epoxy technology inc

EPOXY TECHNOLOGY INC.
P. O. BOX 567
14 FORTUNE DRIVE
BILLERICA, MASS. 01821
(617) 667-3805 Telex: 94-7140

The attached report was presented at the ISHM meeting in Boston in October, 1974. It describes the use of Epo-Tek epoxies in the fabrication of hybrid microwave integrated circuits.

It is our opinion that this is the most important paper yet published dealing with epoxies for microwave applications. The author has fabricated hybrid devices with epoxies that have been used at frequencies as high as 60 GHz successfully.

Epo-Tek epoxies utilized by the author were:

1. H20E two-component, silver epoxy for die attach.
2. H72 two-component, electrically-insulating epoxy for lid sealing.
3. H90 two-component, high-temperature, insulating epoxy for coating purposes.

# EPOXY TECHNIQUES FOR HYBRID MICROWAVE INTEGRATED CIRCUITS

by

Louis Hernandez

AIL, a division of Cutler-Hammer
Melville, New York 11746

## ABSTRACT

Although the use of epoxies in manufacturing hybrid microelectronics at VHF frequencies is well established, their use at microwave frequencies is not widely known. We have developed PIN diode attenuators in MIC configurations at 15 GHz and other MIC's (mixers, oscillators, medium-power amplifiers) in the 2 to 4 GHz range. We have also used epoxies on space-qualified 1-GHz MIC hardware. This paper describes some of the epoxy techniques used to produce and modify hybrid MIC's at microwave frequencies

Conductive epoxies have been used to bond both active and passive devices, insulating epoxies to protect active devices from environmental hazards, and sealing epoxies to meet hermetic sealing requirements. When components are thermally sensitive, epoxy bonding is superior to eutectic die attachment techniques because epoxy bonding can be used at much lower temperatures and provide precise die positioning. Epoxy can be dispensed by manual, screen printing, or automated methods.

The protection afforded by insulating epoxies permits hybrid MIC devices to be moved out of the white rooms to the laboratories, where normal methods can be used to test particular circuits. Thin-film hybrid MIC's can be modified while they are in test fixtures so that the next circuit evaluation can incorporate the new circuit refinements, eliminating costly and time-consuming trial-and-error procedures.

In working with epoxies for microwave MIC's, precautions must be taken. Different coefficients of expansion of the materials used may cause failures of MIC bonded components. When environmental factors are neglected (as they too often are), silver migration may present problems.

Epoxy techniques provide several advantages over other bonding techniques at microwave frequencies higher yield, lower capital equipment costs, shorter training time for assemblers, flexibility in modifying circuits, and compatibility with thermally sensitive components.

## INTRODUCTION

Epoxy application techniques have been developed that enable the microwave engineer to fabricate hybrid devices up to 60 GHz. Traditional eutectic bonding methods limit the substrates available to the microwave engineer to those that can tolerate the high temperatures required in eutectic die bonding, limiting his choice of dielectric constants and substrates. Epoxies suitable for use at microwave frequencies provide a wide choice of dielectric constants (Table I). The flexibility, the brittleness, and the thermal sensitivity of various substrates present some challenging fabrication problems, but epoxies have proven their effectiveness in fabricating microwave hybrid devices. The low curing temperatures of epoxies significantly increase the yield of fabricated devices. Moreover, because epoxy dispensing machines are simpler than eutectic bonding machines they cost less and require less time to train operators in their use.

TABLE I

| Substrate Material | Dielectric Constant | Physical Property |
|---|---|---|
| Sapphire | | |
| C Axis Parallel | $= 11.4$ | Hard |
| C Axis Perpendicular | $= 9.4$ | Hard |
| 99.5% Alumina | $\epsilon = 9.5$ | Hard |
| Spinel | $\epsilon = 8.3$ | Hard |
| YIG | $\epsilon = 16.0$ | Brittle |
| Fused Quartz | $\epsilon = 3.78$ | Brittle |
| Kapton | $\epsilon = 3.5$ | Flexible |
| Mylar | $\epsilon = 2.8$ | Flexible Thermally Sensitive |
| Duroid 5880 | $\epsilon = 2.2$ | Flexible Thermally Sensitive |

## CONSIDERATIONS IN EPOXY SELECTION

Epoxies suitable for use in fabricating microwave hybrid devices should meet the following specifications:

- Low volume sensitivity (0.0001 to 0.0003 ohm/cm)
- Good thermal conductivity (11.5 BTU/ft$^{2}$/$^{o}$F)
- Lap shear strength of approximately 1000 to 2000 PSI
- Minimum resin bleed (since it may cause shorts or render nearby bonding areas useless)
- Minimum outgassing in hermetically sealed packages
- No byproducts that break down into corrosive agents
- Acceptable shelf life (depending on demand and use, from 6 months to 2 years)
- Proper viscosity for the use intended
- Ability to tolerate the wire bonding temperature without weakening or softening
- Pot life stability (to maintain uniformity in batch)
- A curing temperature compatible with the substrate (that is, requires no higher temperature to cure than that which the substrate can tolerate)

Conductive epoxies are available in compositions of silver and gold. Insulating epoxies are available that offer mechanical protection to the devices without affecting their electrical performance noticeably at the higher microwave frequencies.

## TECHNIQUES OF APPLICATION

Epoxies can be applied by screen printing methods using a 200-mesh screen; the deposited amount is approximately 0.002-inch thick. This method is best suited for large volume application and high component densities. Another method uses a bonder tailored precisely for the application of epoxy. A number of machines are available that dispense a precise size and quantity of conductive epoxy. These machines can also position the dies on the substrate. In my opinion, the manual method is best suited for the application of epoxies to the microwave hybrid substrate. The epoxy should be dispensed with an ultrafine needle; the volume of epoxy should be no more than a dot of 0.005 inch in diameter. The chip or terminal of the beam-leaded device is then placed on top of the epoxy dot and gently pushed toward the substrate. When a thin film is desired, a small amount of epoxy can be spread over the site; the chip or terminal of the beam-leaded device can then be positioned on top of the epoxy.

## CURING THE EPOXY

The electrical performance and the physical properties of the epoxy are affected by the curing temperature. The manufacturer's directions on curing temperatures must be scrupulously observed. When modifying microwave devices, consider the additional heat required by the housing. Sufficient time must be allowed for the housing to reach the proper curing temperature; only then should the curing time start. This point can be monitored by means of temperature-sensitive tapes or by a thermocouple affixed to the housing. Some epoxies can be cured over a longer time at a lower temperature; this is important when a thermally sensitive substrate is used. The substrates are then placed in suitable containers (such as glass petri dishes) and then in the air drying oven for the curing time specified for that epoxy. It is also wise to place an equal amount of epoxy (on an unused portion of the substrate) as a control to test the curing of the epoxy.

## SOME INTERESTING MICROWAVE HYBRID CIRCUITS

In some instances precise placement of a semiconductor chip is required. For example, the PIN diodes on the substrate assembly of a 15-GHz attenuator had to be placed inside a ridged waveguide cavity. In this case the height of the diodes as well as the distance between diodes, had to be precisely controlled (to within 0.003 inch). Precise epoxy dispensing was essential--and achieved in manufacturing a large quantity of these attenuators.

Flexible substrates present problems. In fabricating a 60-GHz mixer using Kapton, a gallium arsenide beam-leaded Schottky barrier diode had to be affixed to the metallized Kapton. The metalization was copper with a thin gold flash. If thermocompression bonding had been used the gold film would have been absorbed by the copper and the copper would have oxidized, making the surface useless for bonding. Epoxy bonding solved the problem.

In fabricating a 5 to 6 GHz FET amplifier, a 160-ohm impedance line between the drain of the first and second stages and the drain bias supply was realized by welding a 0.0007-inch diameter wire to the bias line, and then bonding this wire with epoxy to the substrate with an insulating epoxy.

In fabricating and modifying a 1 to 2 GHz amplifier (figure 1), epoxies were used to add components such as chip capacitors, and changing the substrate metallized geometry (that is, extensions of the ground plane). This saved a lot of time since the next artwork generation (figure 2) included all the previous refinements. The transistor chips were coated with insulating epoxy; then the amplifier was moved out of the clean room into the ordinary test lab.

Insulating epoxy protected the delicate wires bonded to transistor chips and diodes, as well as beam-leaded devices; from mechanical damage. In addition, it protected expensive microwave transistors from environmental contamination and microscopic metallic debris, which might have caused failures.

A parametric upconverter whose output frequency was 4.5 to 6 GHz had to operate when cryogenically cooled to 20 K. The active device's chips were bonded to the substrate with conductive epoxy; then the wire bond to the active device was coated with a very thin film of insulating epoxy.

When silver bearing epoxies are used, the problem of silver migration cannot be ignored. We have noted silver migration when the fabricated microwave hybrid devices were tested in a hot and cold chamber. Condensation in the chamber initiates the problem; the application of bias aggravates it. The problem can be solved by the use of gold epoxies. Front-end devices such as RF amplifiers, mixers, and oscillators face similar environmental conditions; sealing epoxies offer practical solutions. Another successful method is the application of a conductive sealing epoxy; the sealed housing is then conformally coated. This sealed housing has passed a salt spray test.

## CONCLUSIONS

The main advantages of epoxies are speed and ease of application and reliability. These important advantages make them economically attractive for use at microwave frequencies, where components are expensive and cannot tolerate high temperatures. Because of their flexibility in curing temperatures, epoxies offer the microwave design engineer a wide choice of substrates and dielectric constants in advanced designs. The successful results of conductive epoxies at 60 GHz merit their consideration for use at 100 GHz.

## ACKNOWLEDGEMENT

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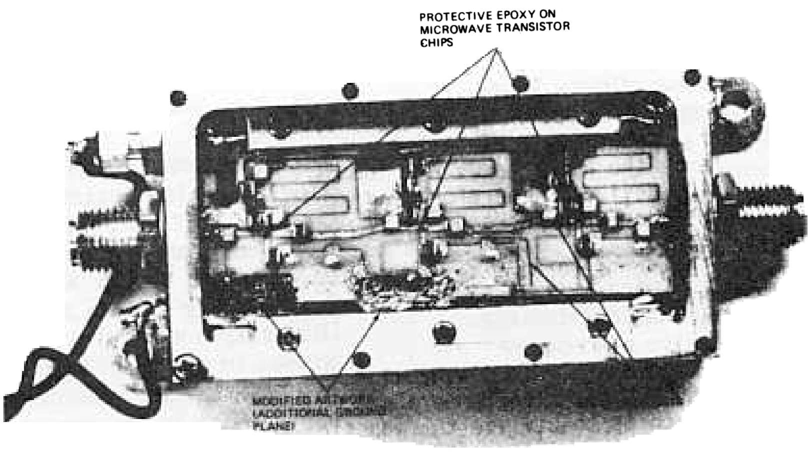

Figure 1. 1 to 2 GHz Amplifier

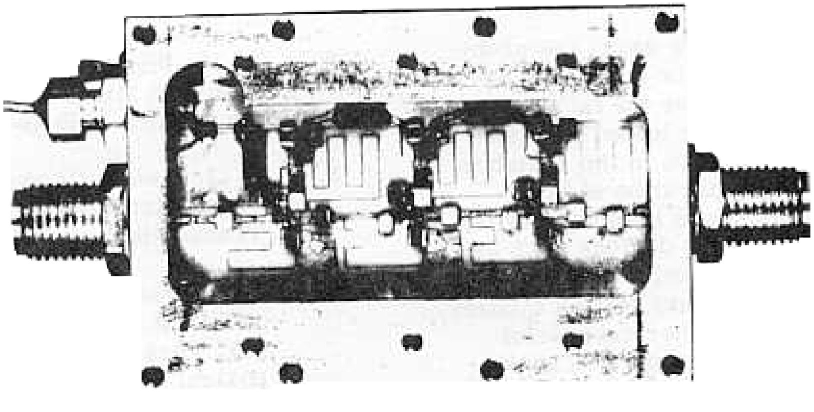

Figure 2. Amplifier With Refinements Included