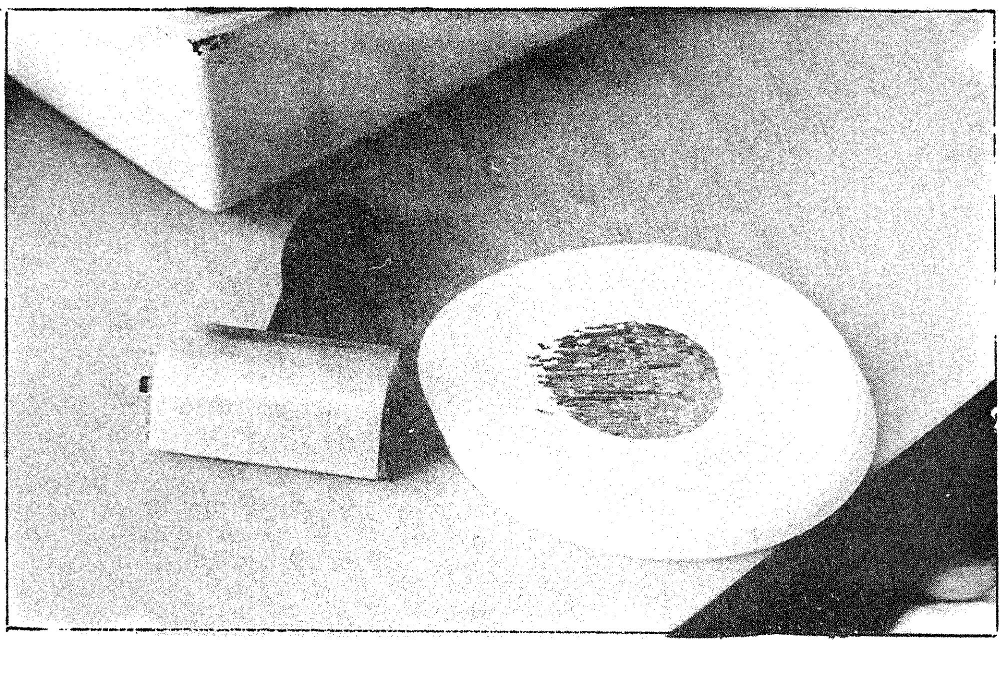


FIG. 43 A BROKEN SILICON SLICE

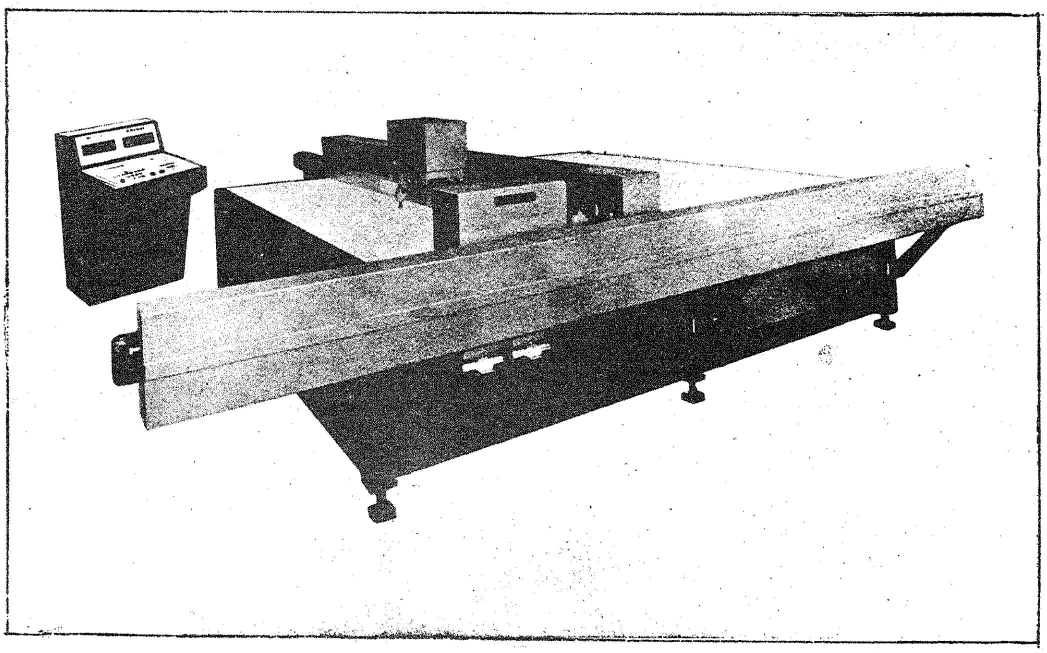


FIG. 44 THE "ARISTO" COMPUTER CONTROLLED DRAUGHTING MACHINE