Conformal Thin Film Packaging for SiC Sensor Circuits in Harsh Environments

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***Abstract* — In this investigation sputtered silicon carbide annealed at 300°C for one hour is used as a conformal thin film package. A RF magnetron sputterer was used to deposit 500 nm silicon carbide films on gold metal structures on alumina wafers. To determine the reliability and resistance to immersion in harsh environments, samples were submerged in gold etchant for 24 hours, in BOE for 24 hours, and in an O_2 plasma etch for one hour. The adhesion strength of the thin film was measured by a pull test before and after the chemical immersion, which indicated that the film has an adhesion strength better than 10^8 N/m^2; this is similar to the adhesion of the gold layer to the alumina wafer. MIM capacitors are used to determine the dielectric constant, which is dependent on the SiC anneal temperature. Finally, to demonstrate that the SiC, conformal, thin film may be used to package RF circuits and sensors, an LC resonator circuit was fabricated and tested with and without the conformal SiC thin film packaging. The results indicate that the SiC coating adds no appreciable degradation to the circuits RF performance.**

***Index Terms* — Sputter, silicon carbide, MIM capacitors, LC resonators, gold etchants, BOE, O_2 plasma.**

I. Introduction

Wireless sensor systems for harsh environments require packaging technologies that are mechanically and chemically robust. The capability to fabricate the package using the fabrication processes of the RF circuits offers great advantage in reducing the package size and cost. Also, the package should not degrade the RF performance of the circuit. Most conventional packaging approaches require extra manufacturing steps to complete the packaging process and are not chemically resistant [1-3]. However, thin film technologies offer such solutions.

A conformal coating of Parylene C used to encapsulate MEMS devices was tested for reliability by die shear testing after thermal shock stressing and 85 ºC/85% RH aging, which indicated poor adhesion in areas [4]. Another group coated metal lines with Parylene and submerged them in a heated bath (55ºC) of isotonic saline for a period of 5 months [5]; the experiment showed that the impedance of the lines did not change significantly over the duration. Low dielectric constant Benzocyclobutene (BCB) was used to coat IC chips and passive components in an embedded silicon substrate [6].

PECVD silicon carbide (SiC) was demonstrated as a thin film packaging technology for microfabricated planar antennas [7]. The antennas were tested with and without the SiC coating and no difference in antenna performance was noted. The coated antennas were submerged in etchants for over 24 hours and no physical degradation was found. Sputtered SiC was also used as a thin film packaging solution for planar antennas on LCP [8]. The antennas were measured with and without the thin film coating and no change in RF performance was found. The films were also subject to chemicals and no change in the film was noted, but adhesion to Au was poor and a Cr adhesion layer was required.

In this study a magnetron RF sputterer was used to deposit a 500 nm thick SiC thin film. The thin film was deposited on patterned gold structures and gold coated surfaces. A range of experiments were performed including etches and adhesion tests to determine the reliability of the films. Also metal-insulator-metal (MIM) capacitors were fabricated using the thin film as the insulator to determine how temperature affects the dielectric constant (ε_r). Lastly, to prove the SiC thin film can be used as a conformal packaging technology for RF wireless circuits and sensors, an LC resonator was developed and measured with and without the SiC coating and anneals.

II. Experimental Procedure

Several experiments were designed to accurately characterize the sputtered SiC thin film. Nine two inch square alumina wafers (doubled sided polished) 500 µm thick were used. Metal lines made of Cr/Au (25/500 nm) were fabricated and patterned using an etch back process on 5 of the wafers. Four of the wafers were covered completely with the Cr/Au metal layer of the same thickness. SiC was sputtered on all the wafers at 300 W. The wafers were then annealed at 300 ºC for 1 hour. On the 4 wafers with completely metalized surfaces, the SiC was patterned with a checkerboard layout, which resulted in every other square on the wafer having an exposed metal surface. All nine wafers were then diced into four 1 inch^2 samples for a total of 36 samples. All 36 samples were then weighed and the thicknesses measured with a

Dektak profilometer of the deposited sputtered SiC layers were recorded. Microphotographs were taken at specific locations on each sample.

The samples were then subject to several types of etchants. The etches consisted of a 24 hour BOE, a 24 hour Au etch (potassium iodine), a 24 hour TMAH etch and a 1 hour O_2 plasma etch (at 300 W). For repeatability, 4 of both the patterned metal structure and the checkerboard samples (total 8 samples) were used for each experiment, except for the Au etch where only 4 samples with patterned metal lines were used and the TMAH etch where only 4 samples with the checkerboard pattern were used.

After the etches were completed, the samples were weighed, the thickness of the SiC was recorded and microphotographs were taken in the same locations as before etching to make a before and after etch comparison. One sample from each etch test, except TMAH, was selected and a layer of Au (50 nm) was deposited across the entire surface of the samples for SEM imaging to verify the conformal coating.

A pull test [9] to determine the adhesion properties of the SiC film was performed on all of the samples, except for the samples that were set aside for SEMs. MIM capacitors were fabricated and measured before and after the anneal to determine how temperature affects the ε_r of the film. Lastly, an LC resonator was fabricated and measured with and without the SiC coating.

III. MEASURED RESULTS

The average weight and SiC thickness difference of the 4 samples of each type before and after each etch are shown in Table 1. The change in weight before and after etching is insignificant except for the samples that were exposed to the BOE, where the weight increased slightly. This is believed to be due to measurement error. The thickness increased slightly but by no appreciable amount and is believed to be due to the formation of an oxide as the samples were not properly stored and exposed to environmental conditions.

Table 1: Weight and thickness change after etching.

Average Change per Sample	Weight (mg)	Thickness (nm)
Reference	0.02	7.2
O2 1hr	-0.59	24.6
BOE 24hr	2.11	7.775
Au etch 24hr	-0.88	N/A
TMAH 24hr	0.00	5.55

Microphotographs were taken before and after etching the samples and are shown below in Figs. 1a to 1d. Figure 1a. is a photo of a reference sample that has not been etched. Figure 1b. is a photo of a sample that was exposed to BOE and shows no distinguishable difference compared to the reference sample. Figure 1c. is a photo of the sample that was submerged in Au etch.

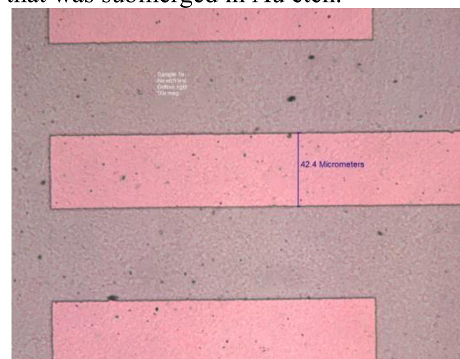

Figure 1a: Microphotograph of reference sample.

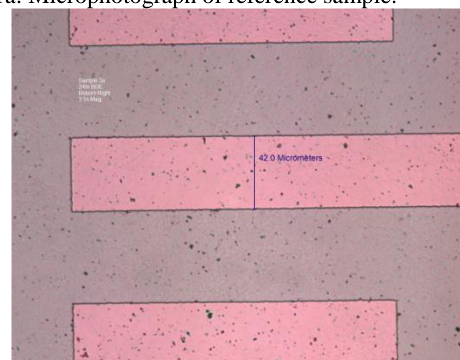

Figure 1b: Microphotograph of sample etched in Au etch.

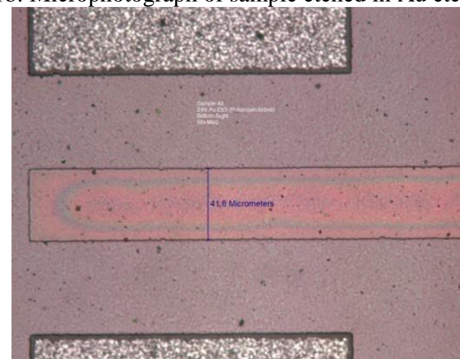

Figure 1c: Microphotograph of sample etched in BOE.

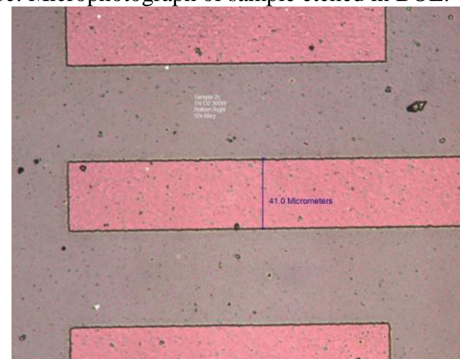

Figure 1d: Microphotograph of sample etched in O_2 plasma .

It is obvious that portions of Au film were etched away; see the undercut of the SiC in the center line, which indicates that the film was not entirely conformal. Figure 1d is the sample which underwent an O_2 plasma etch. No change in film integrity other than a slight discoloration is apparent.

SEM photographs were taken of the 4 samples that were completely coated with a 50 nm layer of gold. Figures 2a through 2d are SEMs of the various etch tests. In Fig. 2a, it appears that the SiC does not adequately cover the Au structure, and in Figs. 2b and 2c, the opening in the SiC film appears to be larger. It is also seen that the SiC does not have holes or voids caused by the etchants.

To determine the adhesion strength of the sputtered SiC thin film, a pull test [9] was performed on all the samples. All the samples had an adhesion strength greater than 10^8 N/m^2. At this adhesion strength the SiC and gold metallization act as if they are essential one layer. The SiC thin film peeled off two samples that had been subjected to the Au etchant at slightly less than 10^8 N/m^2, which further proves that the SiC film did not fully coat the sample, especially around the patterned metal lines.

Four MIMs were fabricated with different areas and a SiC thickness of 500 nm. The samples were measured on a Keithley 590 CV analyzer and 150 µm pitch GGB GSG probes before and after anneal. Before the anneal, the average ε_r is 13 ± 0.8. After the anneal at 300 ºC for 1 hour, the average ε_r is 6 ± 0.4.

Lastly, to prove the SiC thin film can be used as a conformal packaging technology for RF wireless circuits and sensors, a thin film, LC resonator was fabricated with and without the SiC coating and shown in Fig. 3. The resonator was measured using the Agilent's E8364B PNA and GGB CS-5 calibration substrate and 150 µm pitch probes. A section of the CPW feed was masked off to allow for probe contact. Figure 4 shows the measured response before and after SiC thin film coating. The results indicate a 1.7% shift in resonate frequency.

Figure 2a: SEM of the reference sample.

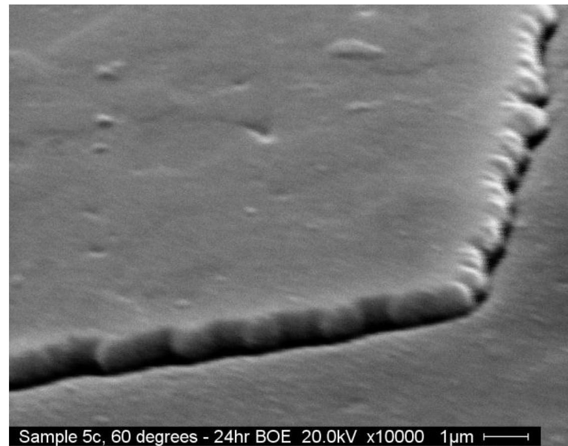

Figure 2b: SEM photograph of the BOE etch sample.

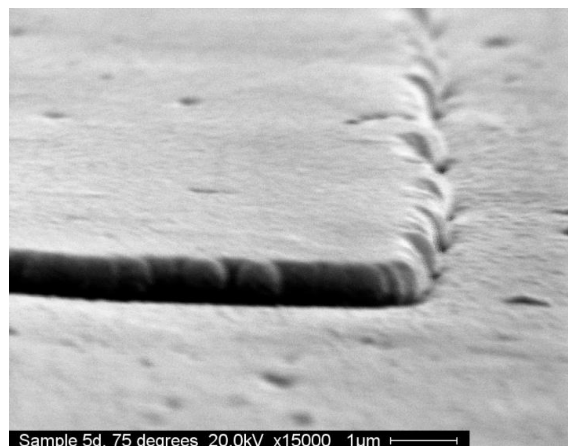

Figure 2c: SEM photograph of the Au etch sample.

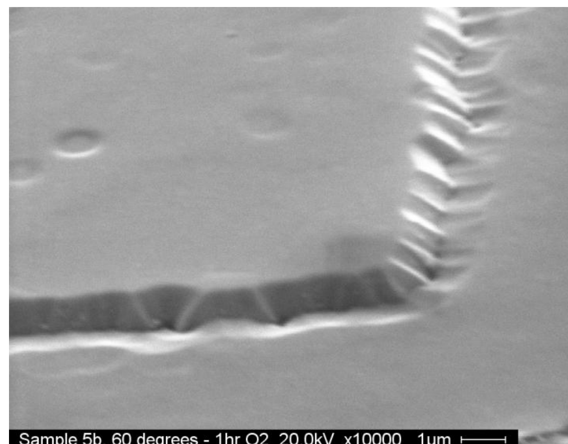

Figure 2d: SEM photograph of the O_2 plasma etch sample.

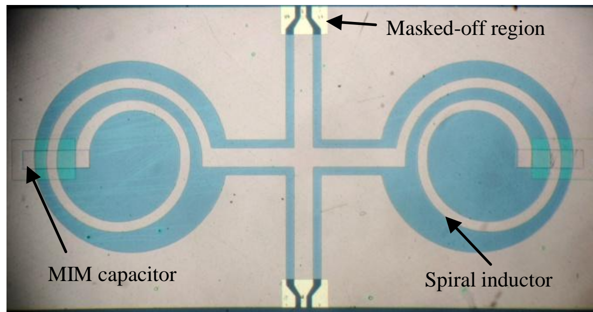

Figure 3: LC resonator with SiC thin film packaging coating.

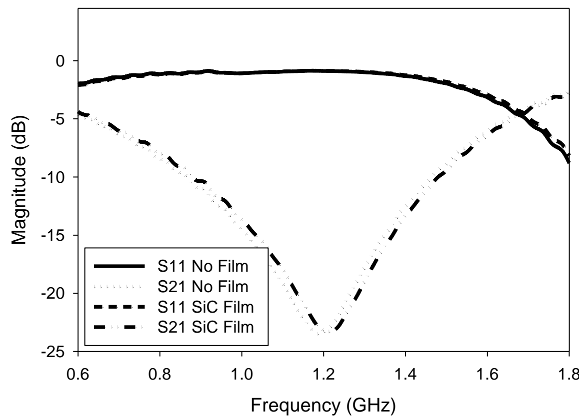

Figure 4: Measured S-parameters of the LC shunt resonator with and without SiC coating.

IV. Conclusion

Sputtered SiC was demonstrated as an effective means for a conformal thin film packaging technology, but further research is required. The anneal of the samples greatly improved the adhesion of the SiC to the Au, thin film structures. Several chemical and mechanical experiments were performed showing the reliability of the sputtered SiC film, but the conformal covering of the thin film circuit components must be improved. Further research into the sputtering methods may solve this problem. To prove the concept of using the SiC film as a packaging technology, an LC resonator was developed and characterized. It was shown that there was very little difference between the measured data of the resonator with and without SiC thin film conformal coating. This study clearly demonstrates that sputtered SiC thin films can be used as a conformal thin film packaging technology for RF wireless circuits and sensors.

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References

[1] C.D. Robertson, M. Matloubain, M. Case, L. P. B. Katehi, “A micromachined conformal package for a k-band low noise HEMT amplifier,” *IEEE Int. Micro. Symp. Dig.*, Vol. 2, pp. 517-520, Denver CO. June, 1997.

[2] L. Kyutae, A. Obatoyinbo, M. Davis, J. Lasker, R. Tummala, “Development of planar antenna in mutli-layer packages for RF-system-on-a-package applications,” *IEEE Electrical Performance of Electrical Packaging Symp.*, pp. 101-104, Oct. 2001.

[3] W. Sang-Hyuk, S. Yong-Bin, S. In-Sang, C. Sung-Hoon, I. Koh, L. Yong-Shik, Y. Jong-Gwan, “Packaging level integrated antennas based on LTCC technology,” *IEEE Trans. on Ant. and Prop.* , Vol. 54, No. 8, pp. 2190-2197. Aug. 2006.

[4] W. Jiali, R. T. Pike, C. P. Wong, “Novel by-layer conformal coating for reliability without hermeticity MEMS encapsulation,” *IEEE Trans. on Electronics Packaging and Manufacturing*, Vol. 22, Iss. 3, 1999, pp. 195-201.

[5] M. Kazemi, E. Basham, M. Sivaprakasam, W. Guoxing, D. Rodger, J. Weiland, Y. C. Tai, L. Wentai, M. Humayun, “A test microchip for evaluation of hermetic packaging technology for biomedical prosthetic implants,” *IEEE Engineering in Medicine and Biology Society Conference*, Vol. 2, 2004, pp.4093-4095.

[6] Fei Geng, Xiaoyun Dingand and Le Luo, “Study on a 3D packaging structure with benzocyclobutene as a dielectric layer for radio frequency application,” *Electronic Packaging Technology & High Density Packaging*, 2009, pp. 85-90.

[7] M. C. Scardelletti, N. C. Varaljay, and C. A. Zorman, “PECVD Silicon Carbide as a Chemically-Resistant Thin Film Packaging Technology for Microfabricated Antennas.” *IEEE Wireless and Microwave (WAMI) Conference*, Clearwater, FL. December 4-5, 2006.

[8] M. C. Scardelletti, J. W. Stanton, G. E. Ponchak, J. L. Jordan and C. A. Zorman, “PVD Silicon Carbide as a Thin Film Packaging Technology for Antennas on LCP Substrates for Harsh Environments”, *IEEE Radio and Wireless Symposium*, New Orleans, LA. January 10-14, 2010.

[9] T. H. Hull, J. S. Colligon and A. E. Hill, “Measurement of thin film adhesion,” *Vacuum*, vol. 37, No. ¾, 1987, pp. 327-330.