Polymer-Membrane-Supported Fin-line Frequency Multipliers

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Abstract This paper reports with experimental proof two polymer-membrane-supported fin-line frequency multipliers that generate from a microwave source a signal well beyond 100 GHz. The frequency multipliers were realized on a 7-micron thick polymer membrane in the absence of any steps involving thermal oxidation and low-pressure-chemical-vapor-deposition (LPCVD).

I. INTRODUCTION

In this paper we report the development of millimeter-wave frequency multipliers fabricated on supporting membranes. Microwave circuits fabricated on membranes have two important attributes that distinguish them from the more typical microwave circuits. Membranes have the essential property that they have very low mass and consequently the membranes have very little impact on electrical performance as they do not perturb fields by an appreciable amount. Thus membrane-supported circuits have relative dielectric constants very close to unity and negligible dielectric loss. These related properties have beneficial effects for millimeter-wave circuits where typically dielectric loss dominates the loss mechanisms and also the physical dimensions are larger than would be required if solid substrates were used. Circuit loss is increasingly dominated by conductive (dielectric) loss mechanisms at higher microwave and millimeter-wave frequencies. This is because resistive loss is dominated by the skin effect and increases roughly proportional to the square root of wavelength whereas dielectric loss mechanisms increase approximately linearly with frequency.

Circuits, whether they are fabricated at microwave, millimeter-wave or higher frequencies have dimensions ideally corresponding to electrical lengths. Functionality in microwave circuits can be characterized as involving transmission line structures with electrical lengths relative to a quarter-wavelength. Obtaining the same functionality at higher frequencies would ideally require scaling so that electrical dimensions remained constant and so physical dimensions would reduce proportional to wavelength. Unfortunately this is not achieved as for one the size of active devices does not scale proportionally and it becomes increasingly difficult to machine and fabricate very small circuits. One consequence of this is that millimeter-wave circuits have electrical dimensions larger than those at microwave frequencies and hence the electrical signal is exposed to dielectric loss mechanisms for longer periods. Achieving lower dielectric constants enables electrical lengths to be larger than they otherwise would be and hence the dielectric loss mechanisms become less significant.

A secondary reason for the emphasis on developing membrane-based fabrication technology is the effort to develop ultra low-weight microwave circuits. Membrane-supported circuits will be important in space-based applications of microwave and millimeter-wave circuits where weight has a dramatic affect on launch costs and hence overall system cost [1]. In the not too distant future large arrays of microwave radiators will be required to beam energy collected in orbit to terrestrial receivers. Our work in membrane-based microwave circuits is in part directed towards the cost effective realization of such systems.

Membrane-supported circuits have been well known for their negligible dielectric losses, low dispersion and almost free-space electrical wavelengths leading to relaxed dimensional tolerances in millimeter-wave and submillimeter-wave circuit design. However, most published membrane-supported planar circuits were processed on a silicon nitride thin film or gallium nitride, both

0-7803-7458-4/02/$17.00 @ 2002 IEEE

of which require expensive and time-consuming steps, such as low-pressure-chemical-vapor-deposition (LPCVD) and deep etching. In order for the merits of membrane-based technologies to be accessible at a lower cost, several polymer-membrane-based micromachining technologies [2–7] have been published as alternatives to silicon-based membrane processing methodologies. Previous work has demonstrated a metal-on-membrane board technique (originally called copper-on-membrane board in Ref [7]) that allows a planar circuit to be rapidly realized on a polymer membrane of thickness less than 10 microns using low-cost lithographical processing equipment. The idea of metal-on-membrane boards resembles Duriod-based printed wiring boards (PWBs) for E-plane millimeter-wave circuits supported on membrane in waveguide. Boards can be pre-fabricated and stored and used as required in much the same manner that PWBs are. More importantly, the membrane itself can be manually cut or photolithographically tailored and this permits direct opening of windows on the membrane. This paper further demonstrates with experimental proof the millimeter wave applications of metal-on-membrane board technology through two examples — two frequency multipliers generating a signal at frequencies beyond 100 GHz from a microwave sources.

II. PRODUCTION OF PRINTED CIRCUITS WITH METAL-ON-MEMBRANE BOARD

The concepts of metal-on-membrane board specific to fin-line applications are summarized in this section. The metal-on-membrane board, as shown in Fig. 1, is pre-coated with a thick layer of good conductor encapsulated between a 50-nano-meter thick shielding layer and a 7-micron thick SU-8 membrane. Underneath the SU-8 membrane is a lift-off layer that does not chemically intermix with the SU-8 membrane. The blank metal-on-membrane boards mounted on an optically smooth glass slide can now be stored for subsequent processing when the metal is patterned to realize a planar circuit. A membrane-supported millimeter wave circuit can be conveniently realized by photolithographically defining a blank metal-on-membrane board as described in [7]. In this publication we presented a technology for realizing membrane-supported microwave circuits using a concept analogous to printed wiring board (PWB) manufacture where a stock of blanks boards is available for relatively low cost subsequent fabrication. This dramatically reduces one-off costs but also enable the cost efficiencies of high volume manufacture of stock, yet customizable, items.

The final membrane-supported printed circuit is then mounted in either metal waveguide or polymer waveguide realized in SU-8 using polymer-based microfabrication techniques as previously described [7].

III. EXPERIMENTAL RESULTS

Two membrane-supported frequency multipliers have been successfully realized on 7-micron thick membrane, Fig. 2, using the previously described membrane processing technique. In both implementations, a single-junction millimeter-wave diode with a junction capacitance of 0.05 pF (DMK2790 from Alpha Industries ™) was used to perform harmonic multiplication on a microwave signal in the absence of any DC bias. Fig. 2(a) shows a frequency multiplier that generates a W-band signal from a microwave source pumped at around 15 dbm. In this design, a W-band signal generated from the diode was filtered using a high-Q fin-line band-pass filter between the fin-line taper and the diode. The window opened on the membrane further enhanced the Q-factor of this band-pass filter. The best conversion loss (see Fig. 3(a)) was around 22.78 dB, obtained from the eight harmonic of a 13.5 GHz input (i.e. 108.21 GHz).

Fig. 2(b) shows another frequency multiplier that generates a G-band output from a microwave source. Fig. 3(b) shows the measured spectrum of the 10 th harmonic of an 18 GHz signal pumped at around 15 dbm. Although the exact conversion loss of this frequency multiplier cannot be confirmed presently, our initial experimental results suggest that the metal-on-membrane board technology can be used for realization of circuits operating at G-band frequencies.

IV. CONCLUSIONS

This paper has presented with experimental proof two polymer-membrane-supported fin-line multipliers, both of which successfully generated a signal well above 100 GHz from a microwave source. The multipliers were implemented using the metal-on-membrane board technology and fabricated on a 7-micron thick polymer membrane using conventional clean-room facilities in much the same manner as etching a PCB on a standard substrate. More importantly, the said metal-on-membrane board technology eliminates the need for any steps involving thermal oxidation and-low-pressure-chemical-vapor-deposition (LPCVD).

REFERENCES

[1] J. C. Lin, "Space solar-power stations, wireless power transmissions, and biological implications," *IEEE Microwave Magazine*, March 2002, pp. 36–42. (Also *IEEE Antennas and Propagation Magazine* Oct. 2001).

[2] W. Y. Liu, D. P. Steenson and M. B. Steer, "Membrane-supported copper E-plane circuits," *2001 IEEE MTT-S Int. Microwave Symp. Dig.*, Vol. 3, May 2001, pp. 539–541.

[3] W. Y. Liu, D. P. Steenson and M. B. Steer, "Membrane-supported CPW, with mounted active devices," *IEEE Microwave and Guided Wave Letters*, Vol. 11, Apr 2001, pp. 167–171.

[4] [3] W. Y. LIU, D. P. STEENSON AND M. B. STEER, "A technique of micromachining suitable for fabrication of submillimeter wave components," *Proc. SPIE 4088*, Sept 2000, pp. 144–177.

[5] W. Y. LIU, "Novel Technique of Thin Photoresist Micromachining for Submillimeter Wave Circuits," *Proc. SPIE* Sept 2000, pp. 4176–4128.

[6] W. Y. Liu, D. P. Steenson and M. B. Steer, "A Simple but novel technique of Micromachining for millimeter wave and submillimeter wave applications," *IWMF'2000 Workshop*, Oct 2000.

[7] W. Y. Liu, D. P. Steenson and M. B. Steer, "Organic micromachining techniques for mass production of millimeter-wave and submillimeter-wave planar circuits", *Journal of Microlithogrpahy, Microfabrication, and Microsystems*, Vol. 1, In Press.

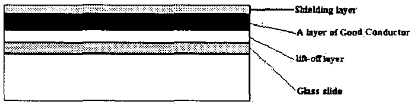
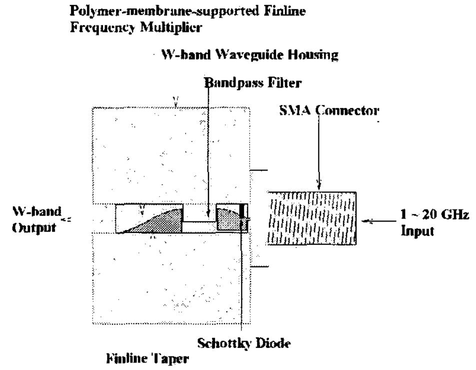
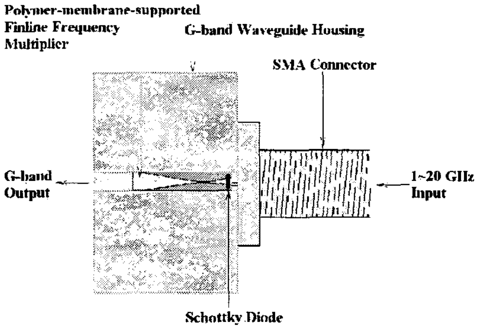


Fig. 1 Cross sectional view of single-sided metal-on-membrane board.

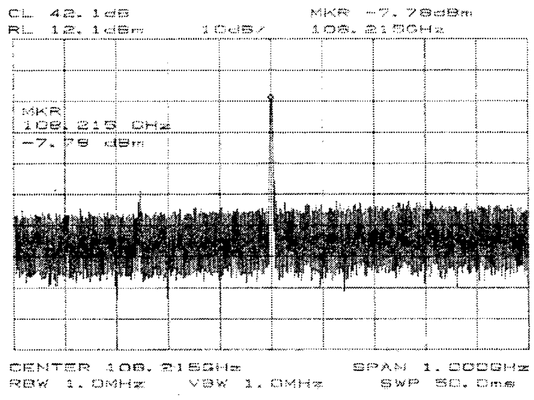


(a)

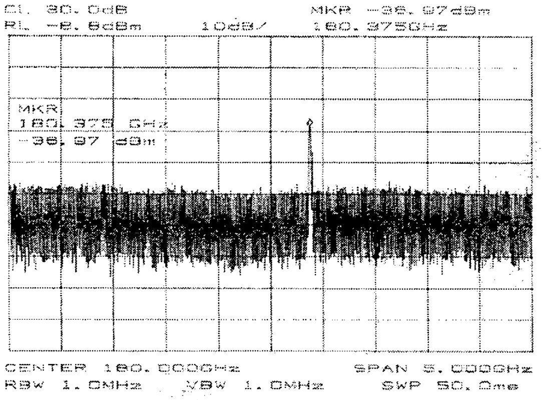


(b)

Fig. 2. (a) Polymer-membrane-supported fin-line frequency multiplier with output at W-band; and (b) polymer-membrane-supported fin-line frequency multiplier with output at G-band



(a)



(b)

Fig. 3. (a) Output spectrum of the Fin-line Frequency Multiplier shown in Fig. 2, when the input was pumped at 13.5 GHz, 15 dbm; (b) Output spectrum of the Fin-line Frequency Multiplier shown in Fig. 3, when the input was pumped at 18 GHz, 15 dbm.