Computerized Scanning Auger Microprobe

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An Auger spectrometer has been automated using a microcomputer. Fundamental considerations in the design and choice of the computerized system are presented and should be of general interest. The spectrometer was a Physical Electronics Ind. model 545 scanning Auger microprobe. The microcomputer chosen was a Southwest Technical Products 6809 computer system. Hardware details are discussed with emphasis on the four computer–spectrometer interface boards. These boards are (1) Auger energy control board, which sets the Auger detection energy with its 16 bit digital-to-analog converter (DAC); (2) read Auger signal board, which reads the Auger signal intensity with its 12 bit analog-to-digital converter; (3) multipurpose DAC board, which uses two pairs of 8 bit DAC's to position the excitation beam and display the data in memory on a CRT monitor, and (4) timing and relay control board, which selects various instruments and power supplies as required during the fully automated depth profiling sputter sequences. Organizational details of the control, analysis, and output software are discussed. The operation of the main Auger control program is emphasized along with its menu driven options, which provide great versatility to the operator. Examples are shown of the various data output modes, which include displays on the CRT monitor and plots from the multicolor digital plotter.

I. INTRODUCTION

Auger spectroscopy can yield a wealth of information about the surface of a sample.[1] It provides information on both chemical composition and bonding. When combined with ion milling, compositional depth profiles can be determined. Most of the spectrometers built in the seventies collected the necessary Auger spectral data to obtain this information. However, they required both a spectrometer operator to control each stage of the data taking process and a skilled analyst to laboriously carry out most of the intensity determinations and other calculations.

Now in the eighties, when microcomputers are readily available and relatively inexpensive, it is desirable to have them carry out both the control and analysis functions. The computer can be used to fully automate the spectral data taking process, depth profiling process, elemental contour mapping, and roving spot analyses. Such automation clearly relieves the tedium of routine spectrometer operation and frees the operator to perform other tasks. Storage of the raw data permits more detailed analyses and more elaborate display of the results. Thus, an analyst can carry out the job faster, with much less tedium, and with fuller utilization of all details in the spectra.

A problem exists as to how the owners of older spectrometers should go about computerizing their systems. Direct purchase of a factory installed computer system may seem reasonable, but such systems are often expensive since specialized interfaces and programs are usually needed. Professionally written software packages often lack provisions for modification to suit the individual user's requirements. To maximize versatility, meet special needs, and lower costs, the computerization can be done as a laboratory project as described in this paper.

Most previous articles concerned with the computerization of Auger spectroscopy are of two types. The first tends to emphasize specialized hardware applications,[2–11] such as improving Auger images; the second emphasizes sophisticated software routines for data reduction.[12–16] This article emphasizes overall design considerations and their implementation when a 8/16 bit microprocessor, a Motorola 6809, is used to control a scanning Auger spectrometer, a Physical Electronics Industries model 545. Details of both the hardware and software are presented, while fundamental design considerations are also discussed to make the results of more general interest.

II. REQUIREMENTS AND DESIGN OF THE COMPUTERIZED SPECTROMETER

The design of the computerized system was based on several fundamental criteria: (1) Straightforward and dependable operation of the system so that keyboard control of the spectrometer is easier than manual control, even for an operator without computer experience. (2) Automated depth profiling so that hours of unattended ion-milling with occasional or continuous data acquisition become possible. (3) Automated excitation beam control so that various spots on the surface may be analyzed and elemental contour maps of the surface can be obtained. (4) Software written in a simple language so that changes can be easily implemented. (5) Convenient and semipermanent data storage so that detailed analyses become possible. (6) Many computer peripherals to enable a variety of data display modes. (7) Low total capital cost ($\approx$\$4000).

A Southwest Technical Products 6809 computer system[17] was chosen to achieve the above criteria. Its strongest recommendation is its capability of satisfying the considerable I/O requirements mentioned above without external expansion of its bus structure. (This system has eight, 30 pin I/O ports, each of which is memory mapped and decodes 16 addresses. In addition, there are eight 50 pin system slots available.) The system has eight data lines and 16 address lines with 56K of user RAM installed on a memory board[18] in a system slot. This has proved adequate for both the main control programs and the analysis programs. However, extended

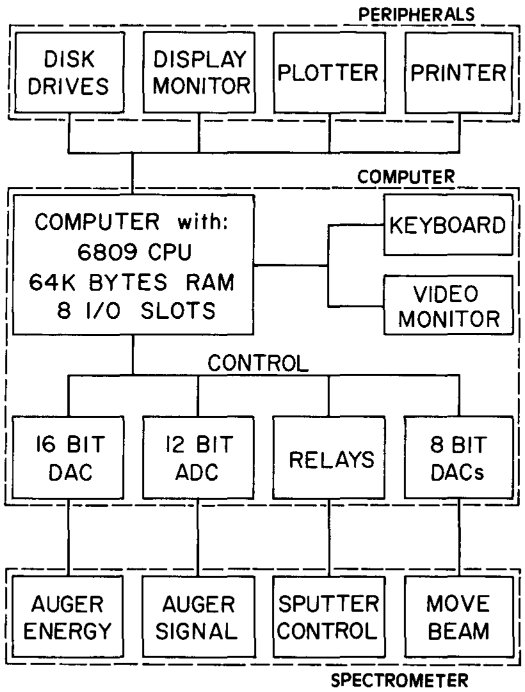

FIG. 1. Schematic of the computer system emphasizing the interfacing structure of the computer to both the peripherals and the spectrometer.

memory addressing (up to 1MB) has recently been implemented and will permit more expanded operations. The central processor is a Motorola 6809[19] 8/16 bit microprocessor located on the CPU board in one of the system slots. This state-of-the-art microprocessor is reasonably fast (1 MHz) and is well-supported by books and other literature dealing with its programming and interfacing to various external devices. (e.g., see Refs. 19–22.)

Actually, two such computer systems have been purchased. One is used to control the spectrometer and take the data, while the other is used for analysis and more elaborate display of the data. This frees the control computer to take data.

The boards in the I/O slots fall into two catagories. There are four specially designed boards, described in Sec. III and shown in the lower part of Fig. 1, which interface directly with the spectrometer. In addition, there are three commercial boards, made by SWTPC,[17] which interface the computer with its peripherals. These boards are a dual serial output board, which is interfaced to the video monitor and keyboard (an ADDS[23] Viewpoint/3A Plus); a disk controller board, which is interfaced to the two double-sided disk drives (Tandon[24] model TM100-2); and a dual parallel output port board, which from one port drives the multicolor, six pen digital *x–y* plotter (a Western Graphtec[25] model MP1000), and from the other port drives the dot matrix printer (a NEC[26] model PC-8023A). These boards are not explicitly shown in Fig. 1 though the peripherals interfaced to them are shown. The general use and operation of the peripherals is summarized below.

One of the two floppy disk drives is used to store the disk operating system, the main Auger control program (which can drive the display monitor, plotter and printer), and sev-

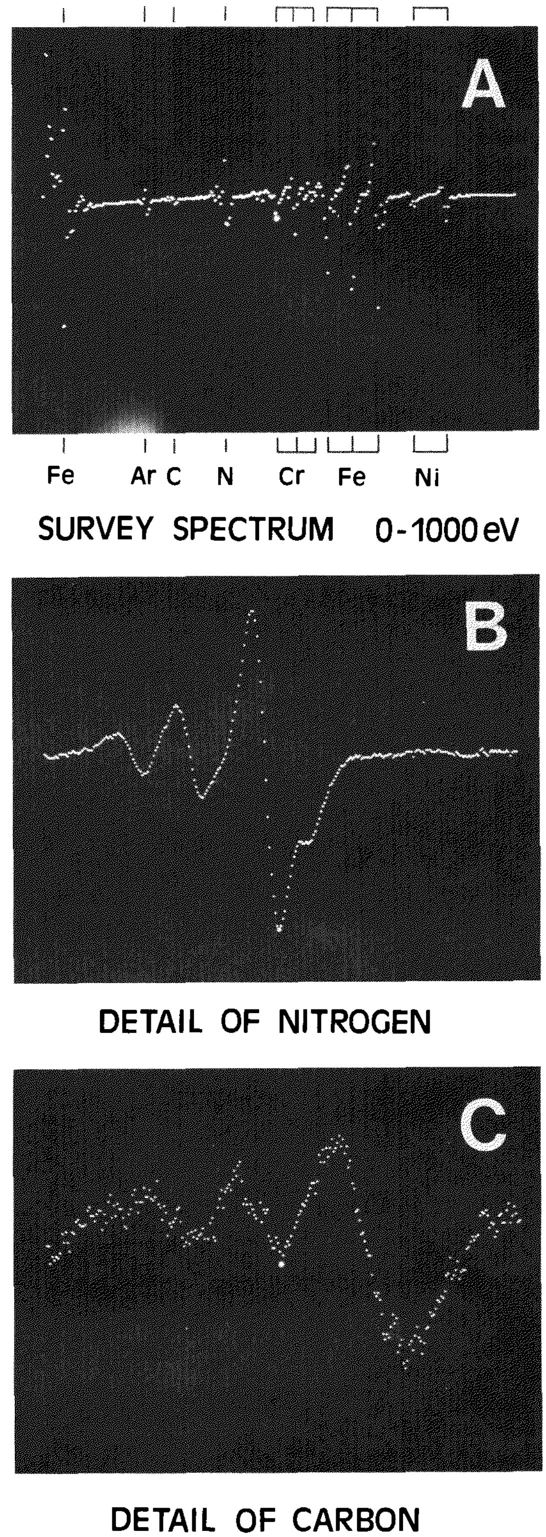

FIG. 2. Pictures of CRT monitor showing Auger spectrum from nitrogen-implanted stainless steel after 13 min of sputtering. The data was repetitively scanned 200 times, but was not smoothed. (A) The energy scale ranges from 0 eV to 1000 eV. For this range of energy, the 8 bit DAC can only display every 20th data point. The strongest Auger lines are labeled. (B) Detail of the nitrogen spectrum. The energy scale and the intensity scale have been expanded relative to those in Fig. 2(A) by 10 and 4×, respectively. (C) Detail of the carbon spectrum. The energy scale and the intensity scale have been expanded relative to those in Fig. 2(A) by 20 and 64×, respectively. Every acquired data point in the energy range shown is displayed (0.2 eV per point). In this figure the cursor which pinpoints the absolute energy can clearly be seen at the bottom of an Auger line near the center of the figure.

eral analysis programs. The second drive holds the data disk for the current sample. It typically contains Auger spectra on data files taken at each depth and/or spot, as well as data files on the same sample which have been processed by any of the analysis programs.

Auger spectra from any of the data files can be placed in RAM and then viewed as an intensity vs energy plot on the SAM's CRT display monitor (a Tektronix[27] model 604). An example of such a plot is shown in Fig. 2. The most recently obtained spectrum is normally displayed. Detailed examination of the spectral data is possible since the keyboard operator can manipulate how the data is to be viewed. Single key commands make it possible to scan all or part of the spectrum (i.e., to expand, contract, and shift the energy scale), to amplify the signal intensity scale, and to obtain the energy of a feature of interest using a cursor displayed on the spectrum.

The output to the plotter can be the entire spectrum or details on one or more regions of interest. An example is shown in Fig. 3. In addition, depth profiles or spacial contour maps can be plotted after an analysis program has searched and retrieved the Auger intensities from the appropriate data files. The data can be plotted as Auger intensities or as atomic percentages. An example of a depth profile plot is shown in Fig. 4.

The printer is used to provide hardcopy details about the spectrometer operating conditions, to output operator remarks concerning the sample, and to list the data files taken on the sample. When the data is analyzed, the printer is also used to output information, such as a table of elemental atomic percentages at each depth.

It is necessary to briefly describe the spectrometer before the interface electronics can be considered in detail. The spectrometer is a Physical Electronics Industries (PHI) model 545 scanning Auger microprobe (SAM).[28] Its electron excitation gun is located on the axis of a single-pass cylindrical mirror analyzer (CMA). The detection voltage on the CMA is adjustable so that it can be ac modulated and swept with an analog ramp voltage. The voltage selected Auger electrons are collected and amplified by an electron multiplier. Then the resulting Auger signal is sent to a lock-in amplifier, which demodulates the signal and hence outputs the signal in the $EdN(E)/dE$ format. Finally, the spectra is plotted on an x–y analog recorder. Depth profiling is done using a 2 kV ion-milling gun with data taken at various stages of the milling process. The CMA potential can also be controlled by a six channel multiplexer, which is used during depth profiling when the operator knows what to look for. In addition, different lateral regions of the sample can be examined by changing the x and y deflection plate voltages to move the excitation beam or scan the surface if desired.

Four special interface circuits have been designed to permit computer control of the SAM. They are (1) the Auger energy control board, which controls and sweeps the Auger energy by digital selection of the CMA voltage; (2) the read Auger signal board, which digitizes the data by converting the Auger analog signal; (3) the multipurpose DAC board, which moves the excitation beam position using digital control of the x and y deflection plate voltages, and also drives the CRT display so that the data can be viewed; and (4) the timing and relay control board, which controls the depth profiling operation by providing interrupt timing and digital switching of various power supplies. Each of these circuits was built on a different I/O interface board as shown in Fig. 1 and is described in detail in the next section.

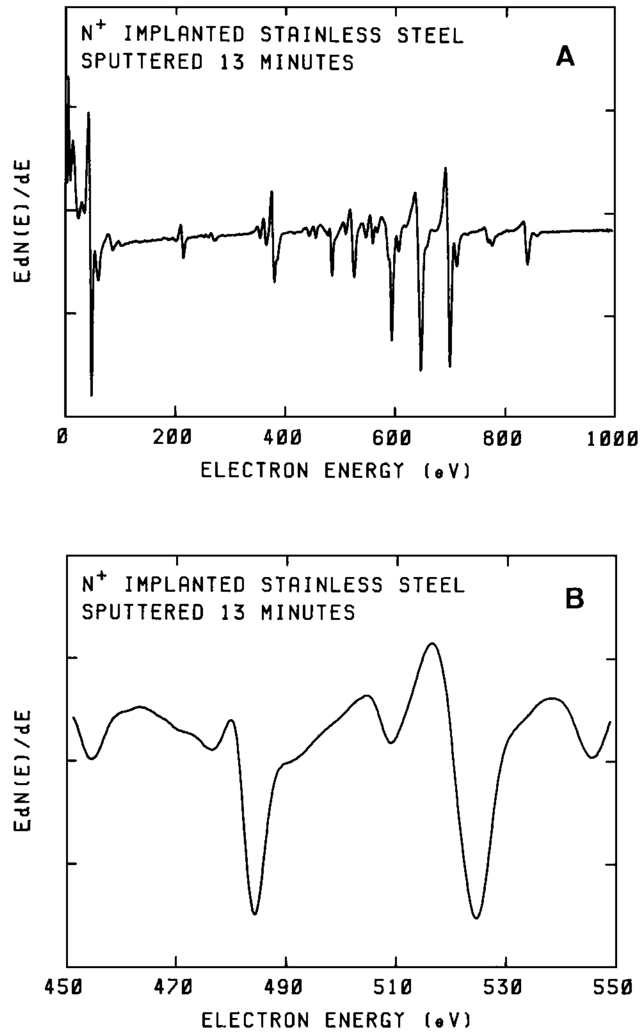

FIG. 3. Hard copy spectral output from the plotter. (A) Spectrum of Fig. 2(A) except data has been smoothed. (B) Detail of smoothed chromium spectrum.

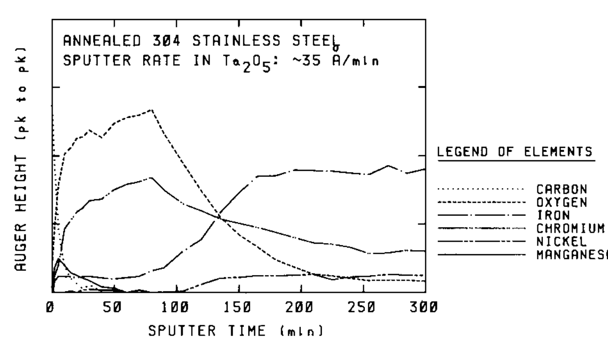

FIG. 4. Hard copy depth profile of annealed stainless steel showing chromium oxide surface layer.

III. SELECTION AND DESIGN OF INTERFACING HARDWARE

A. Auger energy control board

The SAM has a very stable high-voltage power supply whose output is applied to the CMA to detect the monoenergetic Auger electrons. The output from this power supply is set by a low voltage, which is ramped from 0 to − 13.2 V to sweep the entire Auger spectral energy range from − 4 to 2300 eV. Thus, computer control of this energy required only a precise and stable digital-to-analog (DAC) converter followed by operational amplifiers configured to output 0 to − 13.2 V (full scale) so that the full Auger energy range can be covered. The only modification made to the SAM was to rewire the mode select switch so that the multiplex select position (now labeled computer select) switches the control voltage from the SAM's internal supply to the output from the Auger energy control board.

The Auger energy is scanned by repetitively incrementing the energy with a step which is small compared to an Auger linewidth. An 8 bit DAC does not have enough energy resolution to sweep the entire spectral range with a small enough step. Thus, the design was based on a 16 bit DAC as shown in Fig. 5. This DAC, a Hybrid Systems DAC 9331-16-4,[29] provides an energy resolution of 0.035 eV/bit with a guaranteed linearity of 0.14 eV/bit. Since the SAM Auger linewidths exceed 5 eV,[30] considerably more than than 100 data points can be taken per Auger line. (In typical operation, data points are taken every 0.2 eV.) The 16 bit design required the use of a peripheral interface adapter (PIA), a Motorola 6821.[19] The 6809 uses the two 8 bit ports of the PIA to load and latch two 8 bit bytes for conversion. A PIA control line is used to signal the start of conversion. The conversion time of the DAC is about 0.3 μs, which is faster than a single computer operation. The two operational amplifiers (OP-07[31]) in Fig. 5 have low offset voltages. The lower one acts as a current-to-voltage converter with an output from 0 to − 10.000 V. The upper amplifier has an adjustable gain which is set for 1.32.

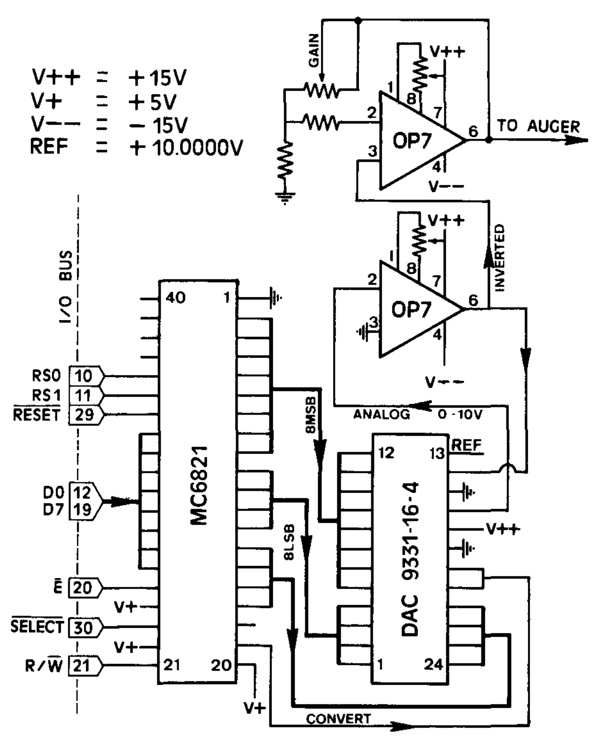

FIG. 5. Circuit of the Auger energy control board showing the interfacing adapter chip, the DAC, and the two operational amplifiers.

In actual operation, both the energy range and step are operator selectable and are typically 0 to 1000 eV in 0.2 eV steps. The minimum time between steps is limited to about 15 μs because of the several machine language steps required to load the DAC and send the start-of-conversion signal. This is not a limiting factor since this time is shorter than the SAM's response time.

B. Read Auger signal board

The demodulated Auger signal is available at the output of the lock-in amplifier, which has a bipolar output with a usable range from − 10 to + 10 V and is designed for use by an x–y recorder. This output can be read by the computer once an analog-to-digital conversion has been made. There are cases where it would be convenient to have the computer directly collect the $N(E)$ signal and this feature may be implemented in the future. However, there are disadvantages to doing this initially. These include modifying the SAM circuitry (none required for above method) and not being able to make a direct comparison with previously acquired data, reference spectra or established sensitivity factors[30] without software manipulation of the data.

To optimize the data taking process, it was desired that both weak signal and strong signal data be taken without using repeated energy sweeps or making gain changes. This means that the analog-to-digital converter (ADC) must have a high resolution. An 8 bit ADC was not considered adequate, even though it would have provided better resolution than the normal chart recorder output. Resolution of 1 part in 4000 was deemed adequate, so a 12 bit ADC was chosen (a Burr–Brown ADC84KG-12[32]). This has proven to be a good choice since the longest signal-averaged spectra taken to date still show several bits of noise without saturation in the maximum signal intensity.

Figure 6 shows the circuit of the read Auger signal board which contains the ADC. To allow for future multiuse analog conversion, all inputs to the board are first sent to a 16 channel analog multiplexer, an Intersil IH6116-CPI.[33] The computer selects which of the 16 channels should be output for conversion. The ADC output is sent to a PIA and the computer reads and stores the converted signal as two 8 bit bytes. The PIA is also used to send the start-of-conversion signal.

The ADC requires about 1 μs to convert each bit. Hence, the 4 most significant bits are ready in 4 μs, which is about the time of one computer instruction step, and the 8 least significant bits are ready before the computer can return to load them. Thus, the ADC is not a time limiting factor.

C. Multipurpose DAC board

Since several additional analog voltages are required, a board was constructed with several general purpose, inexpensive DAC's on it. An 8 bit DAC (an Analog Devices

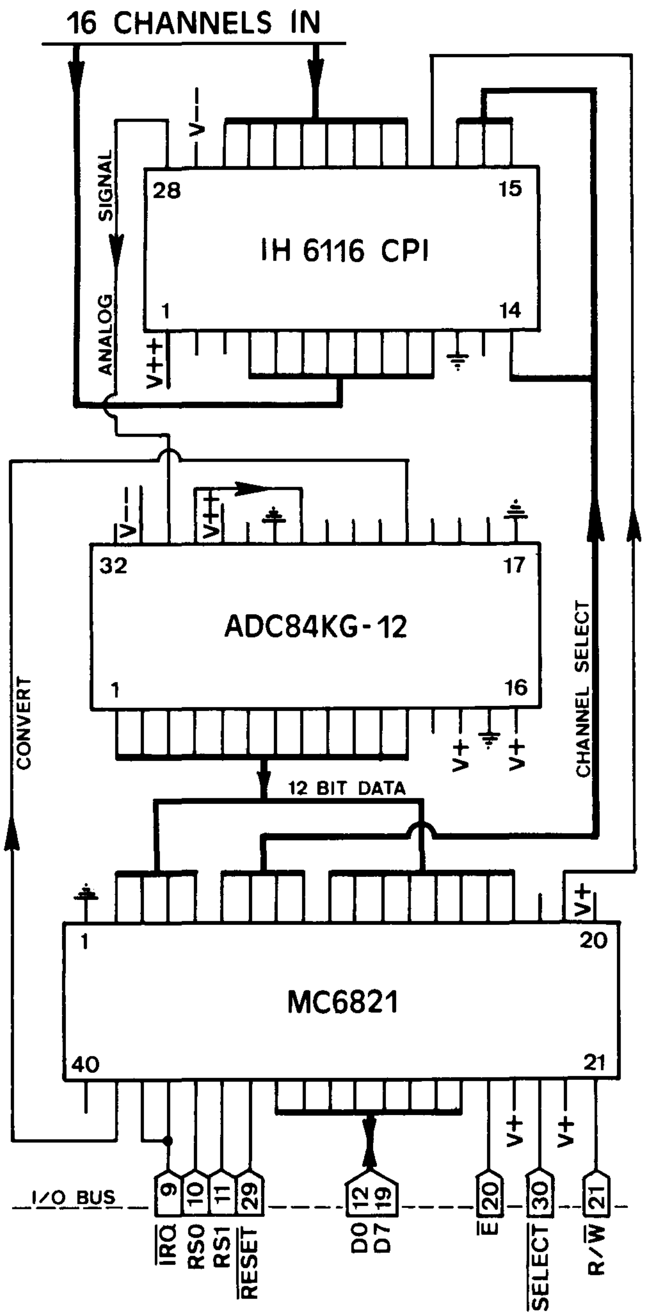

FIG. 6. Circuit of the read Auger signal board showing the analog channel selecting demultiplexer, the ADC, and the interfacing adapter chip. The regulated dc voltages V +, V + +, and V − − are 5.0, 15.0, and − 15.0 V, respectively.

AD558JN[34]) was deemed adequate. This DAC is microprocessor compatible, wired to output 0–10 V, and has a conversion time of 3 μs. The Multipurpose DAC Board contains six of these DAC's and a 74LS155 demultiplexer,[19] which controls the start-of-conversion signal. At the present time, two pairs of these DAC's are in use with each pair providing the x and y voltages to drive a device.

One pair of DAC's controls the x and y deflection plate voltages and thus determines the position of the excitation electron beam on the sample. Computer control of the beam spot has proven useful in two different types of analysis. For elemental mapping analysis, the computer sets the Auger energy on the desired element and then stores the Auger intensities as the beam is swept across the sample. The other type of analysis involves moving the beam to take data at two or more spots on the sample so that a comparison of spectra can be made. For example, comparision of regions inside and outside a corrosion pit or between two differently coated regions can be made. This multiple region analysis can also be done at various stages of the sputter depth profiling.

The second pair of DAC's is used to display the Auger data currently in memory on one of the SAM's CRT display monitors. This is a very convenient way for the operator to view the spectrum. The main control program displays the data on the monitor whenever the computer is not taking data or responding to an operator request. In addition, single key instructions from the keyboard permit expansion, contraction, and shifting of both the amplitude and energy of the displayed spectrum.

Near future uses for this board will be to CRT display the depth profiles during automated profiling and to control the milling rate of the sputter gun during automated profiling so that, for example, low rates can be used initially for examining near surface features with a higher rate being used at greater depths.

D. Timing and relay control board

An additional I/O board was needed to: (1) generate sputter time intervals required when depth profiling; (2) control relays to switch equipment during depth profiling; and (3) provide current date and time information for disk files and other outputs.

A low cost ($120) commercial clock/timer board, a Robertson Electronics CLK68-1,[35] was found that met the above requirements. This board provides current date and time, can generate interrupts from 244 μs to 256 s at software selectable rates, and provides an 8 bit parallel I/O port. Since TTL power levels are not adequate to control the switching relays needed, a seven Darlington power transistor array, a Motorola MC1413,[19] has been added to this board. Each bit of the parallel port controls one Darlington whose output is wired to a 5 V miniature switching relay. The relays have been added near the manual switches in several of the SAM electronic boxes using a circuit design that allows the SAM to be manually operated if the computer is off.

Three power supplies are currently controlled by switching relays operated via the parallel port: the sputter gun power supply (both the filament voltage and the high voltage), the excitation electron gun power supply, and the electron multiplier power supply. The latter two supplies are switched off during sputtering to minimize damage to spectrometer components.

IV. SOFTWARE DESIGN

A. Main Auger control program

The spectrometer control program (main Auger control) and the several data analysis and output programs (see Secs. IV B and IV C) were written primarily in an interpretive 16K BASIC to simplify programming. Machine language subroutines were used only when greater speed or direct access to the CPU's interrupts were needed.

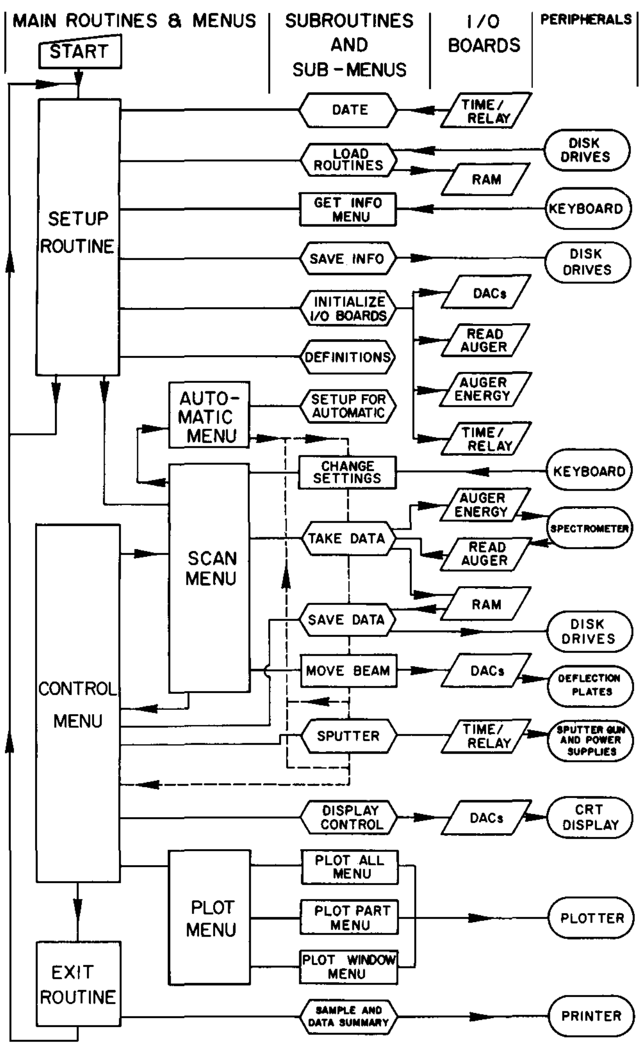

FIG. 7. Flow diagram for the main Auger control program. Lines without arrows indicate two way transmission channels. Dashed lines indicate repetitive operations which occur in automatic mode operation.

The main Auger control program has a number of special features. It is entirely menu-driven with the computer displaying all available program options plus the status of any current operation. The program is fully error trapped; virtually all operator errors are handled in a nonfatal manner. The operator can select either single operation mode or automatic mode. Single mode operation is typically used on samples new to the operator or if unusual features are suspected. Interrupts allow many operations to be performed during the time consuming sputter process, such as data storage on disk, data plotting, and detailed data inspection on the CRT display monitor. In automatic mode, a series of spectral scans are taken. The operator keys in the spot locations and sputter times for all desired scans at the beginning of the program. The data taking process then proceeds without need of an operator.

Figure 7 shows the flow diagram for the main Auger control program. It has three main routines: the setup routine, the control routine, and the exit routine. The setup routine is to initialize and prepare the system to take Auger data. This routine (1) loads the time and date from the timer/relay board, (2) loads the machine language routines from the system disk, (3) requests data from the operator concerning the spectrometer settings and the sample to be examined, (4) stores this data on the data disk, (5) initializes PIA's and other devices on several of the I/O boards, (6) defines various constants used in the program, and (7) passes control to the control routine.

The control routine is the main routine. The primary tasks of the control routine are (1) take data, (2) store data on the data disk, (3) display data in RAM on the CRT monitor whenever idle, (4) control the sputter gun, (5) output spectral data to the plotter in operator-selectable energy windows, and (6) provide unattended automatic mode operation by sequencing through some of the above operations [i.e., take data, store data, move beam (if so desired), sputter, and repeat until done]. Most of these functions are keyboard driven from the control menu. Key commands initiate entry into submenus, such as the scan menu, automatic menu, or plot menu, from which more specialized options can be keyboard selected. Before taking data, the operator selects via the keyboard the upper and lower energy limits of the spectral scan, the step energy between data points, and the number of scans. Typically, 50 scans are made in single mode as this number provides a good signal-to-noise ratio and requires only 1 minute. In automatic mode more (200) scans are taken since the operator is not actually waiting on the spectrometer. [For a given time interval, it was experimentally determined that multiple scanning (i.e., signal averaging) results in a better signal-to-noise ratio than repetitive readings of the intensity at each energy before incrementing. This is expected when the noise spectrum is low frequency dominated.] The scan subroutine was written in machine language to speed up energy sets and data reads. The control routine exits to the exit routine.

The exit routine's sole purpose is to produce a printed output of the information entered by the operator on the sample and spectrometer, as well as a summary of the spectral scans stored on the data disk. The exit routine returns control to the setup routine for analysis of the next sample.

B. Data analysis programs

Programs developed to analyze the raw data are SMOOTH, PEAKS, CONVERT, and DEPTH. SMOOTH is a simple smoothing routine which replaces each raw data point with an average data point calculated from the raw data point and $N/2$ data points on each side of it. The value of N is operator selected as is the weighting factor for the various points. The effect of smoothing is to improve the signal-to-noise ratio at the expense of a slight reduction in resolution. The effects of smoothing can clearly be seen by comparing the data shown in Figs. 2 and 3.

PEAKS is a program which searches a data file for spectral peaks within operator-selected energy windows. It then generates a table of elemental peak height values, and stores it on the data disk. The operator also selects a parameter, related to the signal-to-ratio, which is used by the program to determine if a peak is present. Searching in selected windows is a method also used by the SAM's PHI model 20-055 Multiplex Control unit,[28] but has the disadvantage that elements of interest must be identified *before* the data is taken. Since all our data is stored on disk, the operator has the ability to search for elements at any time.

CONVERT is a program which adjusts the raw elemental peak heights found with PEAKS into atomic percentage using standard sensitivity factors.[30]

DEPTH is a program which collects the data needed to plot depth profiles. It does this by reading the various files generated by PEAKS as each file contains the various elemental peak heights at a specific sputter time. It either outputs a table of relative heights versus sputter time or, using CONVERT as a subroutine, outputs atomic percentages versus sputter time.

C. Data out programs

Data can be output to the printer, plotter, or CRT display. One program which drives the printer is the Exit Routine. It outputs multiple copies of a run summary form. One copy of this form is permanently kept in the laboratory, while the other copies are given to the researcher. The printer is also often used to output files generated by PEAKS, CONVERT, or DEPTH.

Several programs have been developed for the plotter. One will output spectral data to the plotter. The operator selects either raw or smoothed data as well as the spectral range(s) and amplitude(s). Figure 3 shows a full spectral scan as well as a detailed energy window which has been selected for enlargement. The plotter can also use data from the DEPTH program to plot depth profiles. Figure 4 shows a typical depth profile. (It should be noted that various colors allow for plotting many elements on one graph. Of course, this is a feature which is not shown.)

Several programs have been developed to output to video displays. The ZOOM program outputs spectral data from RAM to the CRT display and has been incorporated as a subroutine of the the control routine. It is written in machine language so that a nonflickering display is seen. It is exceedingly handy because simple single-key operations permit "zooming in" on any small spectral region with small or large amplication. Examples of this are shown in Fig. 2. The program is also used to drive a Tektronix model 4010[27] Graphics Terminal, which has been interfaced to the analysis computer. This has made it possible to compare data from different runs. More extensive software is now being developed so that visual analysis will reveal trace elements, small bonding differences, and other subtle spectral features.

V. SUMMARY

A detailed description of how a microcomputer can be used to control an Auger spectrometer has been given. Four special boards were built to interface the spectrometer to the computer. These enable controlling the Auger energy, reading the Auger signal intensity, controlling the excitation beam location, and automating the timing and switching sequences required during the sputter depth profiling. Most of the programs were written in BASIC with machine language programs being used only for specific control applications. A description of the main control program as well as analysis and output programs has been provided. Examples of the various forms of data output have also been shown.

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[1]A. W. Czanderna, *Methods of Surface Analysis* (Elsevier, Amsterdam, 1975), and other review references contained therein.
[2]R. Browning, P. J. Bassett, M. M. El Gomati, and M. Prutton, Proc. R. Soc. London Ser. A **357**, 213 (1977).
[3]A. Mogami, Thin Solid Films **57**, 127 (1979).
[4]J. L. Oppenheimer, Rev. Sci. Instrum. **50**, 572 (1979).
[5]T. J. Schaffner and J. A. Keenan, Scanning Electron Microsc. **1**, 219 (1979).
[6]L. Frank and P. Vasina, Electron Microscopy and Analysis, *Institute of Physics Conference Series 52*, edited by T. Mulvey (Institute of Physics, London, 1980), p. 371.
[7]L. Frank and P. Vasina, Comput. Phys. Comm. **26**, 113 (1982).
[8]M. Prutton, R. Browning, M. M. El Gomati, and D. Peacock, Vacuum **32**, 351 (1982).
[9]B. Chornik, Rev. Sci. Instrum. **54**, 80 (1983).
[10]L. McDonnell and B. Lawless, J. Vac. Sci. Technol. A **1**, 185 (1983).
[11]G. W. Stupian and M. S. Leung, Rev. Sci. Instrum. **55**, 92 (1984).
[12]R. Hesse, U. Littmark, and P. Staib, Appl. Phys. **11**, 233 (1976).
[13]A. F. Carley and R. W. Joyner, J. Electron Spectrosc. **16**, 1 (1979).
[14]V. Martinez, J. Electron Spectrosc. **17**, 33 (1979).
[15]M. Prutton and D. C. Peacock, J. Microsc. **127**, 105 (1982).
[16]J. T. Grant, J. Vac. Sci. Technol. A **2**, 1135 (1984).
[17]Southwest Technical Products, 219 W. Rhapsody, San Antonio, Texas 78216.
[18]Digital Research Computers, P.O. Box 401565, Garland, Texas 75040.
[19]Motorola Semiconductors, 3501 Ed Bluestein Blvd., Austin, Texas 78721.
[20]*"68" Micro Journal* (Computer Publishing, Hixson, Tennessee 37343). A monthly journal covering current topics on 6809 computer systems.
[21]L. A. Leventhal, *6809 Assembly Language Programming* (McGraw–Hill, Berkeley, California 1981).
[22]M. Andrews, *Programming Microprocessor Interfaces for Control and Instrumentation* (Prentice–Hall, Englewood Cliffs, 1982). A textbook with examples using a 6809 microprocessor.
[23]Tandon Corp., 20320 Prairie St., Chatsworth, California 91311.
[24]Applied Digital Data Systems, Inc., 100 Marcus Boulevard, Hauppauge, New York 11788.
[25]Western Graphtec, Inc., 12 Chrysler St., Irvine, California 92714.
[26]NEC, 5 Militia Dr., Lexington, Massachusetts 02173.
[27]Tektronix, P.O. Box 1700, Beaverton, Oregon 97075.
[28]Physical Electronics Industries. Now a division of Perkin–Elmer Corp., 6509 Flying Cloud Drive, Eden Prairie, Minnesota 55344.
[29]Hybrid Systems Corp., 22 Linnell Circle, Billerica, Massachusetts 01821. Cost is $69 for 14 bit linearity or $169 for 16 bit linearity.
[30]L. E. Davis, N. C. MacDonald, P. W. Palmberg, G. E. Riach, and R. E. Weber, *Handbook of Auger Electron Spectroscopy*, 2nd ed. (Physical Electronics Ind., Eden Prairie, Minnesota 1976).
[31]Precision Monolithics Inc., 1500 Space Park Dr., Santa Clara, California 95050.
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