MICRO-MACHINING IN SUBMILLIMETER-WAVE CIRCUITS

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Abstract—**Micro-machining technology has been used in submillimeter-wave circuits for more than ten years, but it is just beginning to appear in receivers on radio telescopes. A variety of rod, membrane, slot, and horn antennas have been demonstrated, together with hollow-metal guides and sliding shorts. Recently, a micro-machined waveguide receiver with a SIS junction on a 1-μm membrance has been demonstrated at 850 GHz with a DSB noise temperature of 450 K.**

INTRODUCTION

Micro-electromechanical Systems (MEMS) are a rapidly growing reasearch area, and are beginning to see large commercial markets in accelerometers for airbags, and blood-pressure sensors. A variety of sophisticated techniques have been developed for making membranes, flaps, pyramidal horns, and sliding structures by a combination of lithography, thin-film deposition, and etching. The size of these structures can be comparable to a wavelength in the submillimeter band, and the control of feature sizes is of the order of a micron. This makes MEMS micro-machining techniques quite suitable for submillimeter-wave integrated circuits.

ANTENNAS

The first application of MEMS to submillimeter-wave circuits was a tapered-rod antenna for a wavelength of 119μm in 1980 (Figure 1). This structure employed anisotropic etching of silicon for the rod, and a silicon-dioxide membrane for supporting a metal coupler. The detector was a bismuth microbolometer. This device had a well-defined directional beam, but only fair sensitivity, because of the bismuth microbolometer [1].

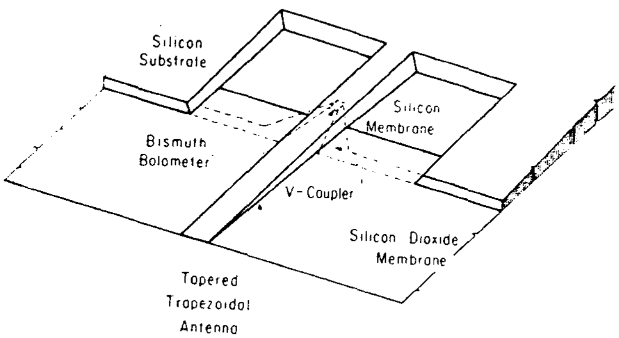

Figure 1. Diagram of a 119-μm silicon dielectric waveguide antenna with bismuth-film bolometer load [1].

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In 1987, Rebeiz *et al.* [2] demonstrated a thin-film metal antenna on a 1-μm thick silicon-oxynitride membrane. This approach eliminates the loss associated with a dielectric lens. The design was a wide-band log-periodic antenna that showed good patterns at 167 GHz, 370 GHz, and 700 GHz. A tunable reflector was added to make the radiation pattern single-sided. Later Ekström *et al.* [3] and Acharya *et al.* [4] developed this idea further to demonstrate tapered slotline antennas with end-fire beams at 348 GHz and 802 GHz. These antennas were made on silicon-oxynitride membranes that had a thickness chosen to control sidelobes, cross-polarization levels, and the symmetry of the beam.

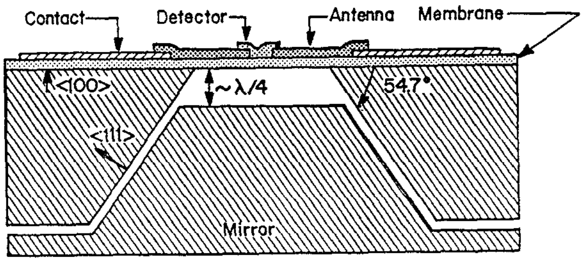

Figure 2. Antenna on a thin membrane with a reflector [2].

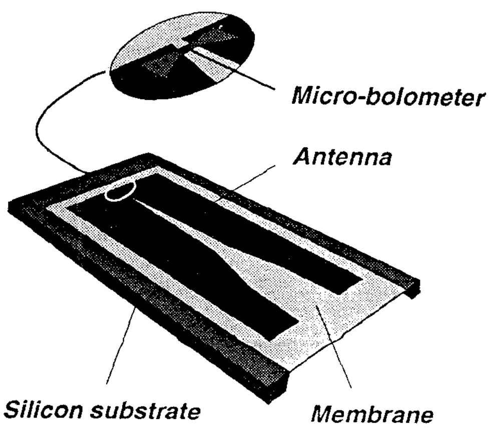

Figure 3. Linearly tapered slotline antenna on a silicon-oxynitride membrane for 802 GHz [4].

Rebeiz also led the development of antennas that employ anisotropic etching of silicon to make reflecting cavities, beginning with a pyramidal horn array at 242 GHz [5] in 1990 and continuing with an 802-GHz integrated horn array [6] and a corner-reflector imaging array in 1991 [7]. The horn arrays have dipole probe antennas that are suspended on a membrane inside the horn. These horn arrays are attractive because fully two-dimensional arrays can be made as a single planar circuit. Recently, de Lange *et al.* [8] reported excellent performance from a superconducting-tunnel-junction receiver using micromachined horns. The DSB receiver noise temperature was 30 K at 106 GHz, which is competitive with conventionally-machined waveguide receivers.

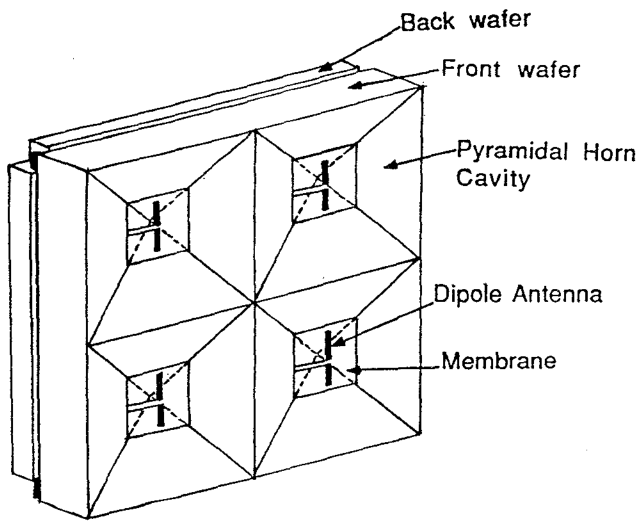

Figure 4. An integrated horn-antenna array with single polarization [6].

TUNERS

Much of MEMS research is oriented toward small mechanical structures with moving parts, but only recently has this technology been applied to submillimeter circuits. Lubecke *et al.* [9,10] demonstrated sliding planar backshorts for a tuning a 620-GHz antenna. These tuners slide along a coplanar waveguide, guided by polyimide frames. The tuners are made of plated gold, and a sacrificial layer of copper is etched out from under the gold to allow the tuners to slide freely. The tuners are electrically equivalent to a cascade of alternating high and low impedance quarter-wave transmission lines.

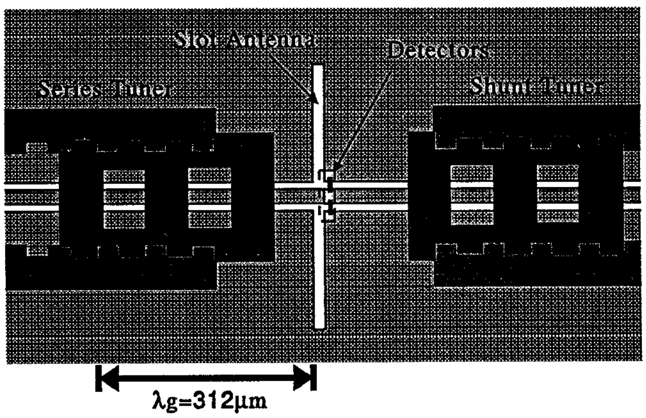

Figure 5. A slot antenna with two sliding shunt tuners for 620 GHz [9]. The tuners are positioned with the hair of an ox.

WAVEGUIDE CIRCUITS

MEMS techniques can also be applied in waveguide circuits. In addition to planar antennas and tuners, it is possible to make rectangular waveguides by micro-machining (110) oriented silicon substrates. This is actually rather difficult, because the mask alignment must be extremely precise. McGrath *et al.* showed that in the frequency range from 75 GHz to 115 GHz, the insertion loss was about 0.4 dB/λ_g, comparable to commercially available metal guides [11].

Recently a waveguide receiver with superconducting tunnel junctions has been demonstrated at 850 GHz [12]. In this receiver, the waveguides were made by conventional machining, but the SIS junctions were mounted on silicon-oxide and silicon-nitride membranes. This contrasts with previous work where the SIS junctions were mounted on quartz substrates. The problem with the quartz substrate is that substrate modes can be excited that ruin the filter response. Using thin membranes eliminates this loss. Kooi *et al.* measured an excellent receiver of 450 K DSB in the frequency range from 790 to 840 GHz at a temperature of 1.9 K [13]. This receiver is suitable for astronomical use in the atmospheric window from 780 GHz to 950 GHz.

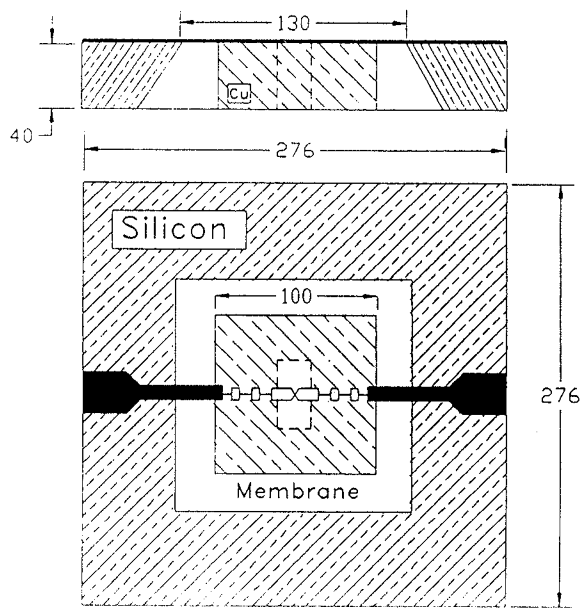

Figure 6. Superconducting tunnel-junction receiver on a insulating membrane with a silicon support structure [12]. The membrane rests on an optically polished flat copper block that acts as a ground plane.

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