Membrane-Supported CPW with Mounted Active Devices

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***Abstract*—This paper reports the fabrication of printed circuit lines on a 5 μm thick membrane that minimizes dielectric loss and effectively eliminates surface modes, both of which are important for operation at millimeter-wave and submillimeter-wave frequencies. The relatively low-cost low-temperature process uses a photosensitive resin (SU-8) to form the membrane and enables devices to be mounted on it.**

***Index Terms*—CPW, micromachining, photosensitive resin, SU-8, suspended CPW, transmission lines.**

I. INTRODUCTION

LOSS in planar transmission media has metallic and substrate origins. Metallic losses, resulting from finite conductivity, become less important at high frequencies as circuit dimensions shrink faster (inversely proportional to frequency) than the skin effect resistance increases (roughly proportional to the square root of frequency). However substrate-related losses increase considerably, particularly at millimeter-wave and submillimeter-wave frequencies. In part these losses are due to dielectric loss, but a significant source of loss is due to the excitation of surface modes. Dispersion is also a significant problem for some planar transmission line geometries. Dispersion and substrate-related losses are largely eliminated by fabricating the transmission lines on a membrane [1]–[9]. These lines are also referred to as suspended stripline, or suspended coplanar waveguide (CPW), etc. This paper demonstrates a technique that uses a thin organic photosensitive resin to realize membrane-supported planar printed circuits to which active devices can be mounted. Measurements to 110 GHz show that CPW lines suspended on this membrane have low transmission losses in the millimeter-wave range.

II. MEMBRANE-SUPPORTED TRANSMISSION LINES

Most membrane-supported transmission line fabrication uses micromachining of silicon [1]–[7]. Typically, a three-layer $SiO_2/Si_3N_4/SiO_2$ supporting film is first deposited on to a high resistivity bulk silicon substrate. The printed circuit is then photolithographically fabricated on the film. The bulk material underneath the film is then selectively etched and the supporting film is left as a membrane backing the new suspended printed circuit. The performance of these membrane-based transmission lines is excellent [4]–[9]. However, the processing approach based on the three-layer $SiO_2/Si_3N_4/SiO_2$ film requires thermal oxidation and low pressure chemical vapor deposition (LPCVD). These approaches require extensive investment. The high temperature thermal processing also places restrictions on prior processing and on the materials used.

The low-cost process presented in this letter eliminates the need for intensive thermal processing. The procedure uses a thin photosensitive organic resin (EPON SU-8 or similar) [8] spun on to a glass substrate to produce a membrane that has been fabricated by us with a thickness of 5 μm and with an optically flat surface. The importance of our low-temperature thermal process is that it allows active devices to be mounted on a membrane of controllable thickness before the final step removing the membrane backing. The mechanical strength provided by the glass backing minimizes mechanical damage to the membrane when the active device is mounted.

III. MICROFABRICATION PROCEDURES

Realization of the structure has two parts: a) fabrication of the membrane; and b) fabrication of a supporting frame.

A. Fabrication of the Membrane

Metallization for the printed circuit is first patterned onto one side of a glass slide that is pre-coated with a sacrificial layer. The active device to be integrated is then bonded to the printed circuit. An ultra-thin layer of photosensitive resin (SU-8) is then formed (spun) on top of the printed circuit and this eventually becomes the supporting membrane. A detailed description of the processing procedure, illustrated in Fig. 1, follows.

1) A microscope glass-slide, Fig. 1(a) is first coated with a layer of silver (or silver chloride), see Fig. 1(b). The silver layer (or the silver chloride layer) will be used as a sacrificial layer, and so the thickness is not important.
2) The printed circuit is then defined photolithographically and thermally evaporated with metal to a thickness satisfying skin depth requirements, see Fig. 1(c). The metallization is preferably gold for a silver sacrificial layer.
3) If a device is to be integrated with the printed circuit it is bonded directly onto the printed circuit using either chip-attach or, as in Fig. 1(d), wire bonding.
4) An ultra-thin layer of the photosensitive resin is sprayed on to the printed-circuit and the structure spun at high speed. Then, the whole wafer is prebaked at 90 °C.
5) The membrane pattern is defined photolithographically and is annealed to form cross-linked polymers by exposure to ultraviolet light. The whole wafer is then postbaked (to no more than 90 °C) to further harden the exposed dielectric membrane. The unwanted photo-sensi-

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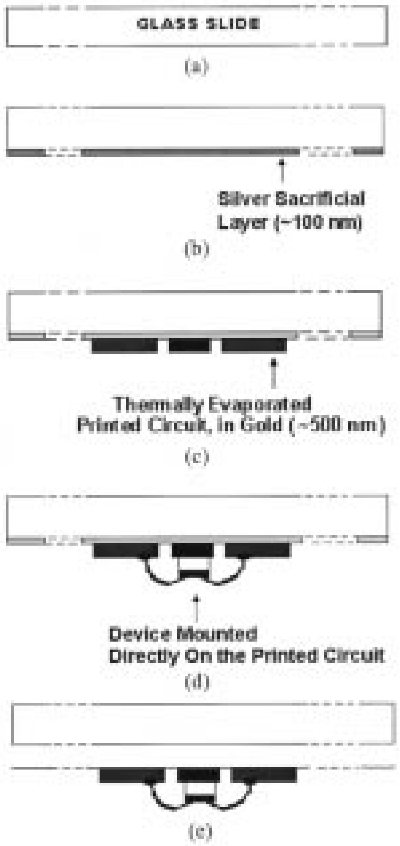

Fig. 1. Fabrication steps for a membrance-supported CPW with mounted active device.

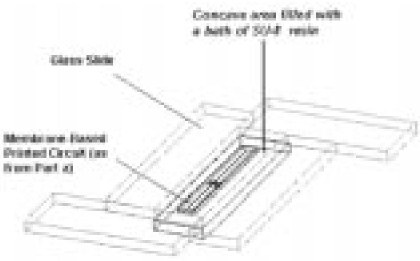

Fig. 2. Bath of thin photosensitive resin (SU-8), contained in a hand-assembled container formed using glass slides.

tive resin pattern is striped off using organic solvent Γ-butyrolactone (GBL) leaving the patterned membrane on top of the sacrificial layer.

If the membrane is to be supported by a waveguide housing, for example, it can be released from the glass slide at this stage by wet-etching the sacrificial layer as shown in Fig. 1(e). Iron III nitride is used to etch a silver sacrificial layer and potassium hydroxide is used if the sacrificial layer is silver chloride.

B. Fabrication of the Membrane Supporting Frame

A supporting frame can be realized using a thickened region of resin. Following is a description of the processing procedure.

1) On the top of the membrane a rectangular well is first assembled as illustrated in Fig. 2. The well serves as a container that maintains a bath of SU-8 of even depth.

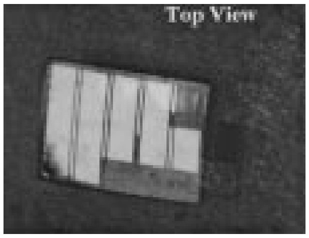

Fig. 3. Membrane-supported coplanar waveguides of different lengths (line width $= 50\,\mu$m, gap $= 40\,\mu$m, membrane thickness $< 5\,\mu$m, membrane distance away from ground $= 110\,\mu$m).

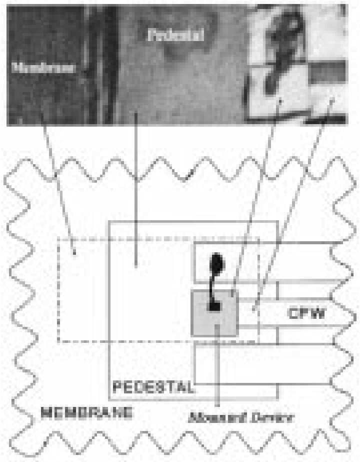

Fig. 4. Method of mounting a device onto a printed circuit supported by an organic membrane (photo taken from the backside of the membrane-supported coplanar waveguide test-set).

2) A thin photosensitive resin (SU-8) is poured into the rectangular well and the whole structure is prebaked.
3) The supporting frame is then photolithographically patterned and the whole structure is post-baked until the resin is sufficiently hardened. An organic solvent is used to remove the exposed resin.
4) The whole membrane-based printed circuit together with the supporting frame is finally removed from the glass slide by wet-etching the sacrificial layer.

Finally the printed circuit metal can be further thickened by electroplating, particularly if the evaporated metal fails to meet the skin depth requirements. The thickened metal strips also protect the membrane from buckling.

IV. EXPERIMENTAL RESULTS AND DISCUSSIONS

A range of membrane-like printed circuits have been realized by us using the proposed methodology and Fig. 3 shows a range of membrane-supported CPW's. Fig. 4 illustrates one of the device-mounting techniques currently in use. Here the SU-8 layer immediately underneath the device is deliberately thickened forming a pedestal. It was found that the weight of the device, silver-loaded epoxy and pedestal does not cause buckling of the membrane for a span area up to 500 μm by 1000 μm. From S-parameter measurements on the membrane-supported CPW's of different lengths, the insertion loss is typically below 0.7 dB/cm across W-band under an enclosed environment [9]

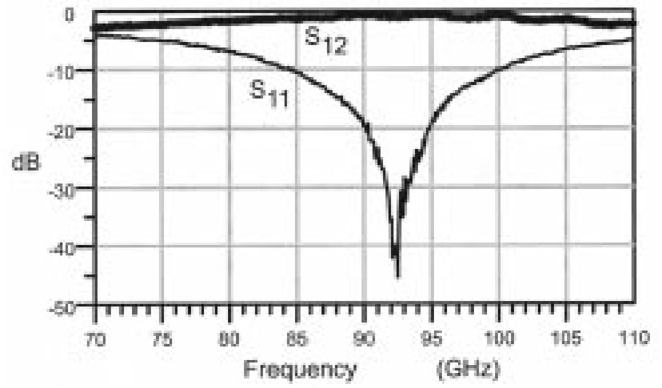

Fig. 5. Measured S-parameters for a 50 Ω membrane-supported CPW line (metal thickness $=$ 200 nm, line length $=$ 1.55 mm).

and 0.14 dB/mm without an enclosure that suppresses the radiation loss to the free space.

Fig. 5 shows the S-parameters of an open (no cavity enclosure) 50 Ω line. The line length was 1.55 mm, corresponding to a free-space half-wavelength of 93.55 GHz. Despite the impedance mismatch due to the dielectric discontinuities at the ends of the 50 Ω line, the S_{11} was lowest around 93 GHz, suggesting that the dielectric influence is predominantly due to the permittivity of air.

V. CONCLUSIONS

This letter presented a low-cost microfabrication technique that enables a printed circuit to be lithographically fabricated on an organic membrane of controllable thickness. The method eliminates the need for high-temperature thermal processing and allows active devices to be integrated without damaging the membrane. A frame of thickened resin provides mechanical stability by maintaining the membrane in tension enabling it to be self-supporting. It has been experimentally demonstrated that the technique can be used to realize low-loss conventional planar membrane-supported printed circuits.

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