PRACTICAL MICROMACHINING TECHNIQUES FOR HIGH ASPECT RATIO SUBMILLIMETER WAVE COMPONENTS

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Abstract- High-performance submillimeter wave circuits often require the use of extremely small three-dimensional waveguide and antenna components. While such components can be difficult and very costly to produce through conventional machining, cost-effective micromachining techniques offer an attractive alternative. The fabrication of 2.5 THz waveguide backshorts and 640 GHz dichroic plates through the use of thick UV-sensitive resin, are described. The technique is suitable for fabricating a wide range of submillimeter wave components, with aspect ratios in excess of 10:1.

INTRODUCTION

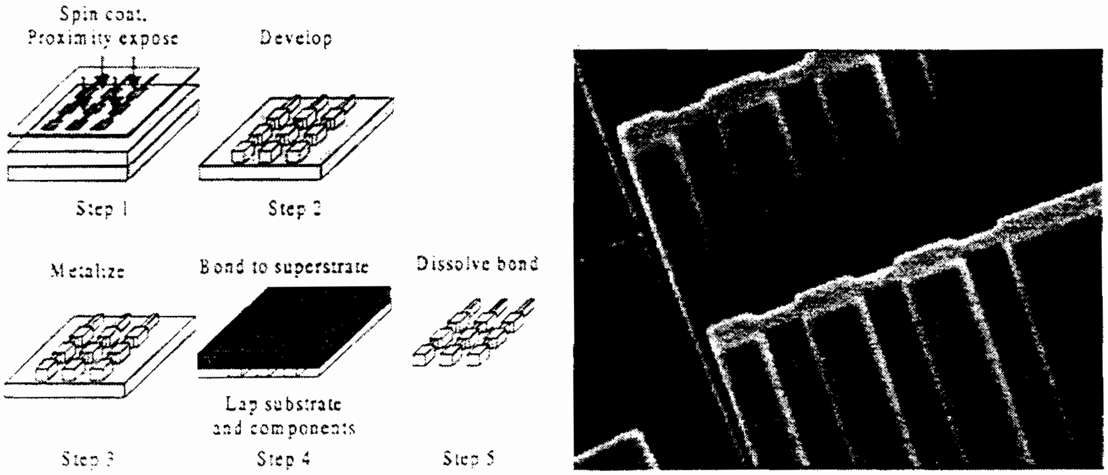
Waveguide technology has been used to produce a variety of high-performance millimeter and submillimeter wave circuits, such as sensitive mixers and efficient multipliers. Various scientific applications including radio astronomy and atmospheric remote sensing, have driven the demand for extending the application of this technology to increasingly higher frequencies. As the wavelength for these circuits reduces however, so do the critical dimensions for waveguide components. While such circuits can sometimes be realized through precision conventional machining and painstaking assembly, their usefulness is thus limited to specialty applications where high cost and limited production can be justified. Micromachining provides an attractive alternative, where highly developed photolithographic integrated circuit fabrication techniques are used for the cost-effective batch-production of components with three-dimensional characteristics.

The anisotropic etching, or *bulk micromachining*, of silicon has been used to form limited three-dimensional submillimeter wave antenna and waveguide structures [1-2], and forms of sacrificial layer, or *surface micromachining,* techniques used for semi-planar hollow millimeter-wave waveguide structures [3] and micromechanically adjustable submillimeter wave integrated circuit tuning elements [4]. Recently, the use of thick UV-sensitive curable resin has been proposed for the formation of waveguide channels of significant height and varied shape is a submillimeter wave mixer block [5]. Here the application of such a resin, the main ingredient of which is EPON SU-8 [6], is extended to the fabrication of ten-micron scale three-dimensional waveguide backshorts for a 2.5 THz mixer developed for atmospheric remote sensing [7], and relatively large diameter frequency selective mirrors, or *dichoic plates*, featuring a uniform pattern of hundred-micron scale holes, designed to quasi-optically isolate 640 GHz signals from 230 GHz signals in a multi-receiver radiometer system . Both have been proposed for the NASA EOS Microwave Limb Sounder [8].

2.5 THz BACKSHORTS

A waveguide backshort consists of a conducting shaft, which when inserted in a waveguide will establish an effective RF short circuit near its tip. A non-contacting backshort achieves this function through a patterned shape which alternately fills and empties the guide for quarter wavelength sections, to produce high/low impedance transitions. Signals incident at a transition are largely reflected, with the transmitted portion being coherently reflected at subsequent transitions. While this design does not depend on establishing or maintaining DC contact, it does depend on critical dimensions which become exceedingly small and difficult to realize for increasing frequency of operation. At 2.5 THz, the wavelength is 120 µm, and a half-height TE_{10} waveguide is 25 µm tall and 100 µm wide. A backshort for such a guide must nearly fill the guide for one section, and then significantly reduce in height for the next, with a repeating pattern.

The batch-process for fabricating the backshorts is shown on Fig. 1. A 120-µm coating of resin is spun onto a silicon substrate, and exposed to UV light through a shadow mask in close proximity to its surface. The unexposed resin is then dissolved in solvent, and the remaining structures and substrate are RF sputter-coated with 2000 Å of gold. The substrate and resin structures are then wax-bonded to a silicon superstrate, and the substrate and unwanted resin are removed with a dicing saw. Once



(a) (b)

Fig.1. Fabrication overview for the 2.5 THz waveguide backshorts (a), and SEM photograph of the process after developing. Cost-effective photolithographic techniques are used to batch process the three-dimensional high aspect ratio submillimeter components .

the desired *width* has been achieved, the backshorts are washed off in acetone an recovered in filter paper.

Examples of the resulting backshorts are shown in Fig. 2. The side-features of the backshorts accurately reproduce the mask pattern, with dimensions on the order of 10 µm, and the width is trimmed to about 90 µm. Manual assembly is required for integration with the mixer block, and RF tests are in progress.

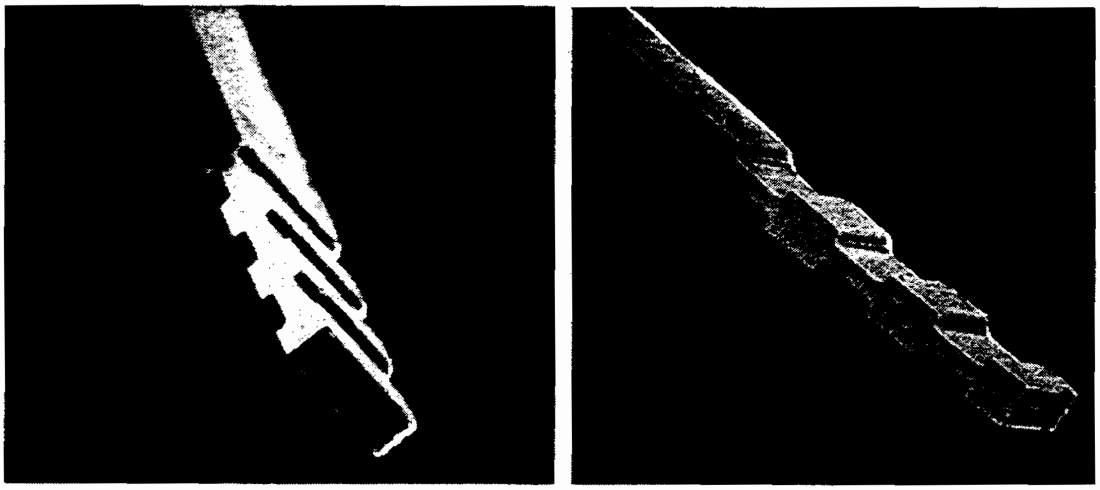

(a) (b)

Fig. 2. SEM photographs of end (a) and side (b) views of the completed 2.5 THz waveguide backshorts. The surface of the backshort tip is approximately 25 µm by 90 µm.

640 GHz DICHROIC PLATES

A submillimeter wave dichroic plate typically consists of a semi-thick conducting mirror, perforated with a closely packed array of waveguide apertures. The aperture dimensions determine the modes and frequencies that will be supported in the plate, and thus transmitted. The thickness of the plate determines the attenuation and rejection of signals below the cut-off frequency of the waveguide apertures. As the frequency of operation increases, the apertures become smaller, yet maintaining adequate thickness is critical for proper signal rejection. It may also be necessary to provide a relatively wide diameter to allow the plate to accommodate a broad beam over a range of incidence angles. The dichroic plates described here feature thousands of apertures with dimensions of 360 µm by 180 µm, and were designed to pass signals at 640 GHz (95% at up to 40° incidence), and reject signals at 230 GHz (~30 dB attenuation). The plate is 250 µm thick, and the perforated surface is 3.5 cm by 3.5 cm.

The procedure for fabricating the dichroic plates is shown in Fig. 3. While the same process used for the backshort fabrication could be applied, this modified process better accommodates the resolution requirements by minimizing process dependence on a highly collimated UV source. A 250-µm thick coating of resin is spun onto a transparent quartz substrate/mask, on the same side as the chrome mask pattern. The resin is exposed to UV light through the transparent parts of the mask, and the unexposed resin subsequently dissolved. The structure is then heat-cured, and the substrate is removed through etching or other convenient means. The resulting structure can be metalized through RF sputter-coating and additionally through electroplating if necessary.

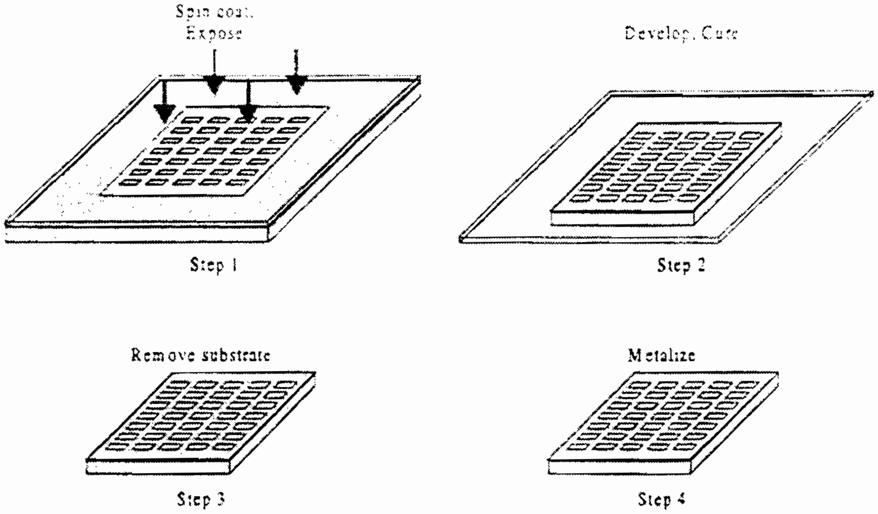


Fig. 3. Fabrication overview for the 640 GHz dichroic plates. The structure is formed directly on the mask to optimize resolution through the full thickness.

A dichroic plate fabricated by this technique is shown in Fig. 4 (a), and an SEM photograph of the aperture detail appears in Fig. 4 (b). To facilitate its application in a quasi-optical submillimeter wave system, the delicate plate can be clamped in an appropriate support structure. It is also possible to selectively remove only the center portion of the substrate, leaving the remainder to support metalized resin structure.

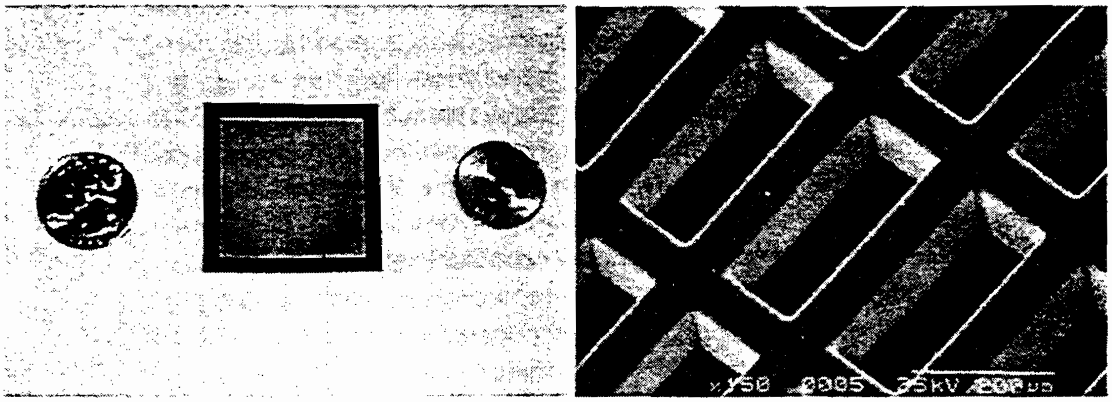


Fig. 4. Photograph of the metalized dichroic plate (a), and SEM of the hole-pattern detail. The plate, shown in comparison with American (quarter) and Japanese (100 yen) coins, is about 4 cm by 4 cm, 250 µm thick, with 360-µm by 180-µm holes.

CONCLUSIONS

The fabrication of submillmeter wave three-dimensional waveguide components through cost-effective micromachining techniques has been demonstrated. Waveguide backshorts for 2.5 THz, with all three dimensions on the order of tens of microns, were formed from a curable UV-sensitive resin. A similar technique was also employed to form a 250-μm thick 640 GHz dichroic plate, several centimeters in diameter and uniformly perforated by patterned holes on the order of a few hundred of microns. This fabrication approach is suitable for producing a wide range of millimeter and submillimeter wave discrete and integrated components, directly from the resin or in combination with electroforming techniques.

ACKNOWLEDGMENTS

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