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Polishing of CVD Diamond Substrates Using Reactive Ion Etching

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Abstract

Multichip modules (MCM) have proved to be a viable packaging technology for achieving small size and high performance. By their nature, MCMs typically integrate multiple bare die into a module that can be the plastic or ceramic package. As a result, the MCM requires an efficient mechanism for removing excess heat. Diamond with its excellent thermal conductivity, is the ideal choice as a substrate material for these applications. Chemical vapor deposited (CVD) diamond substrates makes possible the practical realization of a novel diamond based 3-D MCM. However, the diamond films grown by CVD technique are polycrystalline and have non-uniform film roughness and randomly faceted crystals. These non-planar surfaces reduce the diamond's thermal management efficiency. Therefore, it becomes imperative that the as-deposited diamond films be polished for use in MCMs. Chemical assisted mechanical polishing (CAMP) technique has been developed at HiDEC, University of Arkansas. In this technique diamond is lapped against an alumina plate under a load in the presence of certain chemicals. Although CAMP technique reduces the lapping time considerably, still newer techniques must be developed to reduce polishing cost further. We are currently using reactive ion etching (RIE) to substantially reduce the polishing time. Preliminary studies using reactive ion etching showed etch rates of 500 - 1000 Å/min at low pressures. These etched films showed a considerably higher polishing rate (using CAMP technique) than the non-etched films. Changes in the morphology and structure of the diamond films due to etching and polishing were characterized by scanning electron microscopy (SEM), Dektak profilometer and Raman spectroscopy. This paper presents a systematic study of RIE and CAMP of CVD-diamond substrates.

Introduction

The need to miniaturize electronic systems and to increase the speed of signal propagation for faster data processing is increasing day by day. The emerging multi-chip module (MCM) packaging technology offers great improvements in signal speed and performance while reducing the size of the electronic systems. Silicon, metals and ceramics are commonly used substrates for MCM fabrication. But the increase in the current densities and power levels of integrated circuits are causing heat transfer to be a major issue in designing MCMs. Attention is now being directed to thermal management in the MCM packaging. Diamond is one of the most technologically important materials because of its very attractive properties such as high thermal conductivity, high electrical resistivity, low coefficient of thermal expansion and extremely high hardness. These properties of diamond surpasses those of all established substrate materials, and make it an ideal choice for 3-D MCMs. Chemical vapor deposition of diamond substrates makes possible the practical realization of a novel diamond based 3-D MCM. The fundamental process of chemical vapor deposition involved in the growth of polycrystalline diamond film

surfaces leads to a high degree of surface roughness. Unfortunately, the higher the quality and growth rate of the diamond films, the rougher the surface tends to be. As a result, contact area of as-deposited diamond with the chips will be less, resulting in poor thermal management efficiency. Techniques for limiting such roughness in the deposition process are being explored, but it is reasonable to assume that some degree of post-deposition surface finishing will be required for most of applications.

During the last few years most of the research work reported in the area of dry etching and plasma polishing at high temperatures. Yang et al., and Yoshikawa reported mechanical polishing with hot metal (Yang et al., *Sci. and Tech. of New Diamond*, pp. 135-138, 1990; Yoshikawa, *SPIE*, pp. 1325, 1990). Different plasma polishing techniques like ECR plasma, ion beam, laser beam, and sputtering have been reported for the polishing of diamond films (Beetz et al., *MRS Int. Conference Proc.*, 1991; Tankala et al., *New Diamond Sci. Tech.*, pp. 827, 1991).

Simple room temperature polishing procedures are very difficult and time consuming. Since room temperature polishing increases the polishing cost and more importantly, it has been reported to deteriorate diamond properties. Standard room temperature abrasive polish-

ing has been adopted by many. However, due to the diamond extreme hardness, such techniques have not proven to be economical. At the University of Arkansas, Fayetteville, we have developed a chemical assisted mechanical polishing (CAMP) technique that reduces the polishing time considerably without deteriorating its useful properties. In this study, reactive ion etching (RIE) has been investigated as a potential technique to prepare the diamond surface for final polishing by the CAMP technique at even faster rates.

Materials and Methods

Diamond samples used for this work were supplied by Norton Diamond Films, Northboro, MA. These were 1 cm X 1 cm free standing substrates of thickness 800 μm and surface roughness of 10 - 15 μm . These were grown by magnetically stirred DC Arcjet technique. A Plasma-Therm model SLR reactive ion etching system was used in our experiments to etch the diamond samples. Most of the etching was performed at a RF power of 350 W and in the pressure range of 50 to 250 mTorr. Oxygen was used as reacting gas with flow rates of 20-40 sccm. All etching experiments were done at room temperature. The rate of etching of diamond films was determined from the weight changes measured using an electronic micro-balance.

Two samples, one with RIE etching and the other without, were CAMP-polished under similar conditions for the same amount of time. The results are described below.

Results and Discussion

A scanning electron micrograph (SEM) of a typical as-deposited highly faceted polycrystalline diamond substrate is shown in Fig. 1. It can be inferred from this figure that these films have a large grain size (of around 100 μm), and the grain boundaries are not easily describable. Figure 2 shows a SEM of a polycrystalline diamond substrate after reactive ion etching. It clearly shows a different morphology when it is compared with Fig. 1; holes are seen on several crystals and the grain boundaries have become well defined. Figure 3 shows a SEM of a diamond substrate etched at a pressure of 150 m Torr in the chamber. It shows preferential etching along the grain boundaries. At high pressures (250 mTorr), however, the etching was found to take place preferentially on the top of the crystals (see, for example, Fig. 2). Some wormholes were also observed on top of individual crystals as shown in Fig. 4. Figure 4a shows these wormholes at lower magnification and Fig. 4b shows them at higher magnifica-

tion. Similar results were also observed by Ramesham with air-microwave plasma etching (Ramesham et al., J. of Electrochem Soc., Vol. 139, No. 7, 1992). Different microcrystals have been etched selectively in different directions, but there was no particular direction of etching that could be clearly identified.

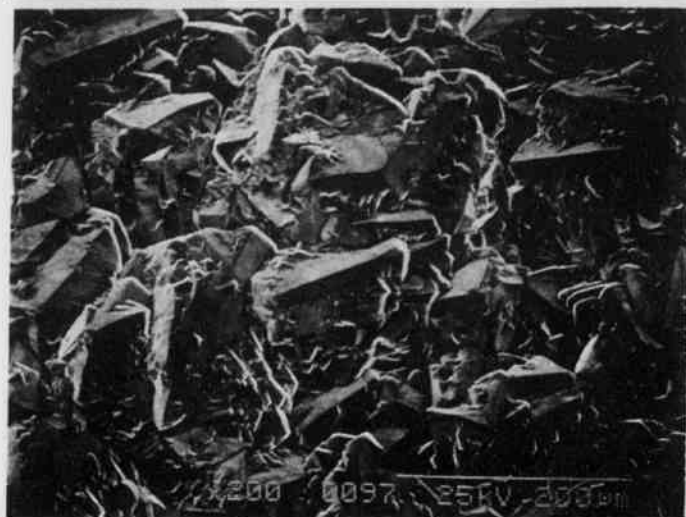


Fig. 1. Scanning electron micrograph (SEM) of a typical as-deposited polycrystalline diamond substrate.

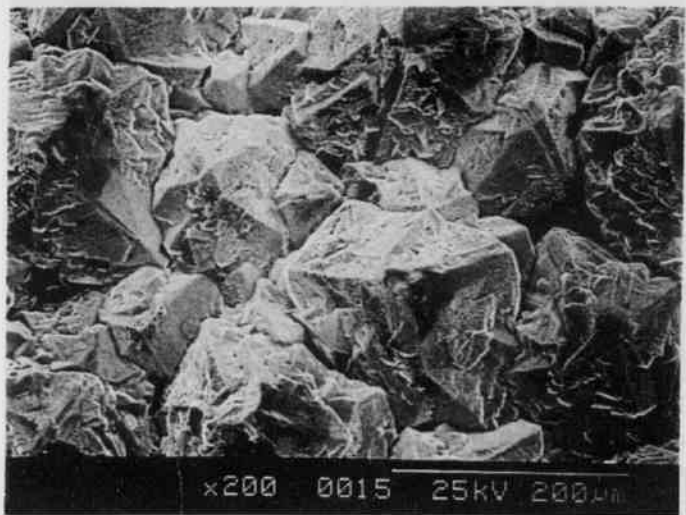


Fig. 2. Scanning electron micrograph of a polycrystalline diamond after reactive ion etching.

Etch rate of diamond was found to increase with increase in chamber pressure. Figure 5 shows a graph of etch rate vs chamber pressure. It was observed that there was no etching below 50 mTorr pressure. At 150 mTorr pressure the diamond started to etch, but mostly along grain boundaries (as in Fig. 3), initially with an etch rate



Fig. 3. Scanning electron micrograph of a diamond substrate etched at a low pressure (150 mTorr) in the chamber (showing preferential etching along grain boundaries).

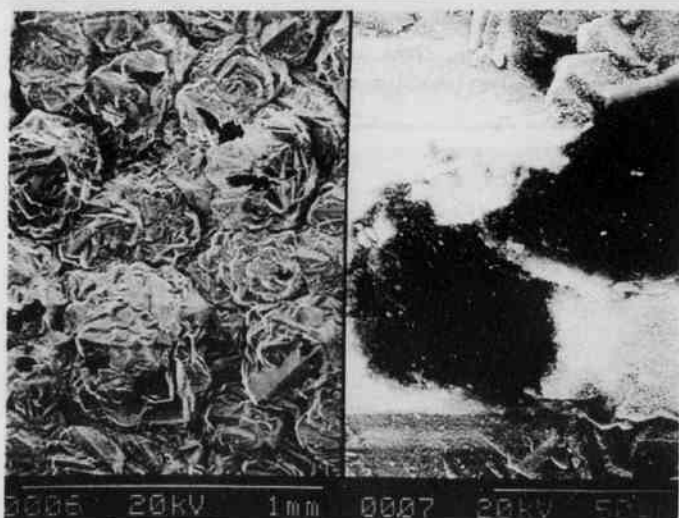


Fig. 4. Scanning electron micrograph of a diamond substrate etched at high pressure (250 mTorr) (with micro-channels) (a) at low and (b) at higher magnification.

of about 500 Å/min. At high pressures (200-250 mTorr) however, etching was mostly on crystal tops as previously shown in Fig. 2 with etch rates of 700-900 Å/min. It was also found that etch rate was increased to 1000 Å/min with a decrease in the flow rate of the reacting gas.

After etching, diamond samples appeared dark and lost their transparency. Figure 6 shows the Raman spectra of diamond films (a) before and (b) after etching. It can be observed from the figure that there is no increase in

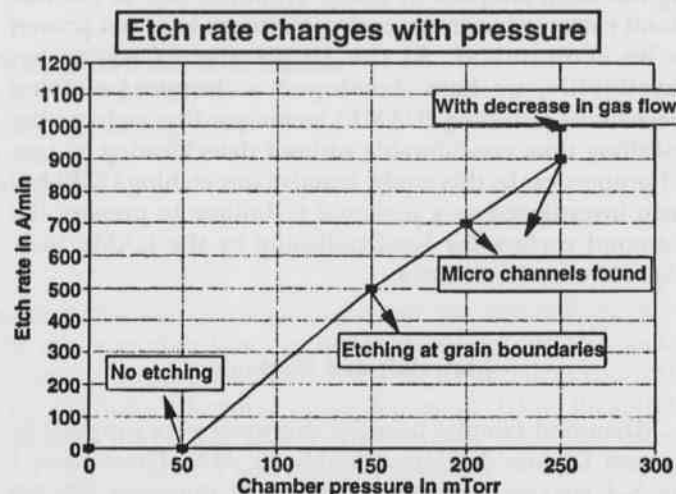


Fig. 5. Plot between the etch rate vs chamber pressure.

graphitic component after etching. Therefore, it can be inferred that the darkening is primarily an optical effect and can be attributed to scattering of light due to the formation of micro channels. Tankala and Debroy also observed similar darkening when they etched diamond films with argon plasma (Tankala K. and Debroy T., New Diamond Sci. and Tech., MRS Int. Conference, pp. 827, 1991).

Figure 7 (a) and (b) show the scanning electron micrograph (SEM) of CAMP-polished diamond samples subsequent to RIE etching and without RIE, respectively. It was observed that the reactive ion etched sample removal rate was high when compared with that of an un-etched sample. Figure 7 (a) shows well polished crystals, whereas Fig. 7 (b) reveals no such polished crystals on the un-etched sample.

Surface roughness was measured at every stage of the process by a Dektak surface profilometer. Decrease in the surface roughness after the RIE was observed in the range of 500-1000 Å.

Summary and Conclusions

Etch rates were observed to increase with the increase in the chamber pressure. Under certain conditions diamond was being preferentially etched along grain boundaries. At high chamber pressures micro-channels were etched on top of the facets, but no preferential etch direction could be identified. The etch rates were found to be between 500-1000 Å/min. A decrease in reacting gas flow rate increased the etch rate. Reactive ion etching of diamond before chemical assisted mechanical polishing helps to substantially (may be to the half)

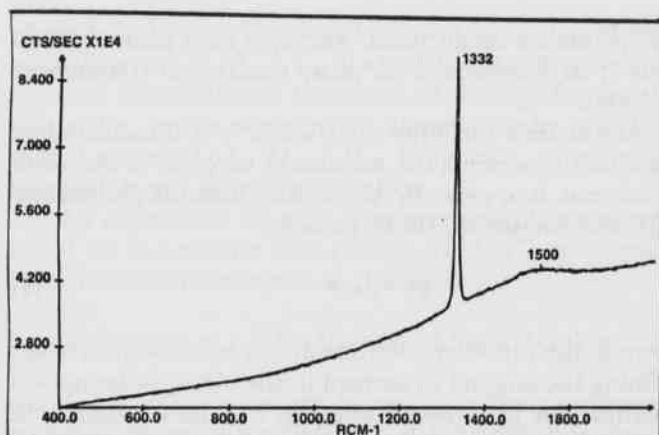
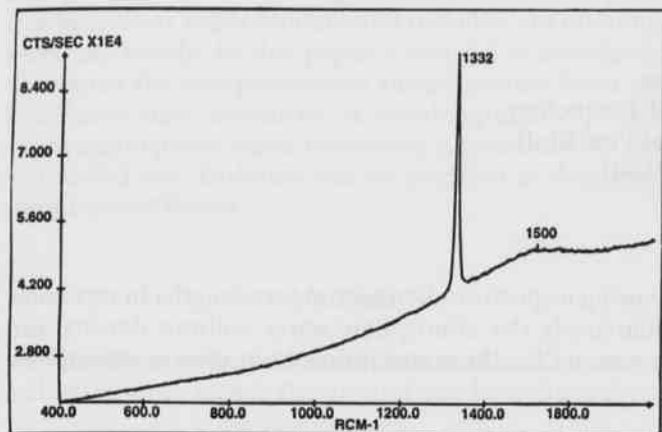


Fig. 6. Raman spectra of a diamond substrate (a) before etching and (b) after etching

reduce the CAMP polishing time by increasing the diamond removal rate.

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Fig. 7. (a). Scanning electron micrograph of a CAMP-polished diamond substrate with reactive ion etching.

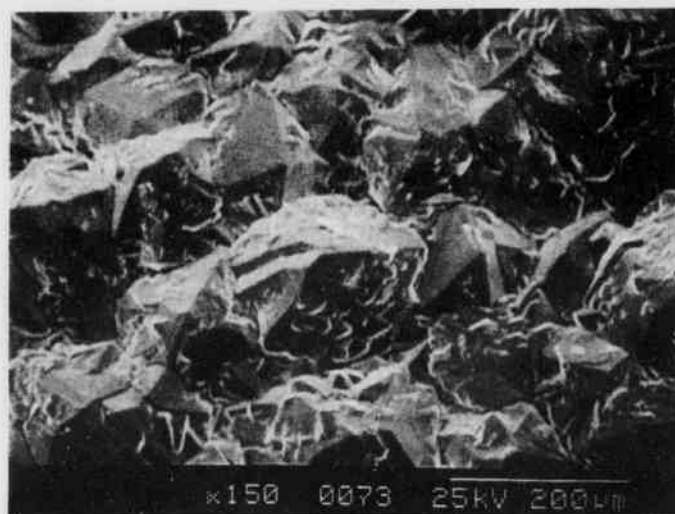


Fig. 7. (b) Scanning electron micrograph of a CAMP-polished diamond substrate without reactive ion etching

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