CVD Diamond Sink Application in High Power 3D MCMs*

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Abstract  As electronic packages become more compact, run at faster speeds and dissipate more heat, package designers need more effective thermal management materials. CVD diamond, because of its high thermal conductivity, low dielectric loss and its great mechanical strength, is an excellent material for three dimensional (3D) multichip modules (MCMs) in the next generation compact high speed computers and high power microwave components. In this paper, we have synthesized a large area freestanding diamond films and substrates, and polished diamond substrates, which make MCMs diamond film sink becomes a reality.

Key words  diamond film substrate;  sink;  3D multichip modules

Electronics manufacturers have recognized that diamond is a material ideally suited for electronic substrates. It has the highest thermal conductivity of any material, high electrical resistivity and a low dielectric constant. In fact, natural IIa diamond is already used for some very high power density applications. However, the size, availability and cost of natural diamond have limited its use as a thermal management material.

Along with the development of the chemical vapor deposition (CVD) diamond synthesis process, it is becoming more and more affordable for large area electronic packaging applications. CVD diamond has only recently become available as large area freestanding substrates fabricated using several chemical vapor deposition techniques. Tab.1 shows a list of properties of CVD diamond and some package materials.

The recent introduction of synthetically produced CVD diamond substrates has led to the proposal of novel 2D and 3D MCM designs which capitalize on diamond’s high thermal conductivity. The literature reflects a growing interest in applying diamond substrate technology to solving 2D and 3D MCM thermal management problems[4~8]. For example, a replacement power electronics module for a flight

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Tab.1  Properties of CVD diamond and some package materials

<table>
<thead>
<tr>
<th>Substrate material</th>
<th>Thermal conductivity W/(m·K)</th>
<th>Electrical resistivity/Ω·cm</th>
<th>Dielectric constant /ε</th>
<th>Thermal expansion ×10^-6/°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>CVD diamond</td>
<td>1300~2000</td>
<td>10^{13}</td>
<td>5.3~5.7</td>
<td>0.8~2.0</td>
</tr>
<tr>
<td>Cu</td>
<td>396</td>
<td>1.6×10^{-6}</td>
<td></td>
<td>18.8</td>
</tr>
<tr>
<td>Al</td>
<td>247</td>
<td>2.7×10^{-6}</td>
<td></td>
<td>247</td>
</tr>
<tr>
<td>AlN</td>
<td>140~230</td>
<td>&gt;10^{14}</td>
<td>8.5</td>
<td>4.6</td>
</tr>
<tr>
<td>BeO</td>
<td>223</td>
<td>&gt;10^{14}</td>
<td>6.8</td>
<td>6.8</td>
</tr>
<tr>
<td>Si</td>
<td>84~135</td>
<td>2.3×10^{5}</td>
<td>11.8</td>
<td>3.0~3.5</td>
</tr>
<tr>
<td>Al2O3 (96%)</td>
<td>20</td>
<td>&gt;10^{14}</td>
<td>9.4</td>
<td>6.4</td>
</tr>
</tbody>
</table>
computer has been designed and fabricated which uses CVD diamond to spread and dissipate large transient power pulses. This 2D implementation incorporates high power MOSFETs in die form, and thin film resistor technology for high wattage load resistors and results in a significant reduction in physical size from the PC board version.

1 Experiments

We have deposited large area freestanding polycrystalline diamond films by using microwave plasma chemical vapor deposition (MPCVD) techniques on Si and Cu substrates. Diamond films are being deposited at 800–950°C on Φ60 mm diameter substrates using CH₄ and H₂ gas mixtures. Deposition parameters are being optimized to yield high deposition rates, minimum stress and void density, and maximum as grown film planarity. All these will reduce post-deposition processing costs significantly.

Fig.1 shows the equipment of MWPCVD, The equipment consists of a 5kW/2.450MHz high stability microwave power source, microwave transmission and coupling system, Φ280 large volume plasma reactor, vacuum system, gas distribution and flow controller, multichannel transient recorder, which can satisfy the needs of CVD diamond films deposition. Fig.2 is the sample of CVD diamond film. Fig.3 shows a scanning electron micrograph (SEM) of CVD diamond film by MPCVD. Fig.4 shows a Raman spectrum of CVD diamond film by MPCVD.

2 Technologies

2.1 Polishing and Planarization

The resulting film is polycrystalline and has rough surface morphology. It has large internal stress build-up and contains a large density of voids within the film. It contains a certain percentage of graphite or other allotropic forms of carbon, especially along grain boundaries and surfaces. All these are strongly influenced by the deposition conditions used. Polishing diamond, the hardest material known, presents a big challenge in post-deposition processing. Planarization and filling of surface voids is another issue that needs to be tackled.

Polishing and planarization CVD diamond film is
essential to its applications in MCMs. We developed a microwave plasma polishing and planarization (MWPPP) process. The effects of the processing parameters of the microwave plasma such as the microwave power, the substrate position and the oxygen flow on the polishing result of the diamond film are studied when using the oxygen as the gas source. The morphology and surface roughness of the etched film are examined and tested by SEM and AFM. Fig.5 shows a SEM of typical MWPPP- unpolished and polished CVD diamond film.

![SEMs of typical MWPPP-unpolished and polished CVD diamond film](image1)

Fig.5  SEM of typical MWPPP-unpolished and polished CVD diamond film

Fig.6 shows an AFM picture of typical MWPPP-unpolished and polished CVD diamond film. The experiments show that the processing parameters of microwave plasma have great influence on the film smoothness and they are related to each other. Under the appropriate conditions, the surface roughness of the resulting film reduces by approximately 50% compared with the roughness of original film. This smoothing method could be easily and effectively applied to the treatment of the diamond film in situ.

2.2 Via Drilling

About via drilling process, we can use a novel technique called laser-assisted liquid ambient machining (LAM) to drill chemically clean, dimensional uniform crack-free via in thick diamond substrates. The choice of liquid is very important to achieve the stated objectives.

![AFM (×3000) picture of typical MWPPP-un polished and polished CVD diamond film](image2)

2.3 Metallization

Conductor metals such as gold and copper must adhere well to the chemically inert diamond surface. A multi-layer interconnect (MLI) processing scheme using appropriate metals and dielectrics need to be developed. Via formation and metallization, and eutectic die soldering are some of the other important problems that must be resolved before diamond-based MCMs become a reality. In the process of metallization, the adhesion of metal to diamond is one of the prime factors in deciding the quality of the electronic packaging application. Especially when CVD diamond is used in high power hybrids and MCMs, The good adhesion strength between metal layers and diamond substrates can be obtained by pre-fire and post-treatment processing using electron beam evaporation techniques and Ti/Ni/Au metallization system. The results show that the adhesion strength can be significantly improved from un-pretreatments 10.0 MPa to 50.0 MPa by the pre-fire of the bare diamond substrates. The system diamond/Ti/Ni/Au indicates excellent adhesion after thermal cycling 100 times between 210 K and 453 K and there are no signs of delamination. The interface diffusion or reaction of Ti/diamond depends on not only the temperature but also the surface conditions of the diamond.

3 Conclusions

Large area freestanding CVD-diamond is the ideal heat spreading material to built 3D MCMs for high-power high-density light-weight electronic systems. However, several processing issues need to be resolved before it can become a reality. We have deposited large area freestanding polycrystalline diamond films by using microwave plasma chemical vapor deposition (MPCVD) techniques on Si and Cu
substrates. And then, we polished, smoothed and metallized the samples. These new processes and novel technologies have been developed which brings the realization of diamond based MCMs closer to reality.

References


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