FABRICATION OF AIR-BRIDGES FOR MILLIMETER WAVE INTEGRATED CIRCUITS

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ABSTRACT

High frequencies and sub-micron geometries inherent in today's millimeter wave integrated circuits mandate utilization of low capacitance cross-over structures such as the air-bridge. A silicon based aluminum air-bridge fabrication process is described. The structure and capacitances associated with these aluminum air-bridges was evaluated for potential use in the fabrication of integrated circuit acoustical disturbance sensors.

INTRODUCTION

In the last few years much interest has arisen for the research and development of technology for the fabrication of millimeter wave integrated circuits. Possible applications include utilization in the areas of radar,communication, and wideband electronic warfare [1].

Conventionally, substrates such as GaAs and InP have been implemented in the fabrication of millimeter wave integrated circuits [2], but silicon based technology for millimeter wave applications has also been recently researched [3].

As technology pushes the operatinal range of integrated circuits to yet higher frequencies and into the realm of sub-micron dimensions, the need for low capacitance cross-over structures in the various metallization schemes has arisen. One such cross-over is the air-bridge.

The air-bridge consists of a higher level metal line traversing a lower level metal line. The air gap is due to the absence of an interlevel dielectric support where the lines actually cross. In short, the higher level metal line forms a bridge over the underlying line by coming off of the substrate.

The use of air as the interlevel medium, as opposed to a dielectric such as polymide, reduces the capacitance inherently associated with two conducting "plates". The reduction in capacitance results from the relative permittivity of air, 1.0, being less than that of an interlevel dielectric, usually in the 2.0 to 3.0 range. The capacitance between two plates is given by the following equation [4].

$$C = (e\ A)/D$$

The area of the capacitor plates (cross-over area) is denoted by A, e is the permittivity of the interlevel medium (resist or air), and D is the distance between the first and second metal lines forming the air-bridge structure. The area which yields the capacitance due to the bridge is shown in Figure 1.

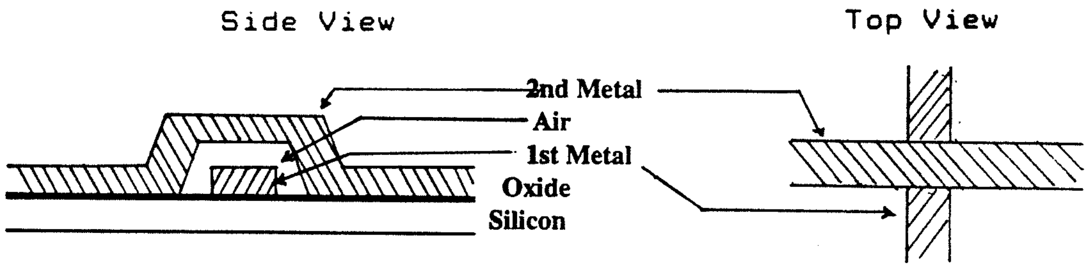

FIGURE 1: Capacitance Inducing Structure.

The characteristic of the air-bridge which makes it a rather unique candidate for an integrated ciruit acoustical disturbance sensor is the fact that as the span dimensions, length and width, of the bridge increases with respect to the thickness, flexing of the span can be promoted when subject to an acoustical disturbance such as compression or decompression. This resulting vibration varies the distance between the two metal lines which, in turn, inversely affects the resulting capacitance.

Typically, air-bridge structures are composed of a gold film utilizing a titanium-tungsten barrier layer to prevent the diffusion of gold into the GaAs substrate [5]. The process developed here utilizes an all aluminum bridge structure in order to keep processing to a minimum.

EXPERIMENT

A test chip, shown in Figure 2, was designed using the CAD program ICE, the Integrated Circuit Editor developed at RIT. The chip consisted of four quadrants each serving a specific function. Quadrant 1 (upper left) consisted of an assortment of air-bridges of varying dimensions, from 10 to 50 microns wide spanning 50 to 70 micron distances. Quadrant 2 (upper right) contained structures to check the ability of turning in mid-air. Quadrant 3 (lower left) was composed of Mesa to Mesa and serpentine air-bridge structures. Quadrant 4 consisted of 30 and 60 micron wide bridges spanning 50 to 170 micron distances. These were used to measure any possible size to capacitance relationships.

The test structures in Quadrant 1 served only to see if a large number of air-bridges could be fabricated successfully. Capacitance values of this large array were not calculated as the only result desired was having no shorts or opens. Quadrant 2 yielded information as to the performance and ability of turning air-bridges. Quadrant 3 was constructed without any "capacitor" structures while Quadrant 4 was created to check capacitances and span capabilities.

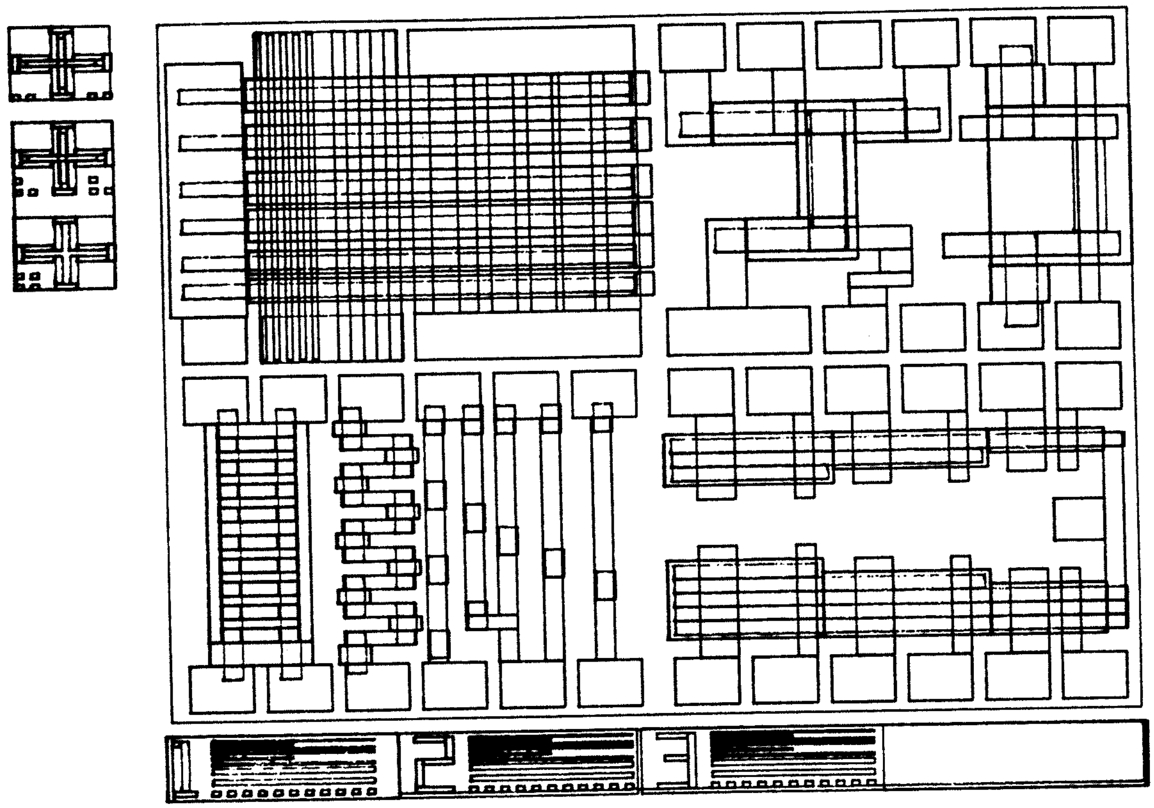

FIGURE 2: ICE Design Test Chip.

The air-bridge test structures were fabricated on oxide over silicon to insulate the bridges. The first metal layer was thermally evaporated to a thickness of 4300 angstroms. Patterning was accomplished using KTI-820 positive photoresist with a Kasper aligner as the exposure tool. The dielectric structures consisted of KTI-820 resist at a thickness of 1.1 um. Patterning was similar to that for the metal layer with the same exposure due to the support structures being predominantly over the first metal lines. Hard-baking of the support structure pattern was identical to that used for the first metal lithography to observe if standard processing of the resist would create supports capable of withstanding the evaporation process. The second metal was process- ed similar to the first.

After the second metal was patterned initial capacitance measurements were made, with the support resist intact,using a Princeton Applied Research Model 410 high frequency capacitance-voltage plotter with the d.c. value set to zero.

The wafers were then plasma ashed for a total of 15 minutes to insure complete removal of the resist support structures. After plasma ashing a few bridge structures were randomly torn away, using a probe, while being observed under a microscope to validate that all the supporting resist was indeed removed.

Figure 3 shows the process steps for creating standard air-bridges and Mesa to Mesa air-bridges.

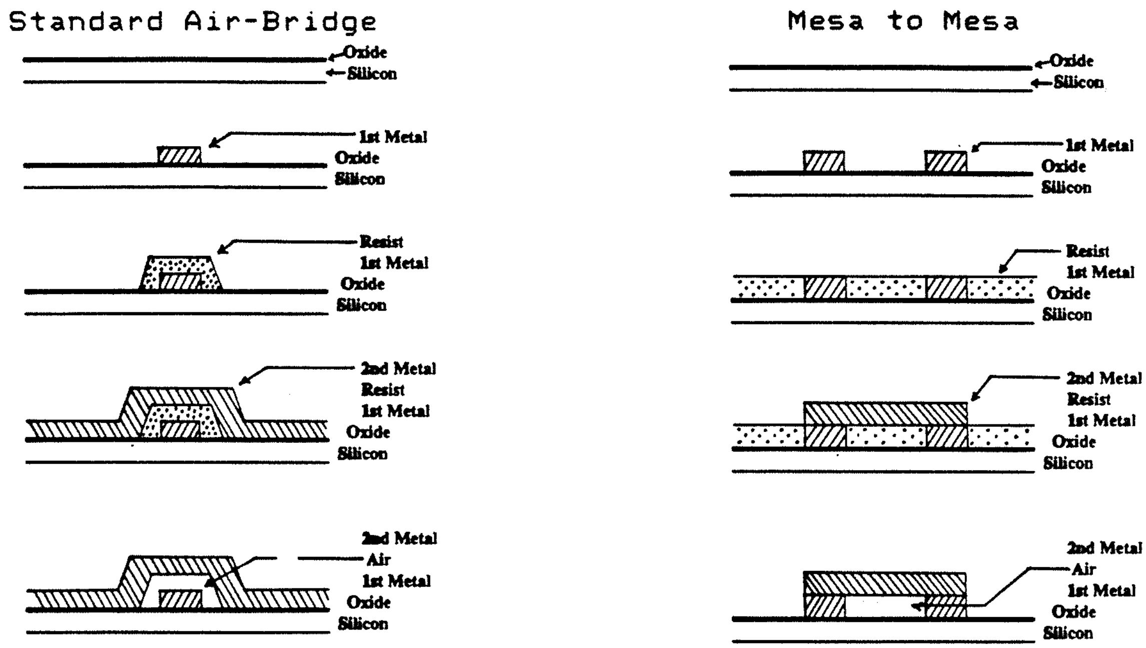

FIGURE 3: Process Diagrams of Air-Bridges.

RESULTS/DISCUSSION

Table 1 show the calculated capacitance values of the air-bridge structures, if applicable, as well as the average measured values and range. Permittivity of the resist was approximated at 2.72.

TABLE 1		Area	Theoretical Capacitance (pf)		Measured Capacitance (pf)	
Quad.	#	(10e-6cm2)	(with resist	w/o)	(with resist	w/o)
1	1	N/A	N/A		11.9	3.56
1	2	N/A	N/A		7.82	9.81
2	1	213	.467	.171	1.96	2.85
2	2	152.5	.334	.123	1.17	2.03
4	1	9	.019	.007	.67	.97
4	2	18	.038	.014	.72	.94
4	3	18	.038	.014	.73	.99
4	4	36	.079	.029	.70	.99
4	5	27	.060	.022	.63	.93
4	6	54	.117	.043	.69	1.10
4	7	90	.196	.072	.98	1.34
4	8	45	.098	.036	.89	1.02
4	9	72	.158	.058	.77	2.07
4	10	36	.079	.029	.73	1.44
4	11	54	.117	.043	.78	1.47
4	12	27	.060	.022	.69	1.55

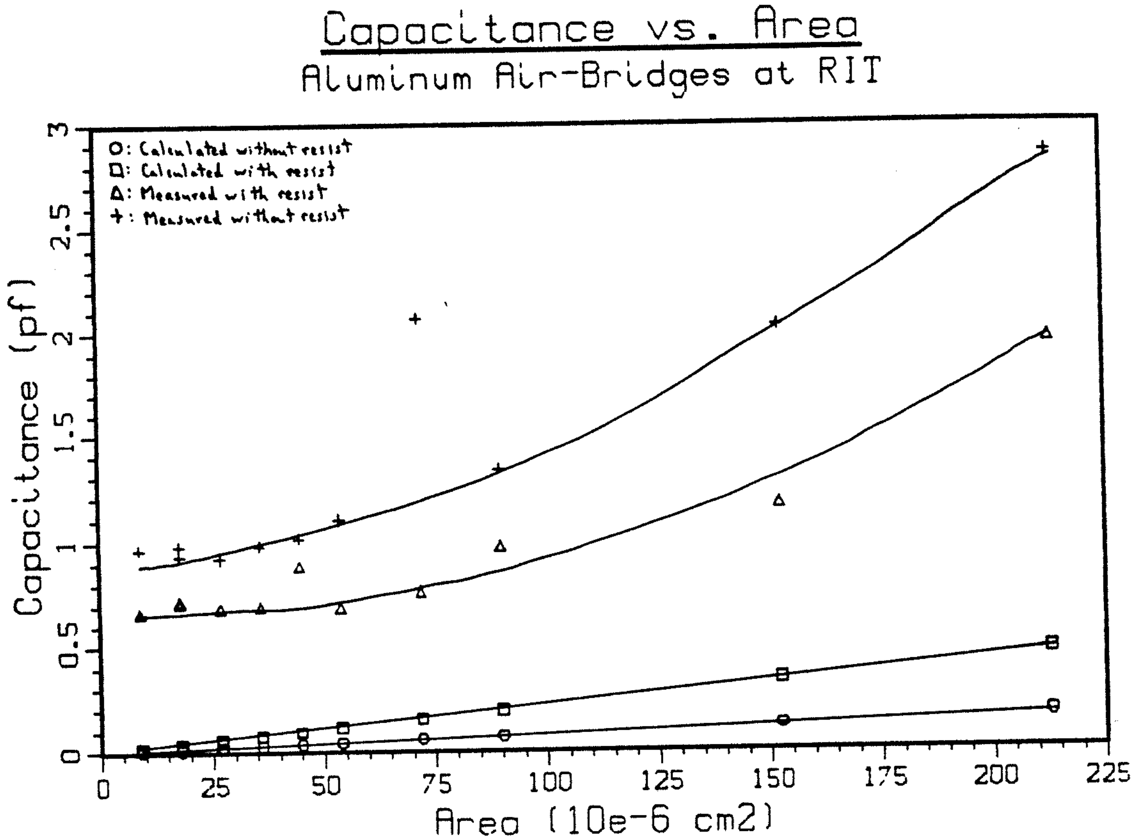

FIGURE 4: Capacitance vs. Size of Air-Bridge.

A plot of the data gathered regarding the capacitance versus size relationship is shown in Figure 4. The plot shows the theoretical as well a measured relationships. The theoretical values show a linear dependence due to the variation of the area of the bridge only. The difference of the slopes for the curve of theoretical with resist and without resist is due to the relative permittivity factor being 1 for no resist present and approximately 2.72 with resist. The curves of the actual values indicate the effects of possible stray capacitances incurred in the probe leads. Another factor that may contribute to the discrepancies observed could be variations in the distance between the first and second metal lines, D. This variation could arise from the sagging of the second metal line due to its length to thickness ratio. This assumption of sagging appears to be relatively well supported by the upward curve of the measured value plots. This upward curve is indicative of a faster increase in the slope which infers a more rapid increase in related capacitance as the size of the bridge "capacitor" increases. Also the presence of undulations in the spans after removal of the support resist is a contributing factor.

Functioning as an acoustical disturbance sensor, of possibly a miniature microphone, it was found that the capacitance did vary when the air-bridges were subject to an acoustic disturbance such as a loud voice or gust of air. Changes in capacitance have been measured ranging from 3.7% of the original value to a 471% increase with the average being 44%.

CONCLUSION

The process developed for creating aluminum air-bridges has shown that air- bridge structures can be fabricated at RIT using established process steps. The air-bridges fabricated can span distances up to 170 microns (the upper limit of this study) and can turn in mid-air. The capacitances obtained after the removal of the resist support structures suggests that a host of other factors influence the values obtained for the finished structures. Further research in this area is required to achieve production worthy air-bridge structures. Possible avenues for study include thickness of the actual spans and bimetal construction.

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REFERENCES

[1] Binari, Neidert, Keiner, and Boos, J.B. "Millimeter-Wave Passive Circuit Components". RCA Review. Vol. 45, December 1984. pp. 579-586.

[2] Niedert, R.E. and Binari, S.C. "mm-Wave Passive Componenets for Monolithic Circuits". Microwave Journal. April 1984 pp. 103-120.

[3] Stabile, P.J. and Rosen, A. "A Silicon Technology for Millimeter-Wave Monolithic Circuits". RCA Review. Vol. 45, December 1984. pp.587-605.

[4] Pierret, R.F. Modular Series On Solid State Devices, Volume 4: Field Effect Devices. Addison-Wesley Publishing Company. Reading, Mass. 1983. pp.43-47.

[5] Andrade, T. "Manufacturing Technology for GaAs Mololithic Microwave Integrated Circuits". Solid State Technology. February 1985. pp. 199-205.