PLASMA STRIPPING OF AN ENCAPSULANT

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1. INTRODUCTION

The work described in this paper has been condensed from a fuller text (1), and is limited to results with planar electrode apparatus. Rapid material removal (stripping) of a specific encapsulant (2) from hybrid, screen printed circuits was the objective. The use of plasma for this purpose had obvious advantages and was already in use industrially to remove polymeric materials, albeit very thin deposits. A distinction peculiar to stripping an encapsulated hybrid is material thickness, nominally on the order of a millimeter. Commercial, barrel-type reactors (3) required weeks of exposure in an oxygen plasma (13.56 MHz, 100 watts) with inconsistant results, too often disasterous. Flexibility also in such equipment was wanting. Best material removal was achieved with modest amateur radio equipment, using less than 100 watts at 13.56 MHz, in a planar-type reactor. Pressure and temperature control were factors that contributed to successful, complete stripping of a circuit.

2. WORK AND RESULTS

Reported here are results from work with a planar electrode reactor. The concluding design is schematically represented in Figure 1. Two features illustrated are a heat-sinked lower electrode, and radial gas flow (4). For the application, temperature control is important and radial gas flow with a heat-sinked electrode are simple ways to achieve this. For the pressures and dimensions used, the plasma proper is confined to the space between electrodes. Specimens are conveniently placed on the lower electrode, which is connected to R. F. ground.

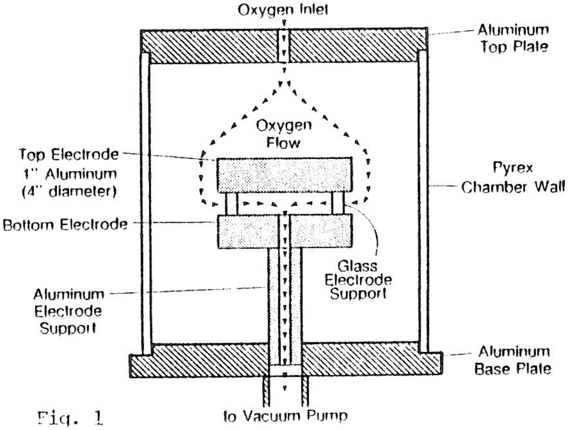

Fig. 1

REACTOR DESIGN

An important feature in this design (not shown), which separates it from commercial equipment in general, is an independent pressure and gas flow adjustment. In the following, where gas pressure is varied, it is at constant flow.

Specimens were of two sorts, namely prepared blanks and actual encapsulated circuits. In the latter, the reverse side was coated with an RTV, silicon rubber that did not react with plasma. Blank specimens, although more massive than actual circuits, were prepared on only one side of a 25 x 75mm glass slide.

Ash or material removal rates reported here are measured in terms of (milligram) weight loss per hour of plasma exposure. By definition, ash rate is dependent upon specimen mass and surface area, neither of which is a constant. Because of this choice, interpretation of data is not always straightforward.

In Figure 2, ash rate is shown versus plasma exposure at two specimen temperatures. Earlier apparatus required adjusting the bottom electrode temperature between hours for these measurements. Clearly, higher specimen temperatures are conducive to higher ash rates, but had to be kept below 183°C, to keep solder termination intact. Other unpresented data show little effect with temperature of the upper electrode. The near-linear rise in ash rate with time is traceable to an increase in specimen surface area. Initially, the specimen surface is smooth; however, in time the surface becomes cratered and cavernous, eventually appearing riddled. With this apparatus design, temperature was under little control except as permitted by the applied power.

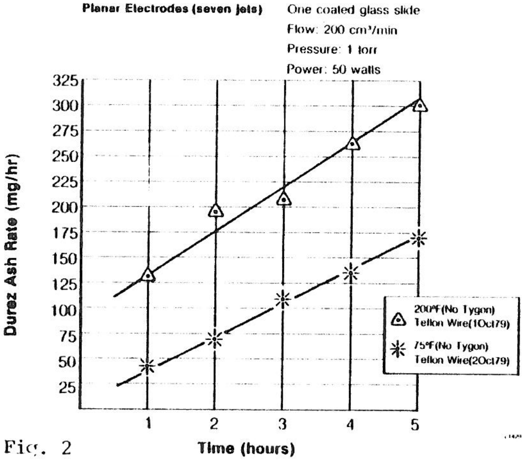

Fig. 2

Figure 3 shows the ashing characteristic of an actual circuit. The rate rises, reaches a sharp peak, and then falls steadily. These rates respectively correspond to an increase in surface area followed by a decrease in mass of material left to ash. As indicated in the figure, cooling of the electrodes was accomplished by removing the electrodes after each exposure hour. The effect of 7 consecutive hours of ashing are shown in Figure 3. During this time none of the solder on the circuit leads melted. However, when the electrodes are not cooled, solder melts as early as the second hour.

It is impractical, however, to cool the electrodes on a routine basis by removing them. It is also awkward and costly to introduce water cooling into a vacuum system. The modified electrode design of Figure 1 allows heat to be conducted to the gas and to the chamber base plate.

To measure the ash rate as a function of input power, the parameters of temperature and surface area had to be held constant. Temperature was controlled as described above by electrode removal and cooling. Surface area was controlled by introducing a virgin sample at each power level. Resultant data are presented in Figure 4, which shows a linear relationship between ash rate and power, indicative of first order chemical behavior.

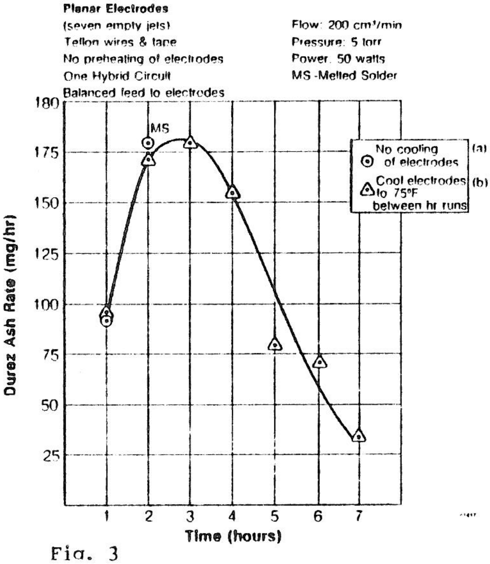

Fig. 3

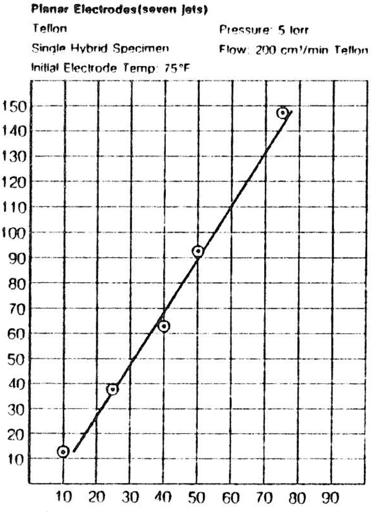

Fig. 4

Two significant findings in this work are demonstrated in Figures 5 and 6. Figure 5 shows the ash rate of a specimen in a pure oxygen plasma, and also in an oxygen plasma burning vinyl (PVC) and teflon (PTFE). A constant ash rate is experienced in pure oxygen. This has been observed to continue even after 16 hours of exposure. The ash rate in the presence of teflon or PVC is markedly altered and improves with time. The increase in ash rate again corresponds to an increase in surface area. This is evident in the surface texture of the specimen as described previously. The enhancement was originally introduced by insulation material on power leads that were made of teflon and vinyl. Also, as Figure 5 shows, teflon was the better of the two. Since then, teflon in tape form was placed around the electrode insulators for convenience. The enhancement does not appear to be sensitive to the amount of tape introduced above some minimum.

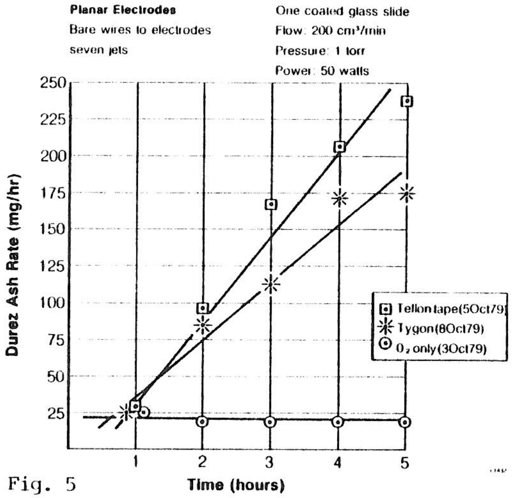

Fig. 5

Early in the work, we began to depart from the milli-torr range of pressures common to plasma etching, stripping, and material removal interests. Systematically, we found improved ash rate with pressure. As shown in Figure 6, using teflon, major improvement resulted at 5 torr but a disproportionate gain resulted at 10 torr.

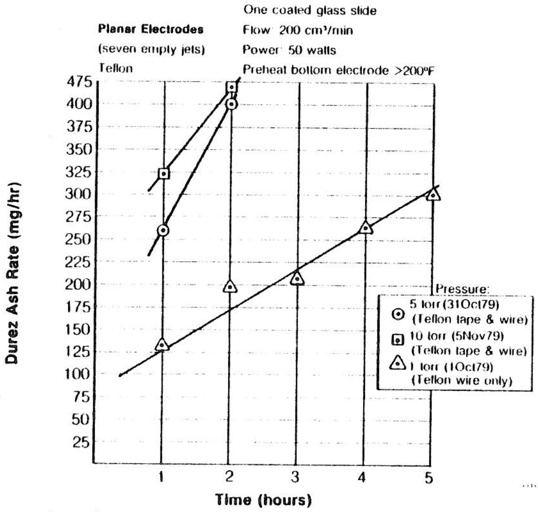

Fig. 6

3. SUMMARY AND DISCUSSION

The primary objective of the work was to strip actual hybrid circuits in a reasonable time. The complete ashing of a hybrid encapsulant in the radial flow reactor at 75 watts could be accomplished in a work day. Solder terminations remain intact and the circuit is left unchanged. No pre-grinding or partial removal of the encapsulant is necessary. Other encapsulant materials were not investigated. The radial flow and heat-sinked electrode design have proven to be superior to barrel-type reactors for material removal. Uniformity of reactions, which although not a major consideration in stripping, minimizes the under-material exposure to the plasma.

Two major contributions to rapid stripping were found: namely, enhanced reaction by the introduction of a solid catalyst (teflon or vinyl), and improved reaction at higher pressures. Although other works (5) have shown improved reactions with increased pressure, none appear to have attempted measurements as high as 5 torr. The catalytic enhancement is not unusual since fluorine radicals are well known to enhance etching and stripping reactions. However, the enhancing species are usually introduced as a gas, for example CF_4. In the present case, whatever the species, they are brought about indirectly by the reaction of the oxygen plasma on a solid. This means of introduction is certainly novel; it has several noteable virtues. Mixing of gas is not required and the need to have a gas manifold with multiple regulators is unnecessary. Simplicity of introduction is outstanding, and cost is minimal since the expensive CF_4 gas is not used. Furthermore, the enhanced reaction seems to be self-regulating. That is, we found the enhancement to be independent of the amount of teflon.

Observations unfortunately did not include spectrographic analysis because it was not available. The catalytic species have been suggested by others. Taylor and Wolf (6) examined removal of polymeric material in an oxygen plasma enchanced by chlorinated and fluorinated species. It seems probable that teflon interacting in the oxygen plasma produces fluorinated species, and similarly the vinyl yields chlorinated radicals and ions.

The enhanced ash rate with either teflon or vinyl is accompanied by increased surface area. We have seen that the specimen gains in surface area until mass loss overtakes it. This does not take place with pure oxygen. In fact, when pure oxygen is used subsequent to use of an enhanced plasma, the ash rate falls to the constant rate depicted in Figure 5. This suggests a reversion of the specimen to its original surface area, which viewed at low magnification is exactly what is observed. Only surface extremities are attacked. This seems to imply that oxygen by itself cannot reach into the material cavities. The similarity to electro-chemical polishing is noteworthy. The concept of local electric fields is invoked for explanation of the reduced surface. The catalytic phenomenon would seem to involve other electric effects, like charge transfer.

In several of the figures, the term jet is used as part of the condition of the plasma. The term jet is ours and may be the same phenomenon under the names "plasma-sac", "plasma sheath" or "SESER" (7) that other workers have analyzed. The jet makes appearances in and around constrictions, cavities, holes, and the like associated usually with a ground electrode. There have been other circumstances reported (1). The phenomenon has been believed to hold some promise for enhanced reactions or other special applications.

Early in this work the jet was experimented with in several configurations, but generally as a cylindrical cavity in a grounded electrode. Material placed in the excited cavity disappointingly was found to react no differently than in the plasma proper. In short, no enhanced reactions could be produced (outside that with teflon). However, the jet cavity does provide localization of reaction, which may be useful. That is, in the case of teflon placed in a cavity, a specimen near the cavity would preferentially experience the catalytic reaction. Whatever the manifestation, we have concluded that the term Langmuir used long ago is appropriate, and that our jet is simply a "cathode sheath" (8).

REFERENCES

(1) An internal technical report entitled "Plasma Stripping of Durez, an Encapsulant for Hybrid Circuit", dated May 9, 1980. 70 pages, 43 figures.

(2) Durez - Trade name of Hooker Chemical Co., Buffalo, N.Y. of a Phenol Formaldehyde resin mixed with calcium carbonate as a filler.

(3) D. D. Wilson and J. R. Beall, "Decapsulation of Epoxy Devices Using Oxygen Plasma", Annual Rel. Phys. Sym. Proc. 1977, p 82.

(4) A. R. Reinberg, U.S. patent #3,757,733 (1973).

(5) Circuits Manufacturing, April 1976, p 42.

(6) C. N. Taylor and T. M. Wolf "Oxygen Plasma Removal of Thin Polymer Films" Polymer Engineering and Science, Mid November 1980, Vol. 20, p 1087.

(7) J. R. Hollahan and A. T. Bell, "Techniques and Applications of Plasma Chemistry", Wiley, 1974 p 67, 68.

(8) I. Langmuir, "The Interaction of Electron and Positive Space Charges in Cathode Sheaths", Phys. Rev. 33, 954 (1929).