calculated data from previous attenuation calculations [1], [2], one should identify the given sheath transfer impedance as an effective value for that mode (e.g., $Z_T(ik)$ for the bifilar mode and $Z_T(ik_0)$ for the monofilar mode).

Using the method discussed recently by the authors [6], the influence of the Γ dependence on Z_T on the excitation factor of the desired bifilar mode was investigated. The results showed that the ratio of the excitation factor for the $Z_T(0)$ assumption was typically 6 dB higher than for either the $Z_T(\Gamma)$ or $Z_T(ik)$ assumptions. This is not surprising since the cable is less leaky in the latter cases. To some extent, this compensates for the decreased attenuation rates insofar as the total system loss is concerned. The important point is that the excitation factors calculated for an effective $Z_T(ik)$ never differ more than 2 dB from the Γ-dependent form $Z_T(\Gamma)$ (even for the worst case where $L_T = 40$ nH/m).

Not surprisingly, the calculated transmission characteristics for such problems will depend on the many details of the assumed model. The large number of parameters, even in such an idealized configuration, makes it extremely difficult to form a comprehensive picture of the overall phenomena. Nevertheless, it appears highly worthwhile to develop engineering design criteria that can be used to estimate system performance. Work on this subject continues.

References

[1] J. R. Wait and D. A. Hill. "Propagation along a braided coaxial cable in a circular tunnel," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-23, pp. 401–405, May 1975.
[2] D. A. Hill and J. R. Wait, "Propagation along a braided coaxial cable located close to a tunnel wall," *IEEE Trans. Microwave Theory Tech.*, to be published.
[3] M. I. Astrakhan, "Reflecting and screening properties of plane wire grids," *Radio Engr.* (USSR), vol. 23, pp. 76–83, Jan. 1968.
[4] D. A. Hill and J. R. Wait, "EM scattering of an arbitrary plane wave by a wire mesh with bonded junctions," *Can. J. Phys.*, vol. 54, pp. 353–361, Feb. 15, 1976.
[5] K. F. Casey, private communication, Kansas State University, 1975.
[6] D. A. Hill and J. R. Wait, "Calculated transmission loss for a leaky feeder communication system in a circular tunnel," *Radio Sci.*, vol. 11, pp. 315–322, Apr. 1976.

MIC Coupler with Improved Directivity Using Thin-Film Bi_2O_3 Overlay

R. N. KAREKAR AND MADAN K. PANDE

Abstract—**Results of the effect of thin-film Bi_2O_3 overlay on a directional coupler at X band are reported. Directivity between 14 and 23 dB was obtained over the band.**

The results obtained with a 12-dB directional coupler during the investigations on 3-layer microstrip, utilizing thin-film oxide overlay, are described. Fig. 1 gives the sketch of the directional coupler showing the type of the overlay employed.

Alumina substrates (0.025 × 1 × 1 in) metallized with 200 Å of chromium, 1000 Å of nickel and 3 μm of gold were used for this study. A 12-dB directional coupler was designed ($f_0 = 9.23$ GHz, $Z_0 = 50\ \Omega$) using data from the papers of Schwarzmann [1], Bryant and Weiss [2], and Wheeler [3]. A 3-percent undercut was allowed in the negative design. Care was taken to keep the uncoupled lengths from each port to the coupled region

Manuscript received February 10, 1976; revised May 5, 1976.
The authors are with the Department of Physics, University of Poona, Ganeshkhind, Poona, India.

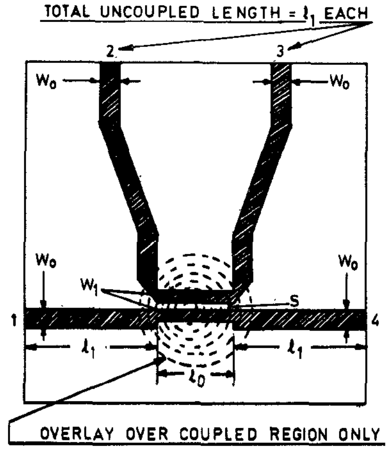

Fig. 1. Sketch of 12-dB directional coupler. Pre-etch geometry, $W_0 = 0.654$ mm, $W_1 = 0.619$ mm, $s = 0.3$ mm, $l_0 = 3.19$ mm.

the same (l_1), and to avoid performance degradation by reflections and mismatches at the transitions and the loads. At X band these port lengths reach the order of $\lambda g/4$ or more. Substrates with photolithographically delineated circuits were mounted in the vacuum deposition unit using masks which exposed mainly the coupled region to the Bi vapor stream. Bi_2O_3 overlay was obtained following the technique reported earlier [4], and based on our previous experience, the thickness of the overlays were chosen to be around 4000 and 9000 Å. The circuits were mounted on an MIC test fixture and connected to a Hewlett-Packard X-band sweep setup, using OSM transitions. The isolated port 3 was terminated with an OSM 50-Ω load cum launcher combination. On the other terminated port a precision OSM/HP 50-Ω coaxial load was used. Transmission measurements from ports 1–2, 1–4, and 1–3 were taken. A number of measurements were conducted to eliminate errors likely to be caused by imperfections of transitions and loads. The TDR display of the OSM launchers showed a resistive match; however, the loss due the use of the two OSM launchers was estimated to be about 0.5 dB. The readings without overlay have been obtained after stripping the oxide layer with dilute HCl. This was done to take into account change, if any, in metallization characteristics likely to be caused due to heat cycling.

The results of the transmission measurements are plotted in Fig. 2 for Bi_2O_3 overlays, along with the readings without overlay. The curves in Fig. 2 show negligible change in forward transmission (ports 1–4) and coupling (ports 1–2) with overlay. The isolation curve (ports 1–3) without overlay reflects a variation in directivity from 11 dB at 8.5 GHz to 4 dB at 12 GHz. A 1-dB increase in directivity throughout this frequency range was obtained with Bi_2O_3 overlay thickness of 3900 Å. When the Bi_2O_3 overlay thickness was increased to 8500 Å, the directivity increased to 23 dB at 8.5 GHz, gradually falling to 14.5 dB at 12 GHz. The isolation curves are approximately parallel to each other. Unfortunately, no return-loss measurements could be taken for want of a coaxial dual directional coupler.

It is of interest to note that in most bulk overlays [5]–[6], the thicknesses used are of the order of 0.125–2 H (where H is the substrate thickness) and it results in a directivity of 20 dB or more. The maximum thickness of overlay reported here is of the order 1.3×10^{-3} H. Further, this thickness is just 0.28 of the thickness of the microstrip conductors (3 μm). It is felt that negligible change in coupling, despite reasonable change in

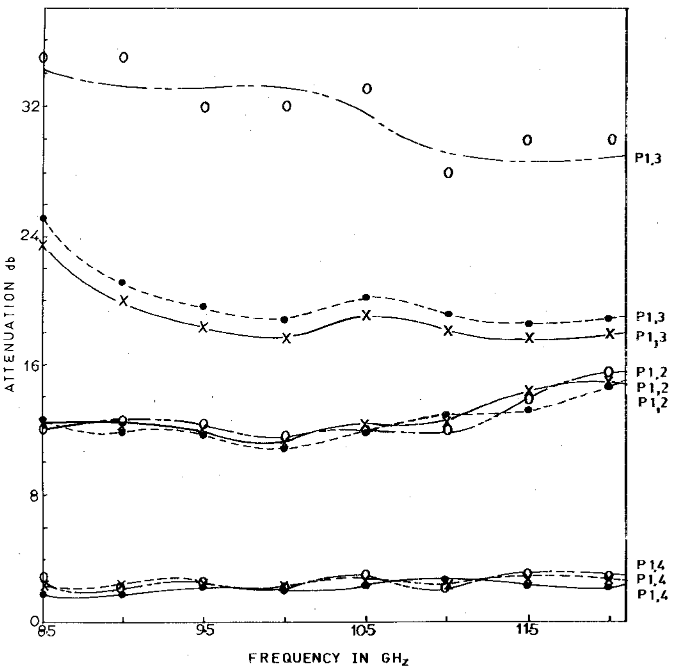

Fig. 2. Plot of transmission measurements ports 1–2 ($P_{1,2}$), 1–3 ($P_{1,3}$), and 1–4 ($P_{1,4}$) for the 12-dB directional coupler. Legend: -o- - - -o- with overlay of 8450 Å Bi_2O_3. - - • - - • - -with overlay of 3900 Å Bi_2O_3. —×— —×— without overlay.

isolation, may have been due to the presence of an air gap (though lesser now) between the two microstriplines in the coupled region and the consequent incomplete confining of the fringing field through the dielectric. It may be pointed out that no allowance was made for the change in impedance due to overlay and the effect of overlay on dispersion characteristics in the design of the coupler.

References

[1] A. Schwarzmann, "Approximate solutions for a coupled pair of microstrip lines in microwave integrated circuits," *Microwave J.*, pp. 79–82, May 1969.
[2] T. G. Bryant and J. A. Weiss, "Parameters of microstrip transmission lines and coupled pairs of microstrip lines," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-16, pp. 1021–1027, 1968.
[3] H. A. Wheeler, "Transmission line properties of parallel strips separated by a dielectric sheet," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-13, pp. 172–185, Mar. 1965.
[4] R. N. Karekar and M. K. Pande, "Effect of thin film Bi_2O_3 overlay on the quality factor of a microstrip resonator," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-24, pp. 262–264, May 1976.
[5] B. E. Spielman, "Analysis of electrical characteristics of edge coupled microstrip lines with a dielectric overlay," Naval Res. Lab., Washington, DC, NRL Report 7810, Oct. 25, 1974.
[6] G. Haupt and H. Delfts, "High-directivity microstrip directional couplers," *Elect. Lett.*, vol. 10, pp. 142–143, May 2, 1974.

Symmetry Experiments with Four-Mesa IMPATT Diodes

C. T. RUCKER, G. N. HILL, N. W. COX, AND J. W. AMOSS

***Abstract*—Experiments with four-mesa silicon p$^+$-n-n$^+$ IMPATT diodes have shown power saturation and reduced efficiency when connected and packaged in electrically asymmetrical configurations. The need for electrical symmetry is illustrated by experiments wherein seemingly trivial asymmetries caused severe saturation of the power output.**

Manuscript received February 6, 1976; revised May 3, 1976. This work was supported by the Air Force Avionics Laboratory.
The authors are with the Solid State Sciences Division, Engineering Experiment Station, Georgia Institute of Technology, Atlanta, GA 30332.

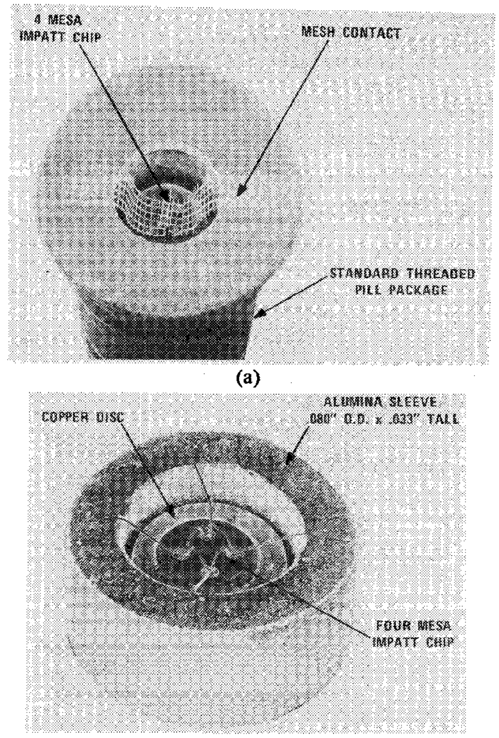

Fig. 1. (a) SEM of four-mesa IMPATT diode with mesh contact. (b) SEM of four-mesa IMPATT diode with multiple wire contacts (after Fig. 2, case IV).

Four-mesa IMPATT devices with integral plated heat sinks have become relatively common as a means of increasing power output (device area) without serious degradation of the device thermal properties [1], [2]. These devices are usually contacted in a symmetrical fashion using one or more gold ribbons, wires, or mesh segments. A typical configuration of this type is shown in the scanning-electron-microscope micrograph (SEM) of Fig. 1(a). During efforts to study the effect of impedance on efficiency very uniform four-mesa silicon p$^+$-n-n$^+$ devices were tested in a somewhat different configuration [Fig. 1(b)] with one, two, three, and then all four mesas connected. The resulting total junction capacitances at breakdown were 0.22, 0.44, 0.66, and 0.88 pF, respectively. For the devices used no change in efficiency was observed if the current density remained constant.

More significantly, these tests provided an unexpected insight into the operation of parallel chips. The initial mesa connections were made as shown in Fig. 2, cases I–IV. All the sketches of Fig. 2 represent various modifications of the detailed construction shown in Fig. 1(b). Cases I, II, and IV behaved exactly as expected giving one, two, and four times the power expected from one mesa at the same current density. Case III did not behave as expected. Instead, this case saturated at less than half the appropriate current density. The saturation was characterized by noisy output and broad-band noise between 0 and 2.0 GHz, but coherent spurious outputs were not observed. Case III was modified as shown in III-A where the diagonal interconnecting wire was added. This change, to a more symmetrical arrangement, resulted in satisfactory operation at higher current but satura-