348-GHz Endfire Slotline Antennas on Thin Dielectric Membranes

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***Abstract*—Tapered slotline endfire antennas, of BLTSA type, have been fabricated on 1.7-μm thin SiO_2–Si_3N_4 (ε_r = 4.5) membranes. Antenna patterns in the E-, H-, D- and D-cross planes have been measured at the design frequency 348 GHz, with bismuth micro bolometer detectors. The antennas have approximately 12 dB directivity, and the −10-dB beam widths are 50° and 56° in the E- and H-planes, respectively. The 348-GHz measurements have been compared with model measurements at 45 GHz, and show good agreement.**

I. Introduction

ENDFIRE slotline antennas on dielectric substrates are well suited, topologically as well as electrically, for integration with millimetre wave devices. They have low side lobe levels, reasonably high directivities (12–15 dB), and typically 40°–60° beam widths (−10 dB level). The antenna pattern is controlled by the antenna geometry, the thickness and the dielectric constant of the supporting dielectric. However, good performance requires that the thickness of the dielectric is kept below a certain value. The thickness (t) for optimum performance is approximately $t = 0.03\lambda\left(\sqrt{\varepsilon_r - 1}\right)^{-1}$ [1]. At THz frequencies, this thickness becomes only a few micrometers (assuming $\epsilon_r = 4 - 5$) causing considerable fabrication problems. A number of different slotline endfire antennas have been developed, see [1]–[3]. Here we have chosen to study yet another design called BLTSA (broken linearly tapered slotline antenna) [4]. The antenna is composed of three linear sections of different lengths, hence its name, see Fig. 1. The BLTSA has shown higher directivity and lower cross-polarized lobes in the diagonal planes (D-planes) than the other designs. It also requires smaller dielectric supporting area, which is mechanically favorable.

II. Fabrication

The 1.7-μm thick dielectric membrane consists of three layers, thermally grown SiO_2, LPCVD deposited Si_3N_4 and SiO_2. With compressive oxide and tensile nitride, the relative thickness of the layers could be selected to form a slightly tensile, and consequently flat and rigid membrane. The membrane layers were deposited on both sides of 385-μm thick silicon wafers. To form the membrane region for the antennas, the

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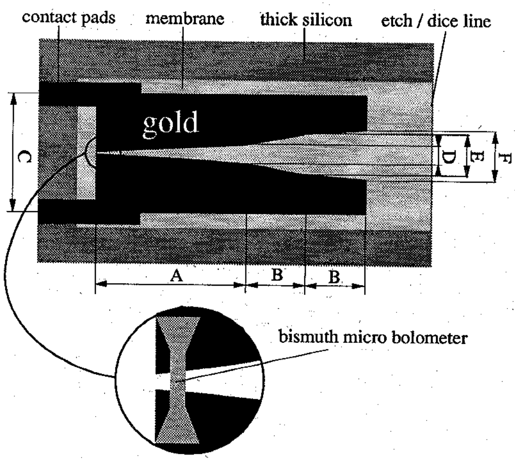

Fig. 1. BLTSA with bolometer on SiO_2–Si_3N^4 membrane. Dimensions of the 348-GHz antenna are A = 3.23 mm, B = 1.29 mm, C = 2.46 mm, D = 0.32 mm, E = 0.78 mm, F = 0.97 mm. Slot is approximately 10-μm wide at the bolometer, and the width of the bolometer is approximately 5 μm.

silicon was etched in EDP from the backside of the wafer, with the backside nitride and oxide layers patterned with the membrane layout and used as etch mask. The nitride and oxide layers on the front side acted as etch stops for EDP.

The slotline antenna requires that the membrane (3.18 × 7.7 mm^2) is left unsupported in the endfire direction. However, for stability reasons the antenna fabrication was performed on completely supported membranes. Slots/holes were then etched in the membranes in the endfire direction of the antennas before the wafers were diced. We found that the membranes were strong enough to allow carefully performed photo lithography. The antennas (chrome-gold), and the resistive room-temperature bismuth micro bolometers were thermally evaporated and patterned by lift-off.

III. Experimental Results

Antenna patterns in the E-, H-, D-, and D-cross-planes were measured at the design frequency, 348 GHz, as well as at 270 and 370 GHz, see Figs. 2 and 3 and Table I. The dynamic range in the measurements was approximately 20 dB.

At the design frequency, the side lobes of the E-plane were as low as −19 dB, which is approximately 9 dB lower than the side lobe levels in the H- and D-planes. The −10-dB beam width was narrowest in the D-plane (43°) and widest in the H-plane (55°). The antenna directivity and beam Gaussisity [4] were calculated to be ≈12 dB and ≈80% (not including the phase) respectively. In these calculations the side lobe levels outside the measured range were assumed to be −20

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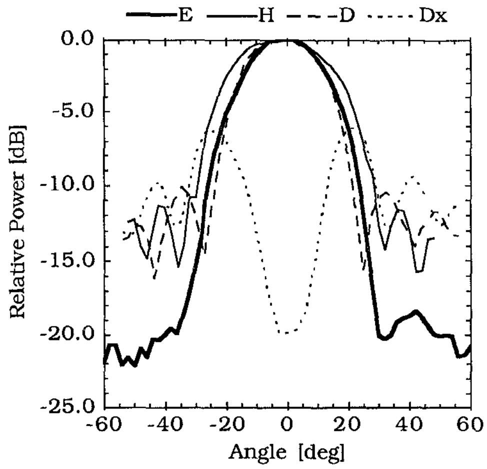

Fig. 2. Antenna patterns of the BLTSA 348 GHz design on SiO_2–Si_3N_4 membrane, measured at 348 GHz.

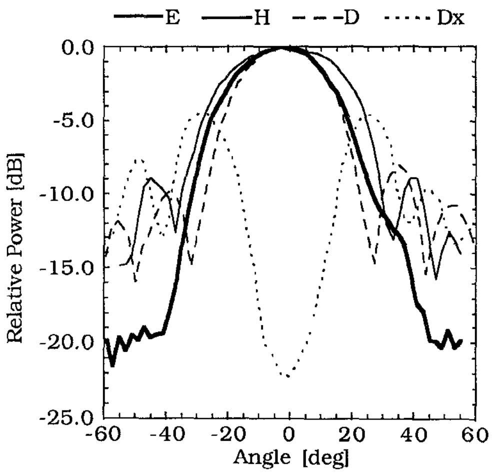

Fig. 3. Antenna patterns of the BLTSA 348 GHz design on SiO_2–Si_3N_4 membrane, measured at 270 GHz.

TABLE I
ANTENNA PATTERN DATA FROM MEASUREMENTS OF THE 348-GHz BLTSA DESIGN FABRICATED ON A 1.7-μm THICK SiO_2–Si_3N_4 MEMBRANE

Frequency		GHz	270	348	370
E-plane	10 dB beam width		59°	50°	49°
	side lobe level	dB	-12	-19	-19
H-plane	10 dB beam width		64°	55°	53
	side lobe level	dB	-8	-11	-11
D-plane	10 dB beam width		50°	43°	42°
	side lobe level	dB	-7	-10	-10
D-cross	lobe level	dB	-4	-6	-6.5
Directivity		dB	11	12	12

dB in the E-plane and -14 dB in the other planes. The back lobes were set to -20 dB. The high cross-pol level in the D-plane, which is inherent for tapered slotline antennas [5], was measured as -6 dB with respect to the co-polarized peak. From previous experience of operating the BLTSA closer to optimum dielectric thickness at frequencies from 30 to 45 GHz, the D-plane cross-pol level was expected to have been a couple of dB lower than -6 dB. we therefore assume that

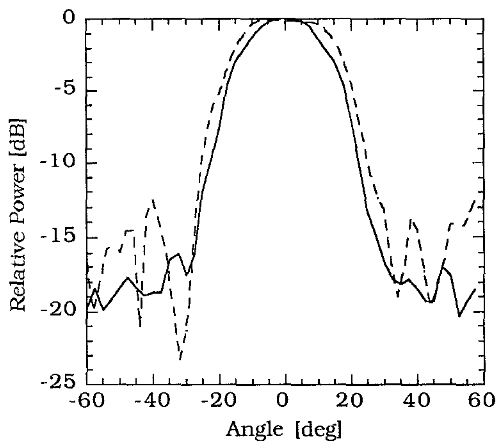

Fig. 4. Antenna patterns from scale measurments of the BLTSA at 45 GHz. Solid line is E-plane. and dotted line is H-plane.

the cross-pol level can be improved if the membrane is made thicker. Apart from the cross-pol level, scale measurements at 45 GHz with the antenna on 12.7-μm thick Kapton foil ($\epsilon_r = 3.5$) gave patterns with good agreement with the 348 GHz patterns, Fig. 4. Operating the 348 GHz antenna at 270 GHz resulted in increased side lobe levels, D-plane cross-pol levels and beam widths. It also gave slightly larger difference between the main lobe width in the D-plane, compared with those of the E- and H-planes. This less symmetrical beam at 270 GHz was due to thinner effective (t/λ) membrane thickness. Theory as well as 45, 270, 348 and 370 GHz measurements, and preliminary measurements at 802 GHz suggest, that scaling the design to terahertz frequencies should yield an even more symmetric beam pattern and still lower cross polarization.

IV. CONCLUSION

Endfire slotline antennas, of BLTSA type, have been fabricated and measured at 348 GHz. The slotline antennas were fabricated on thin (1.7 μm) SiO_2–Si_3N_4 membranes supported only along three sides, leaving the fourth side (in the endfire direction) unsupported. The 348-GHz antenna patterns are excellent and agrees well with 45-GHz model measurements. The SiO_2–Si_3N_4 membranes are somewhat too thin for optimum antenna performance at 348 GHz. It is expected that antennas designed for frequencies above 1 THz on these membranes will perform even better.

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