Plasma Etching of Thick BCB Polymer Films for Flip Chip Bonding of Hybrid Compound Semiconductor-Silicon Devices

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ABSTRACT

Thick polymer dielectric films are highly sought after in emerging applications such as the integration of passive components directly over silicon wafers and the packaging of compound semiconductor, SiGe or Si devices via flip chip bonding. The dielectric materials employed in this hybrid integration range in thickness from a few of microns up to tens of microns. One of the challenges for this type of packaging scheme is plasma etching of the thick polymer film with commercially acceptable equipment and high etch rates.

In this paper, we present results of a preliminary study of plasma etching thick BCB polymer films using a diode plasma etch system, with an emphasis on the etch rate of BCB etch as a function of gas mixture chemistry, RF power and pressure. Through this study we were able to find an etch process window which resulted in fairly high etch rates free of post-etch residues with the sloped etch profile which is desired for this hybrid integration or packaging.

INTRODUCTION

Integration of passive electronic components directly over silicon substrates and packaging of active compound semiconductor devices along with silicon CMOS device via flip chip bonding are two technologies that have seen increased popularity over the last several years for high speed / high frequency applications in the wireless and fiber-optical communication industries[1]. This space-efficient and reliable hybrid integration scheme offers significant advantages in device performance as well as in manufacturing cost. Such emerging technologies often require thick dielectric films with excellent electrical and mechanical properties. The CYCLOTENE™ family of polymer resins, also known as BCB, meet all such requirements[2]. They are available in a wide range of thickness and offer excellent low dielectric constant, low dielectric loss and low moisture adsorption[3].

There are two types of CYCLOTENE™ products: the 4000 series which are photo definable and the 3000 series which are optimized for plasma etch processing. The photo and dry etchable CYCLOTENE™ resins have identical physical and mechanical properties. The 3000 series dry etch grade polymers offer the additional advantage of improved planarization. See Figure 1. Planarization is critical for high yield integration with rough topography such as inductors and opto-electronic components over silicon CMOS devices[4].

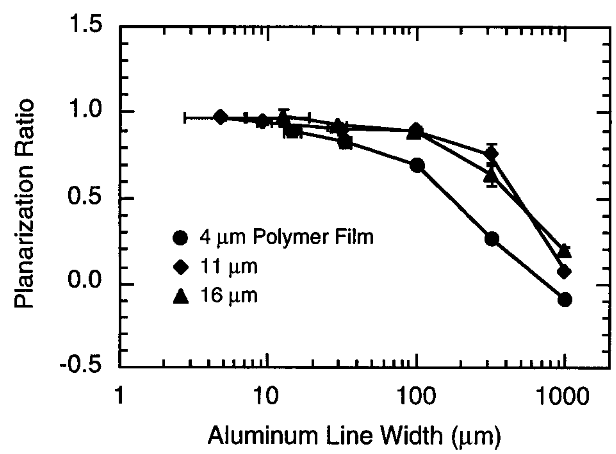

Figure 1. Planarization ratio for dry etch grade BCB polymer as a function of aluminum line width (4 µm thick Al line).

Clearly, one practical limitation of such a scheme is the cost-effective transfer of the via pattern into the BCB. Ideally a dry etch process would combine low capital cost and high wafer throughput. A candidate technology to meet this goal is the basic single wafer diode plasma reactor. Equipment of this type is very mature and proven for high volume manufacturing. The plasma etch chemistry needed to etch BCB does not require placing a load lock between the etch chamber and the fab environment, further decreasing tool cost and complexity.

EXPERIMENTAL AND RESULTS

A commercially available cassette-to-cassette single wafer plasma etch tool was selected for this study. The BCB material selected for this study was CYCLOTENE™ 3022-57 spun to a thickness of 7µm on 150mm diameter wafers. For profile tests, AZP4620 positive tone photoresist was spun to a thickness of 15µm and patterned with a line and via test mask with features ranging up to 50µm.

A screening experiment was run to characterize etch rate and via profile angle for two chemistries: SF_6/O_2 and CF_4/O_2. The controlled variables in the experimental design were RF power, gas ratio, and pressure. Etch rate was determined by partial etch of blanket BCB material using a Tencor™ TF-2 thin film measurement tool.

Figures 2 and 3 show BCB etch rate as a function of RF power and chamber pressure for SF_6/O_2 gas mixture, respectively. The BCB etch rate increased linearly with RF power and pressure. However, the effect of chamber pressure on etch rate is not as significant as RF power. Similar trends for BCB etch rate with respect to RF power and pressure were also observed for CF_4/O_2 gas mixture.

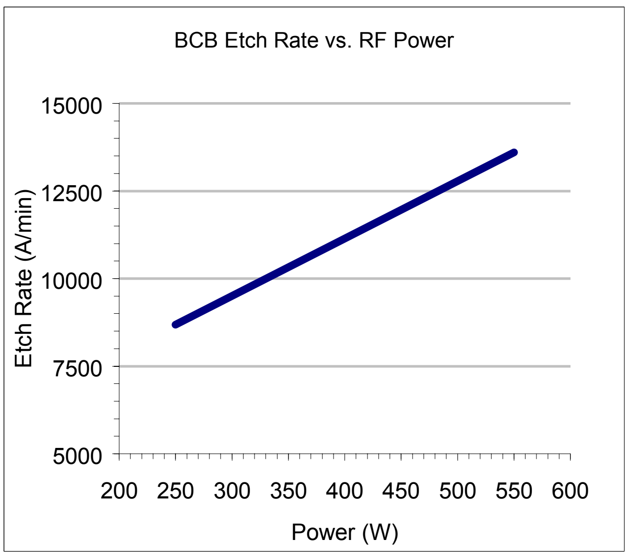

Figure 2. BCB etch rate versus RF power for SF_6/O_2 gas mixture.

Figure 4 presents the result of etch rates as a function of the gas composition for CF_4/O_2 mixture chemistry. In the present study it was found that higher CF_4 concentration in the gas mixture resulted in lower BCB etch rates for the given gas ratio range (from about 17% of CF_4 to about 55% of CF_4). Other etch studies have been reported in the literature[5, 6]. In these cited references it was reported that the BCB etch rate increases with increased CF_4 content in the CF_4/O2 gas mixture initially and then reaches its peak when the concentration of CF_4 is in the range of 50% ~ 60%.

Further increase in CF_4 concentration leads to the decrease of the BCB etch rate.

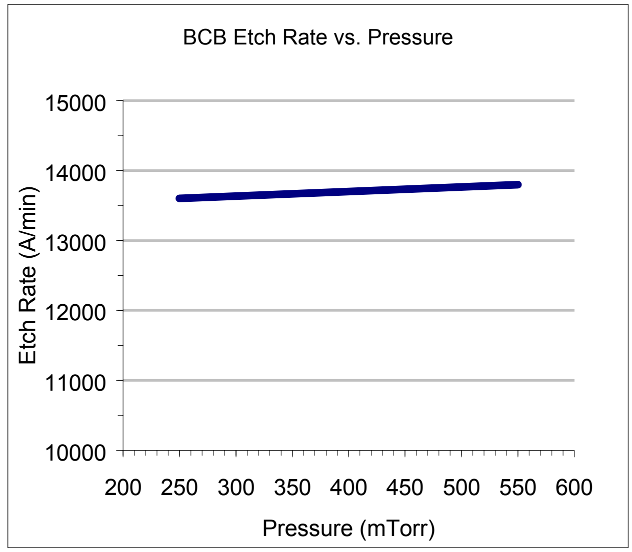

Figure 3. BCB etch rate versus etch chamber pressure for SF_6/O_2 gas mixture.

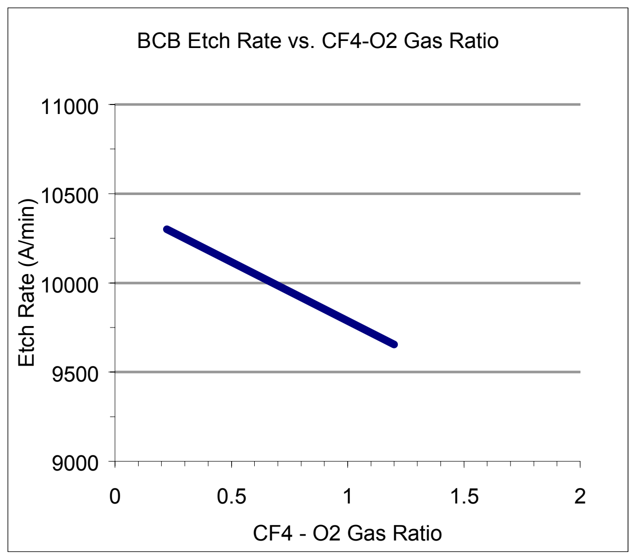

Figure 4. BCB etch rate vs. gas ratio with CF_4/O_2 chemistry.

The resist patterned test wafers were used to determine profile trends over the same parameter space. A continuous variation in via profile angle was observed in the CF_4/O_2 experiments. As the process pressure was decreased, the profile angle increased and became more vertical relative to the wafer surface, as shown in Figure 5. In general, the CF_4/O_2 chemistry had better profile control and smoother sidewall surfaces. Also, no visible post-etch residues were observed for the CF_4/O_2 chemistry, as shown in Figure 6.

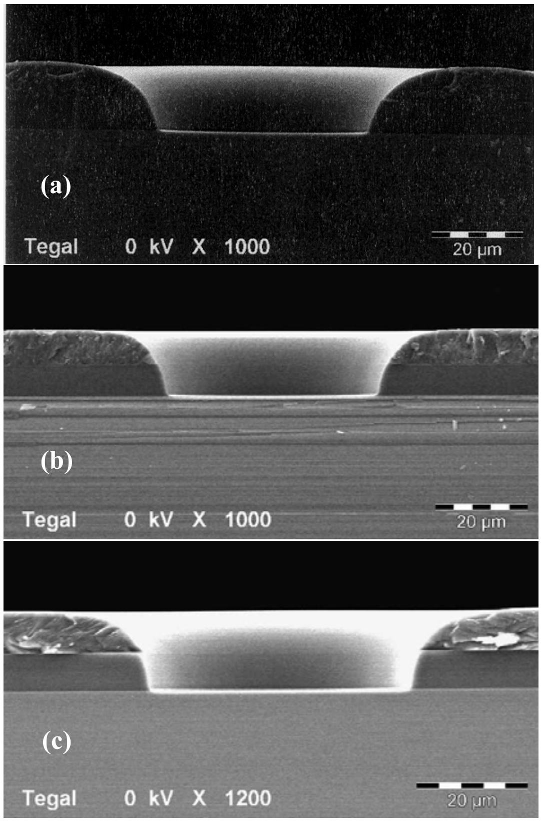

Figure 5. Via profile variations induced by pressure change in CF_4/O_2 chemistry. (a) 600mT, (b) 450mT, and (c) 300mT.

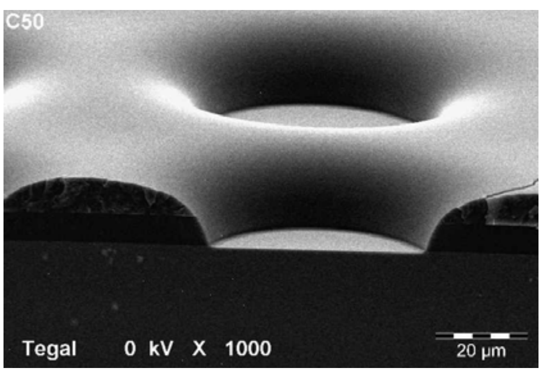

Figure 6. SEM field view of etched via showing no visible post-etch residues.

CONCLUSIONS

A preliminary study of etching thick BCB polymer films was conducted using a Tegal 901e™ diode plasma etch system. Etch rates of BCB films increase with RF power and chamber pressure for both CF4/O2 and SF6/O2 gas mixtures. Variable profile angle of via opening was observed when the process pressure was changed. Lower pressure resulted in greater profile angle (became more vertical relative to the wafer surface). In general, CF4/O2 chemistry led to slightly slower etch rates than SF6/O2, but created a better profile control and smoother sidewall surface. Through this study, we were able to find a viable process window for BCB etch with high etch rate, free of etch residues, and controlled sidewall profile. The results have demonstrated the ability of a cost effective single wafer diode etch platform to etch BCB with high throughput and excellent sloped profile control desired for the hybrid integration of passive components and compound semiconductors with silicon CMOS devices via flip chip bonding technology.

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ACRONYMS

BCB: benzocyclobutene