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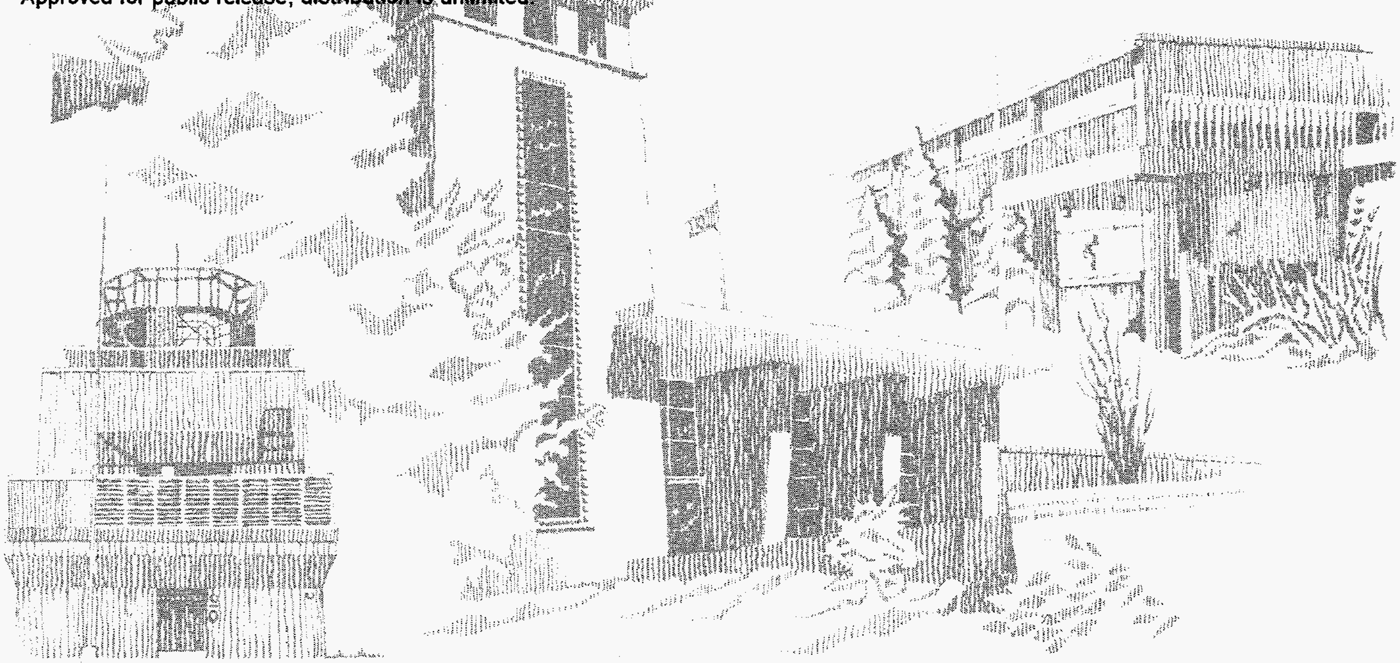

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DESCRIPTION OF A SOLDER PULSE GENERATOR FOR THE SINGLE STEP FORMATION OF BALL GRID ARRAYS

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Abstract

The traditional geometry for surface mount devices is the peripheral array where the leads are on the edges of the device. As the technology drives towards high input/output (I/O) count (increasing number of leads) and smaller packages with finer pitch (less distance between peripheral leads), limitations on peripheral surface mount devices arise. The leads on these fine pitch devices are fragile and can be easily bent. It becomes increasingly difficult to deliver solder paste to leads spaced as little as 0.012 inch apart. Too much solder mass can result in bridging between leads while too little solder can contribute to the loss of mechanical and electrical continuity. A solution is to shift the leads from the periphery of the device to the area under the device. This scheme is called areal array packaging and is exemplified by the ball grid array (BGA) package. A system has been designed and constructed to deposit an entire array of several hundred uniform solder droplets onto a printed circuit board in a fraction of a second. The solder droplets wet to the interconnect lands on a pc board and form a basis for later application of a BGA device. The system consists of a piezoelectric solder pulse unit, heater controls, an inert gas chamber and an analog power supply/pulse unit.

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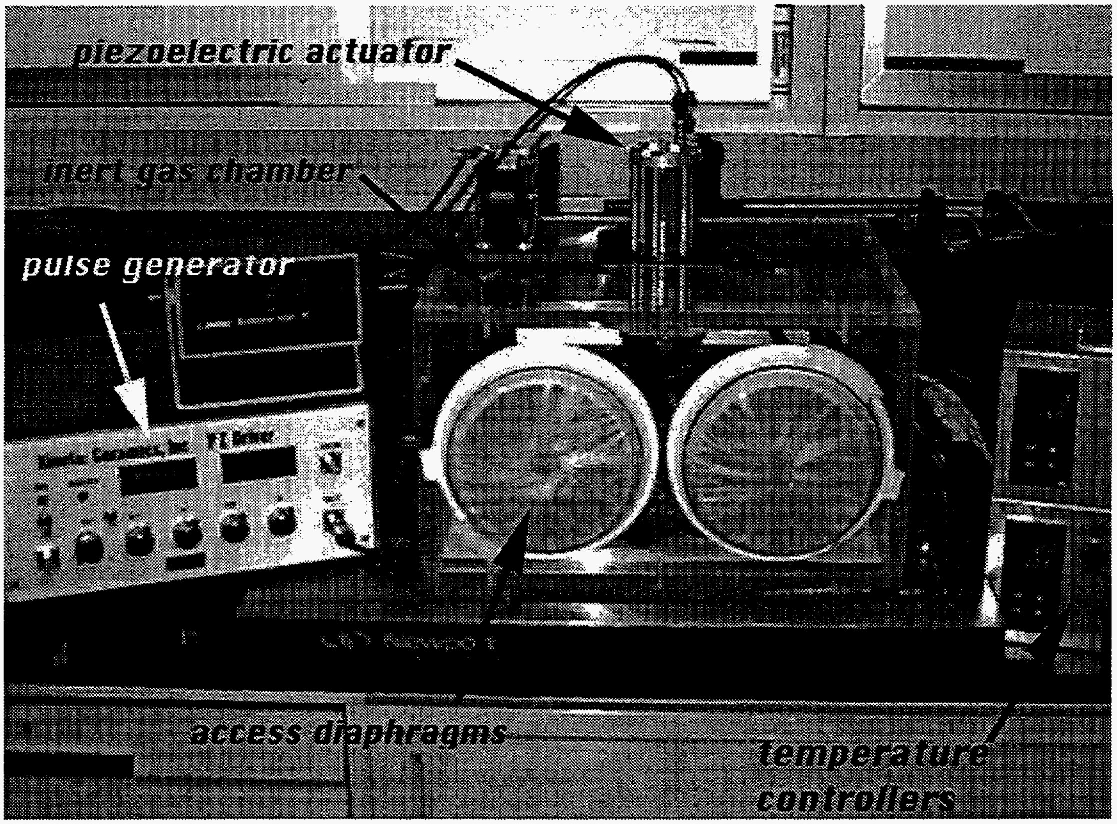

Figure 1: Photo of solder pulse generator.

Introduction

BGA's created with this system are jetted directly onto metallized interconnect lands for the BGA package without solder paste. The advantage of this technology is that it eliminates the need to 1) acquire balls, 2) place the individual balls onto the substrate and 3) reflow by dispensing uniform molten balls that can directly bond with the substrate. The reflow operation and errors due to mishandling of the individual balls are eliminated, saving time, equipment and processing costs. This system could also supply uniform balls to current BGA users.

Description of the Equipment

The equipment that has been designed to jet the arrays of solder balls, shown in **Figure 1**, includes:

- The solder pulse generator, consisting of:
  - Piezoelectric actuator.
  - Belleville spring washer oriented to preload the piezoelectric actuator.
  - Anodized aluminum pulse chamber, solder reservoir and cartridge heater housing.
  - Graphite orifice plate.

- A chamber that surrounds the jetting device and provides an inerted environment of nitrogen gas.
- Custom analog high voltage pulse generator.
- Temperature controllers for the solder melt and pc board heater.

Figure 2 is a section view of the solder pulse generator. A voltage pulse (up to 800 volts) causes the piezoelectric actuator to expand, pushing the piston down and forcing molten solder through the orifice plate. As the voltage drops, a Belleville spring washer returns the piston to its original position. The withdrawal of the piston causes an instability in the fluid displaced from the orifice. As this instability grows, necking of the fluid occurs until "pinch-off" is achieved and a free droplet is formed. The rate of piston motion, piston displacement, solder temperature and orifice size were optimized to form stable solder droplets.

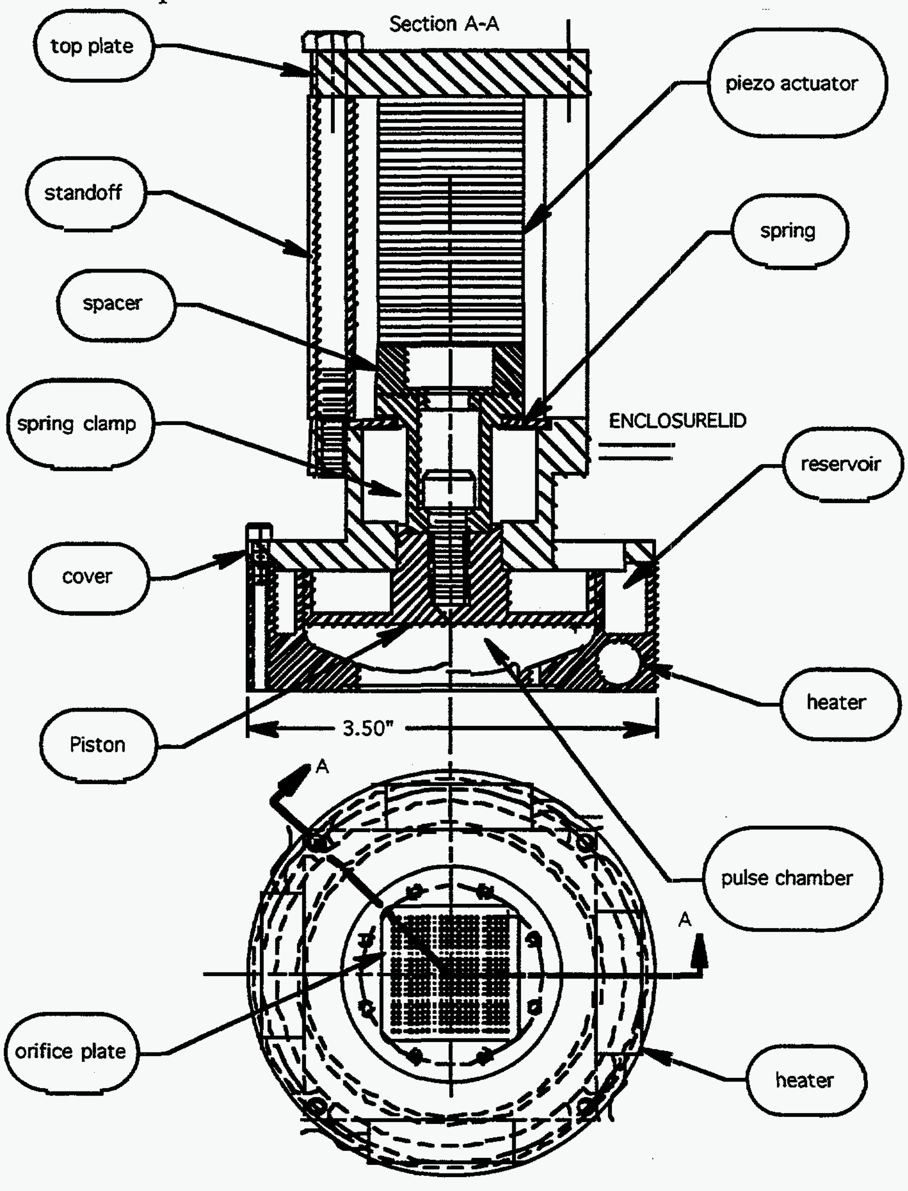

Figure 2. Section view of solder pulse generator. The pulse chamber was designed with smooth curves to minimize fluctuations in pressure along the orifice plate.

The actuator, shown in **Figures 2 and 3**, is a stack of flat piezoelectric crystals. When voltage is applied, all the segments expand uniformly and reproducibly. The bottom of the piezoelectric actuator contacts a spacer and then a spring clamp which bolts to the piston. There is little compliance in system so the displacement generated by the piezoelectric crystal is directly translated into piston motion.

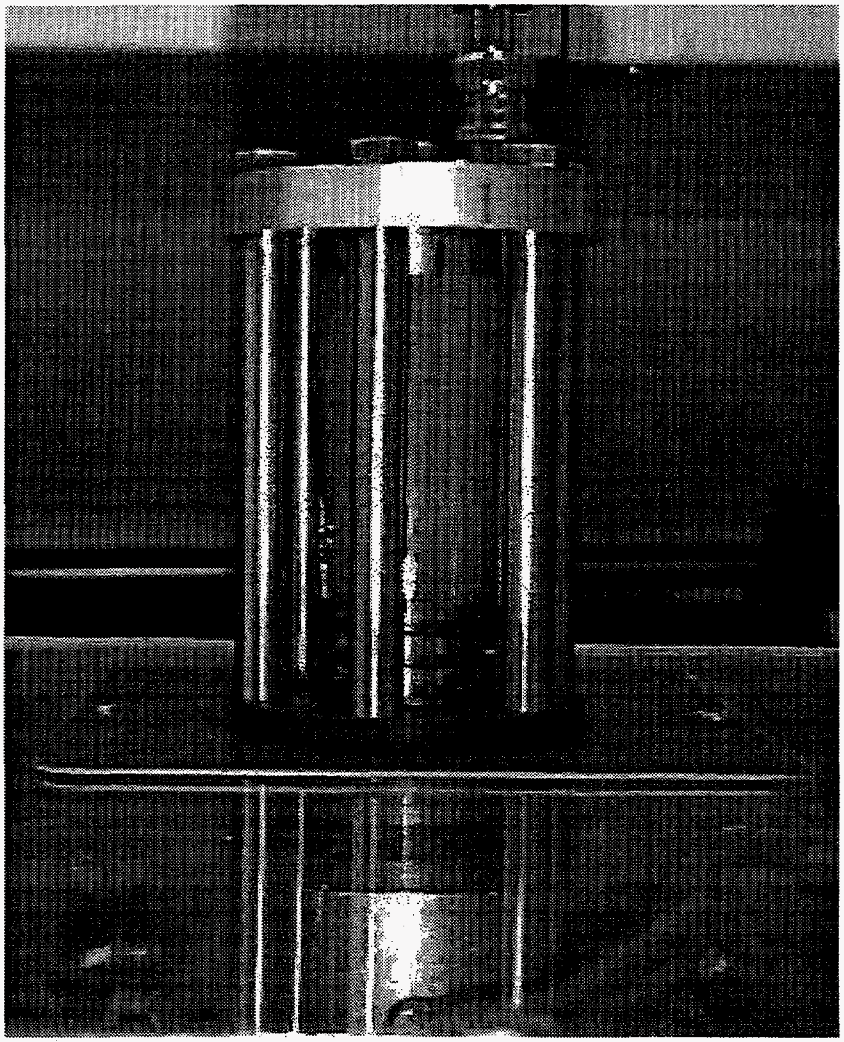

Figure 3. Photograph of the piezoelectric actuator protruding from the inert gas chamber.

The piezoelectric actuator allows precise control of the piston with displacement of up to 0.002 in. and rates from 0. 3 to 1.7 in/sec. A hold time can be inserted into the pulse at the peak from 0 to 9 msec. The piston must only travel about 0.0014 in. to displace the volume necessary to form 400 spheres of 0.030 in. diameter.

The Belleville spring washer is compressed by the spring clamp and is shown in **Figure 4**. The spring preloads the piezoelectric actuator and drives the piston up after the voltage to the actuator is reduced. The compressive preload of the spring is 300 to 400 lb. and is overcome by the force of the piezoelectric crystal. **Figure 5** is a photograph of the piston and spring clamp assembled outside the housing.

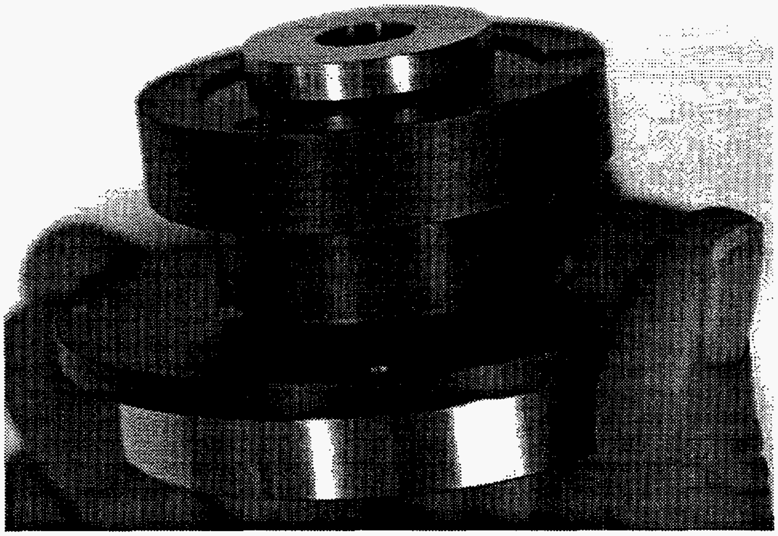

Figure 4. The center housing/reservoir cover of the device contains the Belleville spring washer that returns the piston to the upper starting position. The spring clamp preloads the washer and holds the piston in place as shown; the actuator further preloads the spring in the final assembly. Note the piston below the cover plate.

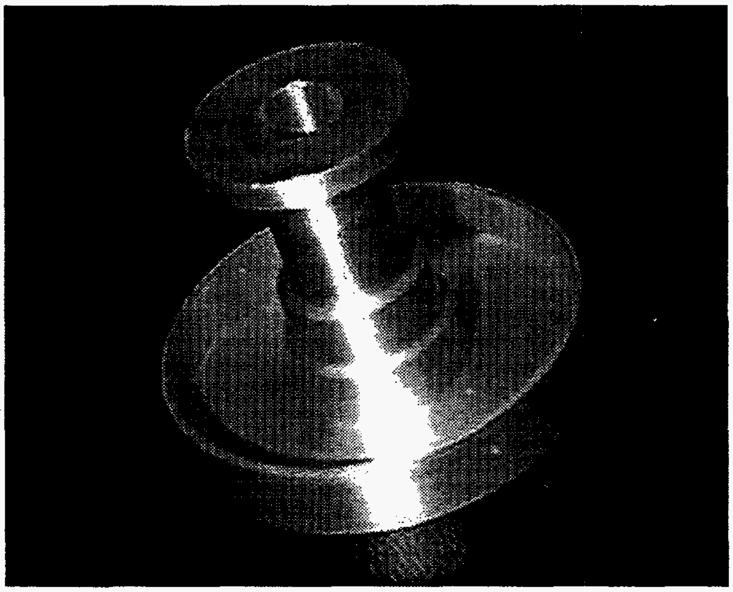

Figure 5. Anodized aluminum piston/spring clamp assembly.

The reservoir/pulse chamber (**Figure 6**) is made from anodized aluminum that resists wetting/alloying with the molten solder. Temperature of the molten solder is adjustable to within 1° C and controlled via proportional integral derivative (p.i.d.) feedback control with a digital temperature controller. The controller applies 120 VAC through a solid state relay to four 100 W cartridge heaters mounted in the housing. Heat conduction through the device requires a continuous source of cooling air to the piezoelectric actuator. **Figure 7** is a photograph of the reservoir filled with molten solder.

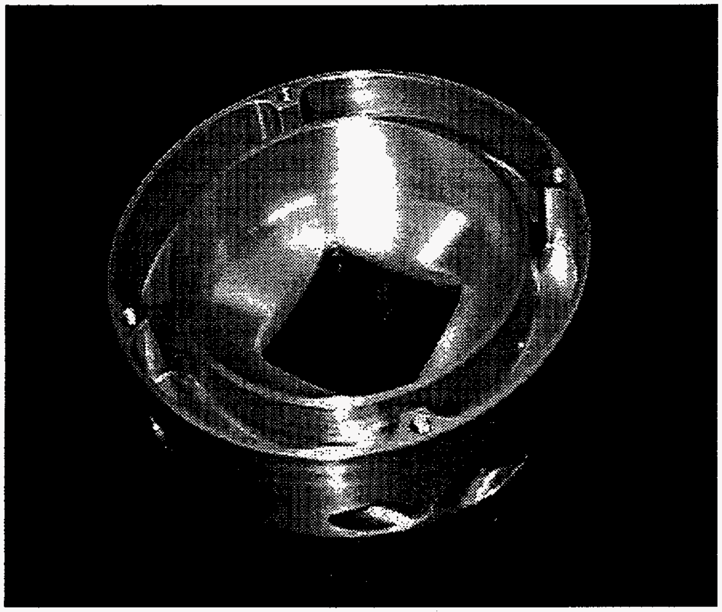

Figure 6. Anodized aluminum housing. The orifice plate mounts in a counterbore beneath the pulse chamber on the underside of the square hole. The reservoir surrounds the piston bore and pulse chamber. The cartridge heater bores are beneath the reservoir tangent to the pulse chamber.

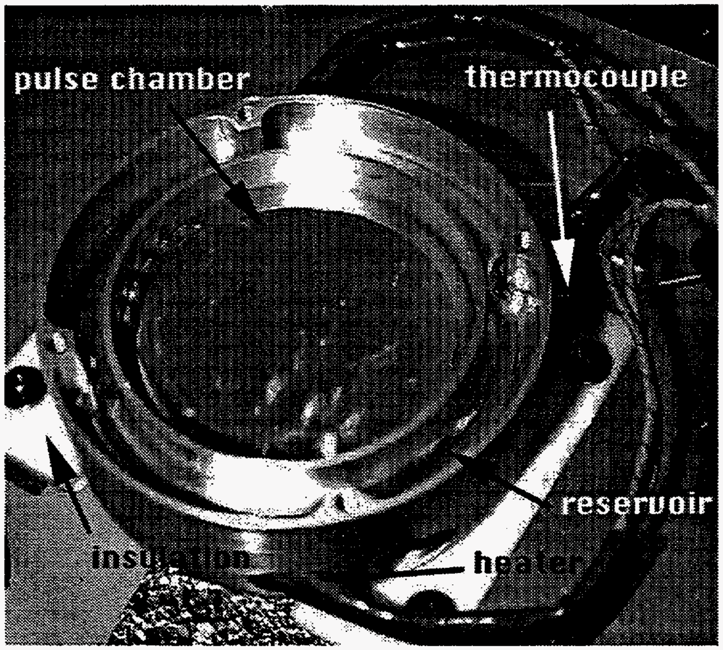

Figure 7. Housing (with cover and piston removed) mounted on testing stand and filled with solder. The piston/piezoelectric actuator assembly is inserted into the pulse chamber while the solder is molten. The reservoir is then filled to the top before pulsing begins.

The solders used in electronic packaging are typically Sn-Pb based materials that rapidly oxidize in air when in the molten state. Therefore, it is important to control the atmosphere around the molten solder bath and below the orifice plate. The atmosphere is controlled by placing the entire jetting assembly inside a Plexiglas container that is equipped with a flow-through source of pure nitrogen gas. A photograph of the Plexiglas enclosed system is shown in **Figure 1**. While in operation, nitrogen continuously flows through the chamber, lowering the oxygen level to near 100 parts per million, which is suitable for this application. The piezoelectric actuator extends above, but is sealed from, the enclosed chamber so that it can be easily cooled.

The orifice plate that is used to jet the solder balls fits into a counterbore beneath the chamber and piston. The grid is made of pyrolytic graphite. Graphite was chosen because it can be accurately machined to the tolerances required for the hole spacing and distribution. Also, it will not dissolve into the molten solder and it has sufficient strength to withstand the solder pulses. The orifice plate and an alumina paper gasket are attached to the solder reservoir with cap screws. A photograph of the orifice plate is shown in **Figure 8**. Orifice plates may have different size and spacing of holes. This allows the application of the jetting device to any BGA geometry.

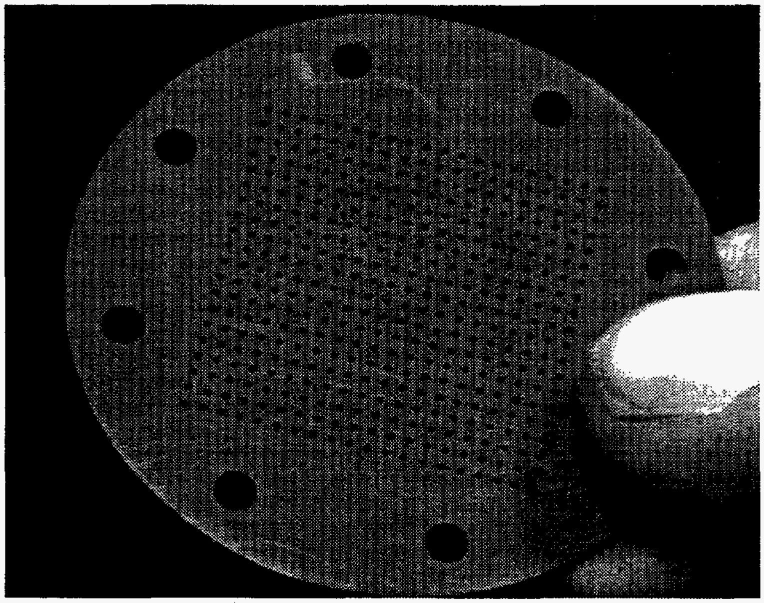

Figure 8. Graphite plate .025" thick with 20x20 array of .020" orifices. Larger holes are for #4-40 attachment screws.

To demonstrate the deposition of solder on copper pads a test board was designed to fit under the jetter. The boards were made from 0.062" thick FR-4 with a matching 20x20 array of 0.028" diameter 1/2 oz. copper interconnect lands.

The board (**Figure 9**) is positioned 0.100" under the orifice plate and exactly aligned with the holes in the orifice plate. The board is preheated to 180° C to aid the wetting of the copper interconnect lands. The board rests on an aluminum block heated with a cartridge heater. The temperature is controlled to within 1° C. The block is located with an insulator made from a phenolic resin board (**Figure 10**). A schematic of this arrangement is shown in **Figure 11.**

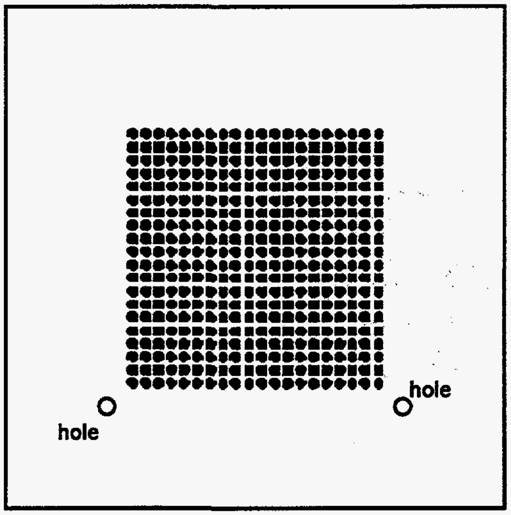

Figure 9. Schematic of 2" x 2" test circuit board.

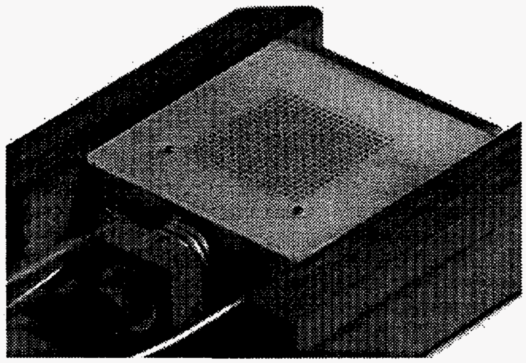

Figure 10. Circuit board heater attachment with circuit board. The cap screw and spring allow precise alignment of board to orifice plate.

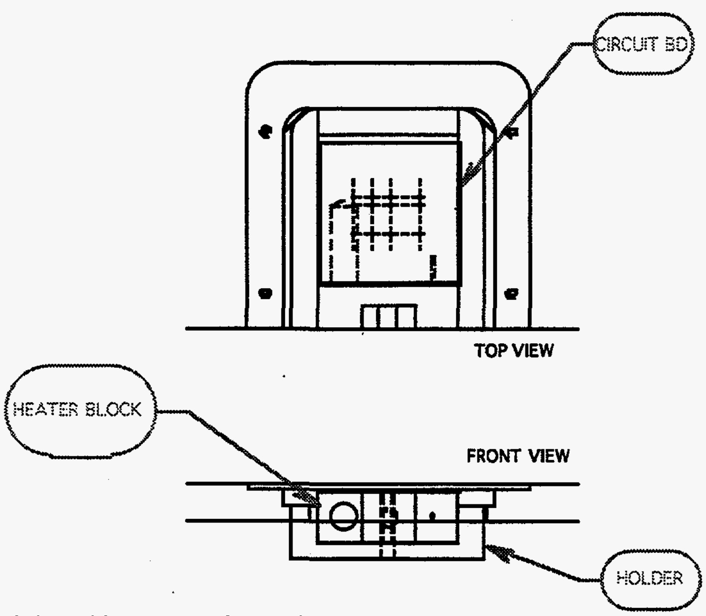

Figure 11. The circuit board heater attachment is mounted below the pulse generator (which is not shown).

Prototype Results

Piston displacement vs. time was characterized by mounting a spring loaded displacement transducer in contact with the piston and recording the results with a digital oscilloscope.

A number of factors contribute to determining the size and shape of the jetted balls. The magnitude and duration of the pulse define the size of the balls. The hole diameter, plate thickness, temperature, viscosity, surface energy of the molten solder and the depth of the solder above the orifice plate (ambient pressure) determine the shape of the displaced fluid during the formation of free droplets. The location of the jetted solder is defined by the number and spacing of the holes. These variables were found to be interrelated; therefore, in order to bound the scope of the project, only one ball size, .030," and one array dimension, 20 x 20 (1"x1"), was sought.

Experiments were conducted with several orifice sizes. Experimental graphite orifice plates included 1) .040 in. thick with .008 in. dia. and .010 in. dia. holes and 2) .025 in. thick with .022, .020, .018, .016, .014, .012, .010, .008 and .006 in. dia. holes. The goal of the orifice plate research was to determine the effects of hole size and plate thickness on the size and shape of the droplets created. For example, 0.030 in. diameter solder dots could be formed through 0.012, 0.014, and 0.016 in. orifices with adjustment of the piston displacement, pulse time and hold time. The most reliable 0.030 in. solder drop creation, at 205°C, was with the 0.014 in. orifices. The corresponding displacement pulse is shown in **Figure 12**.

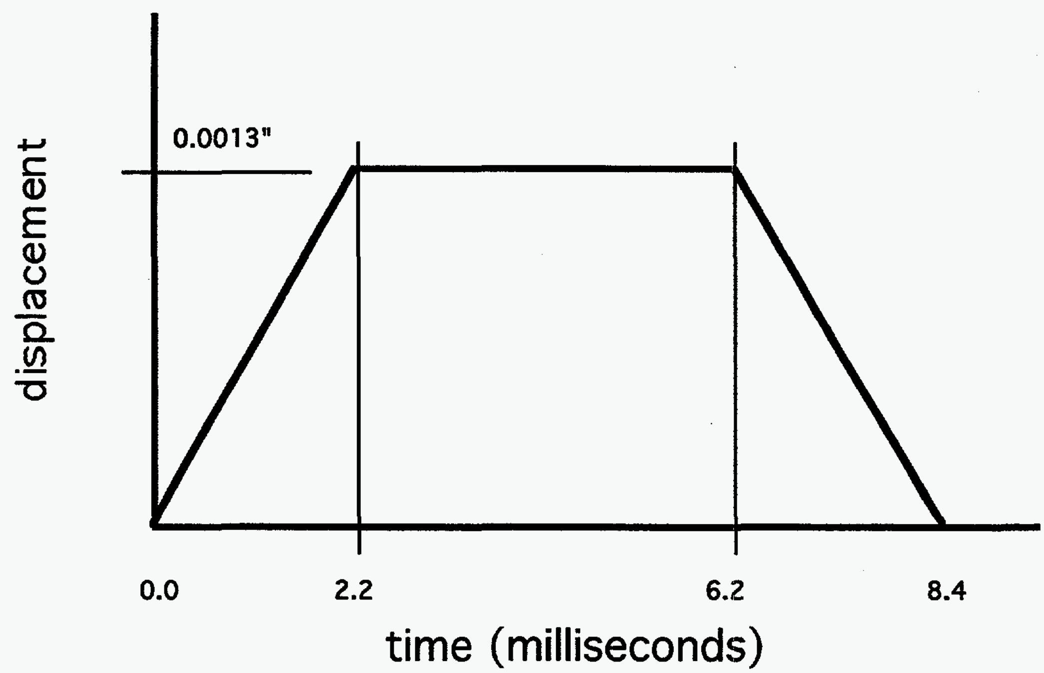

Figure 12. Piston displacement vs. time for .030" diameter solder dot jetted through 0.014" diameter orifice onto 0.028" diameter interconnect lands.

When temperature was varied, pulse characteristics had to be varied to obtain the same solder dot size. A large range of droplet sizes(<50% or >150%) may be formed by adjusting the displacement and solder temperature.

Changes in pulse characteristics affected the size uniformity of the array. At a given piston displacement, a non-optimized displacement rate caused a circular array of tails or pendant droplets to form on the center of the orifice plate. If the pulse was too slow, the tails would form in the center; too fast and they would form outside the center. With the proper combination of ramp rate and hold, a uniform front of droplets would emerge from the orifice plate.

Initial tests with the prototype jetter, shown by the high speed photography in **Figure 13**, resulted in tails that would randomly attach to the fallen balls or remain attached to the orifice plate.

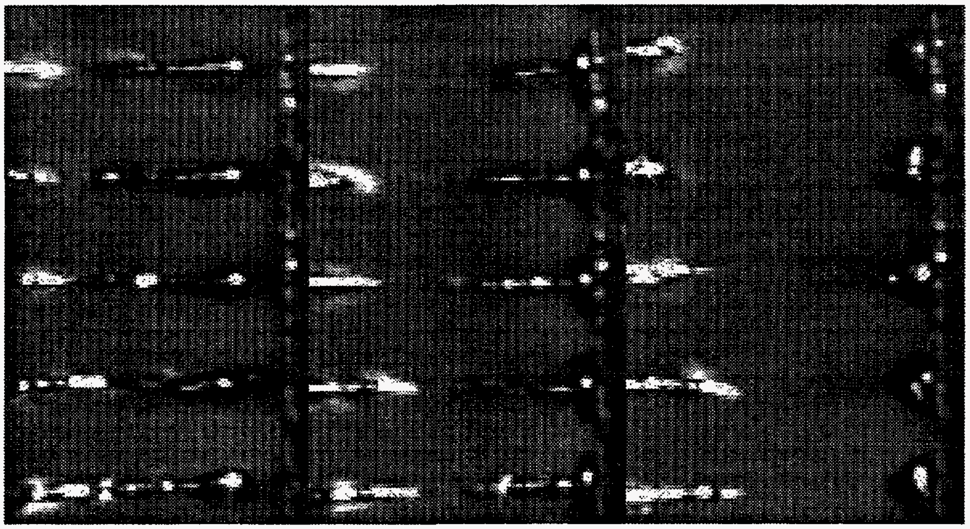

Figure 13. High speed photography at edge of orifice plate rotated 90° CCW from vertical taken in air. The droplets fall from left to right. Note the tails remaining at the orifices.

The problem of tail formation was attributed to the presence of oxygen in the chamber that reacted to form an oxide skin on the solder inhibiting ball formation. The environmental Plexiglas chamber was built to allow solder ball creation in an inerted nitrogen atmosphere. The formation of tails on the solder balls was no longer observed as illustrated by the high speed photography series in **Figure 14**. These photographs show that several small spheres were formed as the solder was extruded through the orifice. These smaller spheres all can be seen by the large array of wetted balls created in **Figure 15**.

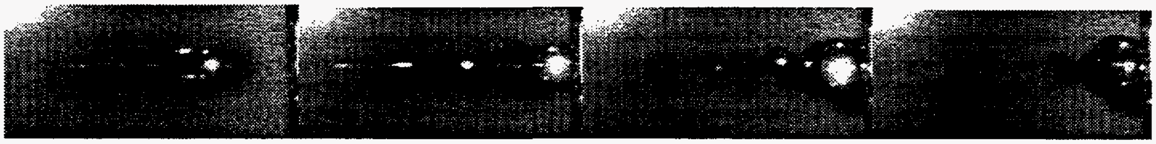

Figure 14. High speed digital photographs taken at 1000 frames per second, 30 microsecond exposure time from left to right at the edge of a 20x20 array of orifices. In inert atmosphere, small spheres form almost immediately after solder has extruded through the orifice. The spheres then pile up on the same copper interconnect land, with a resulting diameter of .030." Note the absence of tails on the right.

By reducing the piston displacement and varying the the pulse ramp and hold, it was possible to obtain stable single sphere droplets. With a 0.012 in. dia. orifice, single spheres about .008 in. larger than the orifice, or about 0.020 in. diameter were created. With a 0.018 in. dia. orifice, single spheres 0.026 in. diameter were created. With Orifices larger than 0.014 in., however, uncontrolled flow through the orifice plate became problematic. In all cases there is a delicate balance between surface tension, capillary action through the orifice plate, and the pressure above the orifice plate.

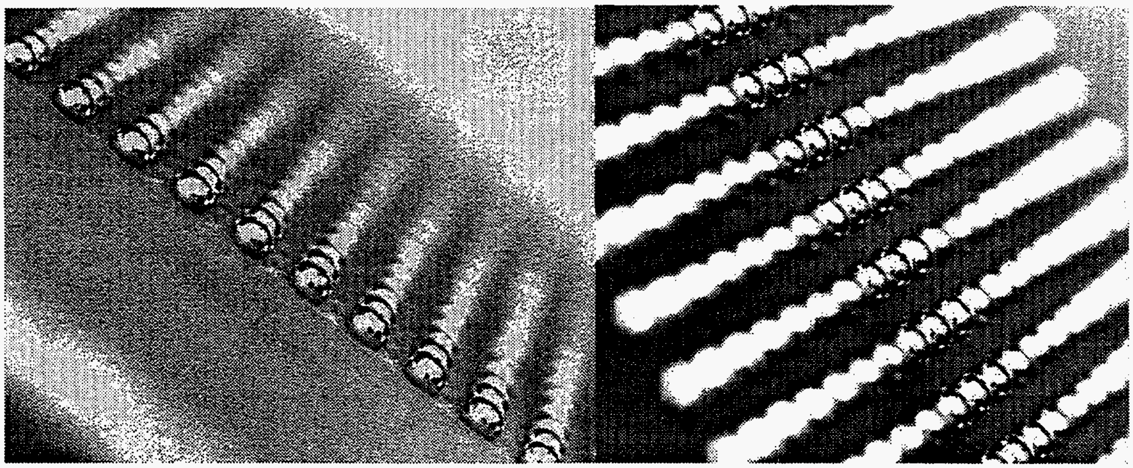

Figure 15. Photographs of pc board with 20x20 array of .030" wetted solder balls deposited simultaneously by solder jetter.

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