MEMBRANE-SUPPORTED COPPER E-PLANE CIRCUITS

W.Y. Liu, D.P. Steenson, M.B. Steer

IMP, University of Leeds, Leeds, LS2 9JT, United Kingdom

***Abstract* — This paper reports the realization of copper E-plane circuits on a micromachined 5 micron thick organic membrane. As the membrane is both thin and optically smooth, dielectric loss and the excitation of surface modes are virtually eliminated. Measured losses of lines are no more than 0.4 dB/cm at W-band. The relatively low-cost low-temperature process uses a photosensitive resin (SU-8) to form a self-supporting membrane to which devices can be mounted. The realization a finline resonator and an E-plane bandpass filter are presented.**

I. INTRODUCTION

E-plane components are well-known for their excellent transmission efficiency and for enabling planar components to be integrated into an enclosed waveguiding system. Most reported E-plane printed circuits are based on standard substrates of thickness greater 100 microns. For operation above W-band (i.e. 110 GHz), this thickness becomes comparable to the guide wavelength and substrate-related losses increase considerably. In part these losses are due to dielectric loss, but a significant source of loss results from the excitation of surface modes. Dispersion and substrate-related losses are largely eliminated by fabricating the transmission lines on a suspended membrane [1–8]. In an earlier publication [6] we presented a process for creating a non-insulated membrane-supported printed circuit. In this process, a membrane was formed on a sacrificial layer deposited on a glass slide. Gold metalization was deposited on the membrane, then patterned and, finally, an active device mounted on it. We report here the further development of this process into another alternative technology: a process that features thick, low-cost silver or copper metalization yielding low resistance E-plane circuits having the dielectric thickness of no more than 5 microns. The major development is the elimination of the need for a sacrificial layer thus enabling relatively higher conductivity metals to be used.

II. MEMBRANE-SUPPORTED E-PLANE CIRCUITS

Unlike silicon-based membrane realization technologies [1–4], realization of an optically smooth organic membrane as proposed in this paper can be achieved using relatively low temperature processing. The procedure reported here uses a thin photosensitive organic resin (EPON SU-8 or similar) [7,8] spun on to a silicon or glass slide to produce a membrane that has been fabricated by us with a thickness of 5 microns and with an optically flat surface. Unlike Gold, which is soft and expensive, copper is sufficiently tough and relatively cheap to be thickened to make the resulting membrane self-supporting. Additionally, copper and SU-8 do not react so that copper metalization can be used. On the other hands, sandwiching the metal between two layers of organic resin prevents oxidation.

The process permits processing of multiple-layers and opening of windows, thus enabling other variations of E-plane circuits to be formed. Active devices can be mounted on the backed-membrane before the final step of membrane lift-off, with all processing involving the active device are at low temperatures (at 90°C).

III. INSULATED/NON-INSULATED MEMBRANE-SUPPORTED E-PLANE CIRCUITS

The steps in the fabrication of insulated or non-insulated E-plane circuits are shown in Fig. 1. What follows is a description of the processing procedures in details.

1. The ultra-thin layer of photosensitive resin is first formed onto an optically smooth silicon slide, Fig. 1(a).
2. Metalization for the E-plane printed circuit is then deposited and patterned, Fig. 1(b). The metal is preferably copper or silver, both of which are highly conductive, and is thermally evaporated to a thickness enabling the whole fin to be self-supporting.
3. An active device can then bonded to the E-plane printed circuit as demonstrated in [6], Fig 1(c).
4. Another thin layer of photosensitive resin is spun onto the top of the printed circuit, Fig 1(d). This layer of resin, when left unexposed, can act as a temporary shield protecting the metalization from being attacked by the any etchant during the silicon removal and can be removed in the last stage to form a non-insulated E-plane circuits. Alternatively, this layer can be hardened by exposure to ultra-

0-7803-6540-2/01/$10.00 (C) 2001 IEEE

violet light so as to permanently form an insulated shield that facilitates DC-bias. This layer in both cases is typically 2 to 5 micron thick.

5. Next, the printed circuit is released by wet-etching the silicon slide with potassium hydroxide, Fig. 1(e).
6. The covering layer of photosensitive resin formed in step 4, if unexposed, can be finally striped off using organic solvent -butyrolactone (GBL) to form a non-insulated E-plane circuit, as shown in Fig. 1(f). Otherwise, the final E-plane circuit is insulated.

IV. EXPERIMENTAL RESULTS AND DISCUSSIONS

A range of membrane-supported E-plane circuits have been realized on a membrane of thickness around 8 μm, and two are described here: a finline resonator, and an E-plane bandpass filter. From a series of S-parameter measurements on these circuits, the transmission loss was found to be less than 0.4 dB/cm across W-band. Both insulated and non-insulated E-plane circuits exhibit similar performance, presumably due to the dielectric effects being negligible.

A finline resonator, as shown in Fig. 2, is mounted on one side of the split block waveguide. Fig. 3 presents the experimental characterization on a finline resonator. The Q-factor of the resonator, as reflected by the S_{21} of Fig. 3, is more than 100.

Fig. 5 presents the S-parameter measurement of an E-plane bandpass filter, shown in Fig. 4 with a passband insertion loss is around 0.5 dB.

The guide wavelength was found to be very close to the free space wavelength, suggesting that the dielectric effects on the E-plane circuit is virtually negligible. More importantly, matching the guide wavelength to the free-space wavelength considerably relaxes dimensional tolerances.

V. CONCLUSION

This paper presented a simple and low cost microfabrication method that enables E-plane circuits to be rapidly realized using organic-based processing. The final membrane-supported E-plane circuits are both optically smooth and self-supporting. It has been experimentally demonstrated that the technique can be used to realize low-loss membrane-supported E-plane components for millimeter wave and frequencies and can be extended to submillimeter-wave frequencies.

REFERENCES

[1] V. M. Lubecke, K. Mizuno, and G. M. Rebeiz, "Micromachining for terahertz applications," *IEEE Trans. Microwave Theory Tech.*, Vol. 46, pp. 1821–1831, Nov. 1998.

[2] R. M. Henderson, and L. P. B. Katehi, "Silicon-based micromachined packages for high-frequency applications," *IEEE Trans. Microwave Theory Tech.*, Vol. 47, pp. 1563–1569, Aug. 1999.

[3] M. Stotz, G. Gottwald, H. Haspeklo, and J. Wenger, "Planar millimeter-wave antennas using SiNx-membranes on GaAs," *IEEE Trans. Microwave Theory Tech.*, Vol. 44, pp. 1593–1595, Sept. 1996.

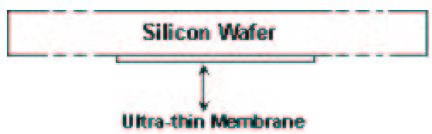
[4] G. Sajin, E. Matei, M. Dragoman, "Microwave straight edge resonator (SER) on silicon membrane," *1999 IEEE MTT-S Int. Microwave Symp. Digest*, pp. 283–286, June 1999.

[5] J. E. Harriss, L. W. Pearson, X. Wang, C. H. Barron, Jr., and A.-V. Pham, "Membrane-supported Ka band resonator employing organic micromachined packaging," *2000 IEEE MTT-S Int. Microwave Symp. Dig*., pp. 1225–1228, June 2000.

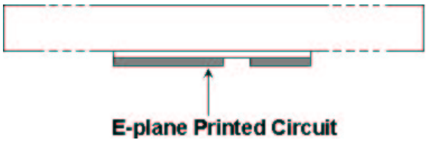
[6] W. Y. Liu, D. P. Steenson, and M. B. Steer, "Membrane-supported CPW, with Mounted Active Devices," accepted for publication in *IEEE Microwave and Guided Letters, 2001*.

[7] C. E. Collins, R. E. Miles, G. M. Parkhurst, J. W. Digby, H. Kazemi, J. M. Chamberlain, R. D. Pollard, N. J. Cronin, S. Davies, J. W. Bowen, and D. P. Steenson, "Use of novel photoresists in the production of submillimetre wave integrated circuits," *4th Int. Conf. on Millimeter and Submillimeter Waves and Applications, SPIE*, pp. 108–109, July 1998.

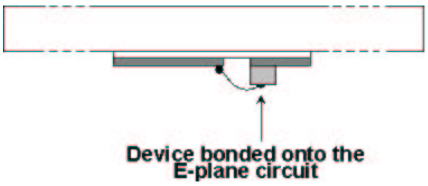
[8] J. W. Digby, C. E. McIntosh, G. M. Parkhurst, B. M. Towlson, S. Hadjiloucas, J. W. Bowen, J. M. Chamberlain, R. D. Pollard, R. E. Miles, D. P. Steeson, L. S. Karatzas, N. J. Cronin, and S. R. Davies, "Fabrication and characterization of micromachined rectangular waveguide components for use at millimeter_wave and terahertz frequencies", *IEEE Trans. Microwave Theory Tech.*, Vol. 48, pp. 1293–1302, Aug 2000.



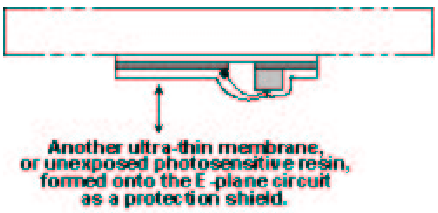
(a)



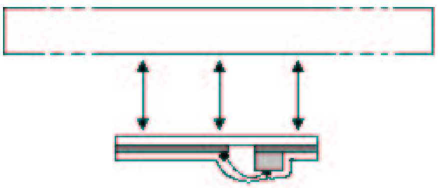
(b)



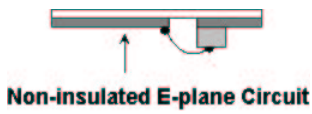
(c)



(d)



(e)



(f)

Fig. 1. Fabrication steps of insulated membrance-supported E-plane circuits with mounted active device.

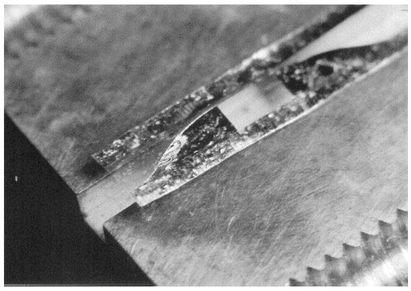


Fig. 2. Photograph of finline resonator of length 1.8 mm shown mounted in half of a split block waveguide, with metalalization of 5 microns thick

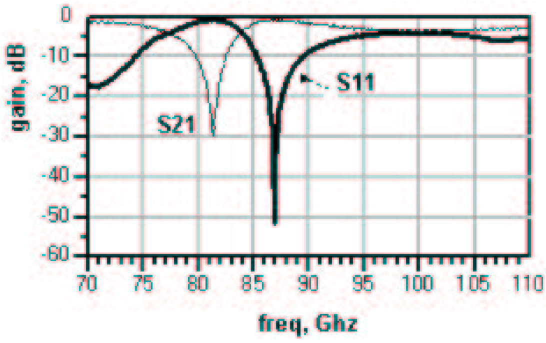


Fig. 3. Measured S-parameters of a finline resonator , with resonant frequency = 81.5 GHz, resonator length = 1.8 mm.

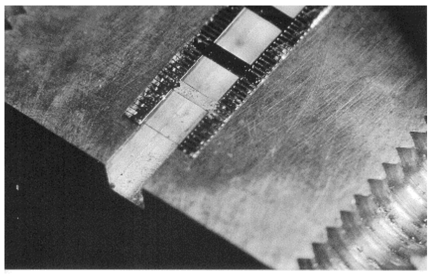


Fig. 4. Photograph of E-plane ladder bandpass filter shown mounted in half of a split block waveguide, with metalization thickness = 5 microns

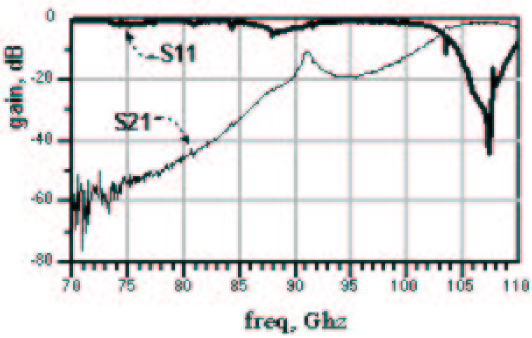


Fig. 5. Measured S-parameters of a bandpass filter with passband frequency centered at 107 GHz.