Indirect Bonding of Ni-Electroless Plated AlN and Cu by Hot Pressing Method

Chung-Daw Young and Jcnq-Gong Duh

Abstract—The electroless Ni (EN) plating method was employed to metallize the AlIN ceramic substrates. The EN-plated AlIN substrate was bonded with the Cu foil to form a sandwich-like AlN–EN/Cu/EN–AlIN assembly by hot pressing in vacuum with a pressure of 6.5 MPa for 30 min. For the bonding temperature below the Ni–P eutectic temperature of EN at 880°C, the samples were bonded through solid state diffusion. On the other hand, the samples were bonded via a liquid phase media through wetting and diffusion if the bonding temperature was above 880°C. An optimum adhesion strength around 10 MPa was achieved within the bonding temperature range 600–700°C. Fracture occurred in the EN/Cu interface above 700°C. The increasing temperature enhanced interdiffusion of Cu and AlN to form a strong bond, yet resulted in a large residual thermal stress in the AlN/EN interface. The bonded samples with etched AlIN was the highest as compared to those of as-received and polished AlN, although the surface roughness of the etched AlIN was the same as that of the as-received one. It is argued that the etched surface of AlIN with micro-etched holes provides the anchor sites for interlocking with the EN film, which results in a good mechanical bonding in the joint. However, a mechanical trimming on the edges of bonded samples would damage the joint, and a low adhesion strength is instead observed.

Index Terms—Indirect bonding, electroless plating, EN, AlN, hot press, eutectic.

I. INTRODUCTION

In industry, metals and ceramics are widely used in many fields, such as mechanical, electronic, chemical, and aerospace application. Due to their distinct differences in physical and chemical properties, neither metals nor ceramics can be used independently to comprehensively meet the increasing complexity in today’s industry. If the bonding of metals and ceramics could be guaranteed, the applications of metals and ceramics will be expanded extensively and will benefit each other.

The metal/ceramic bonding is especially important in the microelectronic industry. For a small-size and high-performance electronic device, high line density generates much heat per unit volume, which will be dissipated out to environments to ensure less damage induced by heat impact in the interfaces between active and/or passive metal elements and ceramic substrate. An attractive AlIN ceramic with excellent thermal conductivity (normally 150–220 W/m K, with theoretical value reaching 320 W/m K) are considered to be the better substrate material. In addition, the AlIN ceramics have excellent flexural strength around 3200 kg/cm², high electrical resistivity (10¹¹–10¹⁴ Ω cm), low dielectric constant 8.8 at 10 MHz), no toxicity, and the coefficient of thermal expansion (4.5 ppm/°C) is close to that of Si (4 ppm/°C). These merits make AlIN a potential substitute for Al₂O₃ in the electronic application.

In the microelectronic package, copper with high electric and thermal conductivity is an excellent material as conductor and heat sink. Combination with Cu and AlIN exhibits the essential potential of applications in the microelectronic field. Unfortunately, different atomic bonding structures (metallic for Cu and ionic for AlIN) make these two materials difficult to bond together. Ochuchi et al. [1]–[4] carried out a series of studies by Cu sputtering deposition on surfaces of AlIN single crystals. The optimum adhesion strength evaluated by the pull test method was only around 7.5 MPa. It is much lower than the fracture strengths of parent materials, which are greater than 300 MPa for Cu and around 500 MPa for AlIN, respectively. In the experiment of wetting of AlIN by liquid Cu, a wetting angle (θ) around 150° was observed by Rhee [5]. From the combination of Dupre and Young equations (Wₐd = γLV(1 + cos θ), γLV is the surface energy of liquid metal) [6], it is indicated that work of adhesion (Wₐd) for separating the Cu/AlIN interface is low. Thus, poor adhesion of Cu on AlIN is anticipated.

A wide variety of processes in metallization of AlIN have been proposed, such as thick-film metallization by screen printing with the employment of fritted Cu [7], Mo–MoN [8], [9], Pd–Ag [10], and fritless Au [11] and Ti–W–Mo [12]; sputtering a thin Au–Pt–Ti [9], Ti, Pd, Au [13] and Cu [1]-[4] film; soldering [14] and brazing [15] with Ag–Cu–Ti alloys of CuNi, Incucl and Tichel; direct bonding of Cu by the Cu–O eutectic method [16]; eutectic with high melting point metals, say, W [17]; electroless plating of Ni [18], [19] and hot pressure bonding of Fe [20]. Among these methods, good adhesion on AlIN by pure metal wetting can not be achieved [5]. Hot pressure bonding of Fe on AlIN at 1400°C for 60 min under a pressure of 100 MPa also exhibited poor adhesion strength of 7 MPa, with the fracture occurring within the ceramic part [20]. It should be pointed out that sputtering by ion gun generation in high vacuum is expensive and difficult to operate. In addition, the highest adhesion strength of Cu on
AIN by sputtering was as low as 7.5 MPa [1]–[4]. In order to achieve higher bonding strength, some types of interlayers or chemical reactions in the interface are desired. Brazing and soldering with Ti alloy can achieve good adhesion strength up to 30 MPa through a chemical reaction to produce a TiN thin layer in the interface [14], [15]. However, the dimensions of brazing metals cannot be controlled precisely and accurately. Thick-film metallization has the problems of densification of porous metal film [7], [10]–[12] and generally needs glassy frits as the interlayer [7]–[10], which, on the contrary, has low thermal conductivity and is detrimental to the heat dissipation. Direct bonding of Cu to preoxidized AIN accompanied with forming an interlayer of eutectic composition [16] or forming aluminate phases [21], [22] also encounters the same heat dissipation problem. In addition, the application of cofiring is limited to the metals with high melting points.

Among these metallization methods, the electrodes Ni (EN) plating on AIN ceramic method appears to be the most appropriate one. The EN deposit has lower thermal expansion coefficient [23] than that of Cu and is closer to that of AIN ceramic. Good adhesion, good conformity of EN on the AIN substrate, and interdiffusion with Cu to form a solid solution are easily achieved. Besides, the easy operation, low price, and wide usage in different kinds of materials—such as metal, plastic, and ceramic—all make the EN plating method have more potential in application. It is argued that element P, resulting in eutectic liquid with Ni in the AIN/Cu interface to wet AIN ceramic, may enhance the bonding of Cu to AIN. In addition, P dissolves into the Cu matrix to form a solid solution with Cu, which also contributes to render a homogeneous and strong interface with a continuous variation of physical and chemical properties in interface. The wetting angle of Ni and its alloy on AIN was investigated by Tromelj and Kolar [24]. This value is smaller than that of Cu, which indicates that Ni will form a more stable interface than Cu with AIN. Therefore, bonding with a Ni-containing intermediate layer to join AIN and Cu is expected.

Although many investigations have reported that the electroless Ni (EN) plating is a promising method for metallizing the oxide ceramics, such as Al₂O₃, few of them are concerned with AIN ceramic [18], [19]. In this study, bonding of AIN and Cu with a deposited EN film as an interlayer was carried out through both solid-state bonding and liquid phase bonding, depending if the bonding temperature is higher or lower than the eutectic temperature of EN film. AIN ceramics of as-received, polished, and etched were used in the AIN–EN/Cu–EN–AIN assembly to investigate the effects of surface roughness and surface morphology on the bonding strength. In addition, the adhesion strength, interfacial morphology, phases formation, and elemental redistribution after bonding are discussed.

II. EXPERIMENTAL

Commercial AIN substrates (SH-15, Tokuyama Soda Co., Ltd., Japan) with addition of Y₂O₃ as the sintering aid were used in this study. The specifications of as-received samples are as follows: size, 25 mm × 25 mm × 0.63 mm; surface roughness, around 0.2 μm; and flatness, ≤ 0.05/25.4 mm/mm.

A flowchart of the electroless Ni plating process is shown in Fig. 1. The compositions of solutions in sensitization, activation, and electroless plating are presented in Table I. Details of the electroless Ni plating and pretreatment of AIN were also reported elsewhere [25], [26]. The EN metallized AIN substrates were cut into pieces in dimension 6.3 mm × 6.3 mm × 0.63 mm for bonding.
TABLE I

<table>
<thead>
<tr>
<th>Processes</th>
<th>Chemical species</th>
<th>Concentrations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitization</td>
<td>SnCl₂, 2H₂O</td>
<td>16 g/l</td>
</tr>
<tr>
<td></td>
<td>HCl</td>
<td>30 ml/l</td>
</tr>
<tr>
<td>Activation</td>
<td>PdCl₂</td>
<td>0.1 g/l</td>
</tr>
<tr>
<td></td>
<td>HCl</td>
<td>8 ml/l</td>
</tr>
<tr>
<td>Electroless Ni plating</td>
<td>NiSO₄, 6H₂O</td>
<td>20 g/l</td>
</tr>
<tr>
<td></td>
<td>NaH₂PO₄ · H₂O</td>
<td>27 g/l</td>
</tr>
<tr>
<td></td>
<td>Na₂H₅C₂O₄ · 6H₂O</td>
<td>16 g/l</td>
</tr>
<tr>
<td></td>
<td>pH adjuster</td>
<td>H₂SO₄</td>
</tr>
</tbody>
</table>

Fig. 2. Schematic diagram of the bonding machine.

Fig. 3. The temperature profile and vacuum condition during bonding at temperatures 400°C to 950°C.

### III. RESULTS AND DISCUSSION

The composition of element P in the electroless-plated Ni (EN) film with thickness 2–3 μm is around 11.3 wt%, analyzed by EDX. This value is close to the content of element P in the eutectic composition of Ni–P alloy. It is expected that the EN film exists as a solid state below the eutectic temperature, while it is a liquid phase above. Thus, the bonding of EN-metallized AlN and Cu can be conducted in two ways: One is solid-state bonding by diffusion only and the other is liquid-phase bonding through both wetting and diffusion.

#### A. Solid-State Bonding Below Eutectic Temperature (880°C)

The sandwich-like AlN–EN/Cu/EN–AlN assemblies were pressed with pressure of 6.5 MPa in a vacuum chamber at temperatures of 400°C, 600°C, 700°C, and 800°C, respectively. The adhesion strengths of these bonded assemblies are shown in Fig. 4. No appreciable adhesion was found at 400°C. The assembly was separated away from the interface between AlN–EN and Cu after retrieval from the vacuum chamber. As the bonding temperature was raised to 600°C and 700°C, the average adhesion strength increased to 10 MPa. The fracture took place in the EN/Cu interface for 600°C-bonded samples. However, for 700°C-bonded samples,
The adhesion strength of the samples assembly with as-received AlN, electroless plated Ni, and Cu foil bonded at temperatures ranging from 400°C to 800°C.

Fracture occurred predominantly in AlN/EN and only partially in EN/Cu interfaces. If the bonding temperature was further increased to 800°C, the average bonding strength declined to 4 MPa and the failure occurred entirely in the AlN/EN interface. With respect to the range of the test temperatures, it is observed that adhesion strength reaches a maximum value between 600°C and 700°C, as shown in Fig. 4.

It is argued that the strength of sandwich-like AlN-EN/Cu/EN-AlN assembly depends on the characteristics of two different interfaces, i.e., AlN/EN and EN/Cu. The adhesion strength of EN film on the as-received AlN substrate is around 5 MPa, as evaluated by a pull test method. When the bonding temperature is as low as 400°C, the interface of AlN/EN of the bonded sample exhibits a higher adhesion strength than the EN/Cu interface, despite the fact that the mismatches of coefficient of thermal expansion (CTE) in these two interfaces are similar (around 6 μm/m°C) and that the EN and Cu possess a similar atomic bonding structure as compared to EN and AlN. This indicates that the diffusion and reaction between EN and Cu are slow under this temperature level. From the cross sectional view, as shown in Fig. 5(a), the EN particles protruded on the surface of the as-deposited film retain their shapes on the fractured surface in the EN film side after bonding. The Cu foil fails to deform sufficiently to contact the EN film tightly, possibly owing to the fact that the temperature is not high enough to soften the Cu foil. The corresponding Ni X-ray mapping of Fig. 5(a) is shown in Fig. 5(b). As a result, the interaction of Cu and EN is weak after bonding under the low temperature level of 400°C, in which the assembly appears un-bonded.

As the samples were joined at temperatures above 600°C, the interaction of Cu and EN took place. Except for AlN, Cu, Ni, and Ni₃P, no other compounds or phases were found on the fractured surfaces on both AlN—EN and Cu sides, as shown in Figs. 6 and 7, respectively. The cross sectional view in Fig. 8(a) exhibits good contact between Cu and EN, as well as between EN and AlN, Fig. 8(b) is the corresponding Ni X-ray mapping. The concentration profile indicates that the highest concentration of elements Ni and P of the EN film remain in the interface, while a trace of Ni exists in Cu matrix near the EN/Cu interface, as shown in Fig. 9. Since Cu can form the solid solution α phase with Ni and solid solution or eutectic composition with P, the bonding in the EN/Cu interface is enhanced through the elemental interdiffusion of Cu, Ni, and P.

The amount of Ni diffusing into the Cu foil increases with the bonding temperature. The concentration profiles of Ni and...
Cu around the EN/Cu interface are more smooth for samples bonded at 700°C than that at 600°C, as shown in Fig. 10. In addition to the lower peak value of Ni for samples bonded at 700°C, as shown in Fig. 10, the cross sectional morphology and the weaker Ni X-ray mapping as shown in Fig. 11(a) and (b) indicate that the EN film is thinner for samples bonded at 700°C than that at 600°C. It is attributed to the diffusing of Ni into the Cu matrix. Although the bonding of EN and Cu becomes stronger with increasing temperature, the thermal stress introduced in AlN/EN interface is also raised accordingly. As a consequence, the fracture of the sample bonded at 700°C after adhesion testing occurs in the AlN/EN interface. It should be pointed out that Ni-diffused Cu, as seen in Fig. 10, can not be distinguished by XRD from pure Cu, because they have the same crystal structures. The adhesion strength of AlN/EN interface increases from 5 MPa for the EN as-metallized state to around 10 MPa in average after bonding at 700°C with the Cu foil. As shown in Fig. 6 and 7, the EN film with only the Ni₃P phase adheres mostly on the Cu side of the fractured samples. It is argued that the bonding strength of intermetallic compound Ni₃P and AlN is stronger than that of AlN and as-deposited amorphous Ni-P film.

Fig. 12(a) and (b) represents the cross sectional view and Ni X-ray mapping of samples bonded at 800°C, respectively. The discontinuous distribution of Ni in the EN film is observed in Fig. 12(b). It is attributed to the decrease of Ni in the EN film owing to the diffusion of Ni into the Cu matrix. The phases on

![Fig. 6](image6.png)

**Fig. 6.** X-ray diffraction patterns of the fractured surface on the AlN side for the samples bonded at temperatures 400°C to 950°C.

![Fig. 7](image7.png)

**Fig. 7.** X-ray diffraction patterns of the fractured surface on the Cu side for the samples bonded at temperatures 400°C to 950°C.

![Fig. 8](image8.png)

**Fig. 8.** The cross sectional view of the samples bonded at 600°C. (a) SEI morphology; (b) Ni X-ray mapping.

![Fig. 9](image9.png)

**Fig. 9.** The concentration profile of elements Al, Y, Ni, P, and Cu across the joint of the bonded assembly at 600°C.
TABLE III
SUMMARY OF FRACTURED SURFACES OF BONDED SAMPLES FOR THE AS-RECEIVED, ETCHED, AND POLISHED AlN BONDED WITH Cu FOIL AT 600°C AND 700°C AFTER EN METALLIZATION

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>As-received AlN</th>
<th>Etched AlN</th>
<th>Polished AlN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>600°C</td>
<td>700°C</td>
<td>600°C</td>
</tr>
<tr>
<td>#1</td>
<td>3/4 C</td>
<td>8/9 C</td>
<td>4/5 C</td>
</tr>
<tr>
<td>#2</td>
<td>3/4 C</td>
<td>2/3 C</td>
<td>C</td>
</tr>
<tr>
<td>#3</td>
<td>C</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>#4</td>
<td>3/4 C</td>
<td>4/5 C</td>
<td>C</td>
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<tr>
<td>#5</td>
<td>4/5 C</td>
<td>C</td>
<td>A*</td>
</tr>
<tr>
<td>#6</td>
<td>C</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*(fraction) C: fraction of fracture area observed in the AlN/EN interface; A: fracture entirely in the Cu/EN interface; *: unbonded after taking from chamber; —: unfractured after adhesion testing, adhesion strengths are higher than 12 MPa and the maximum is up to 21 MPa.

Fig. 10. The concentration profile of elements Al, Y, Ni, P, and Cu across the joint of the bonded assembly at 700°C.

Fig. 11. The cross-sectional view of the samples bonded at 700°C. (a) SEI morphology; (b) Ni X-ray mapping.

eutectic liquid drops were observed on the edges of bonded samples in the EN/Cu interfaces, since the eutectic liquid flowed out from the EN/Cu interface under a pressure of 6.5 MPa during hot pressing. Only small amounts of liquid remained in the concave sites, which were formed due to the surface roughness of AlN substrates. The remaining EN looked like isolated segregation between the AlN substrate and the Cu foil, as indicated from the Ni X-ray mapping in Figs. 13(b) and 14(b). Diffusion of element Ni into the Cu matrix was
Fig. 12. The cross sectional view of the samples bonded at 800°C. (a) SEI morphology; (b) Ni X-ray mapping.

Fig. 13. The cross sectional view of the samples bonded at 910°C. (a) SEI morphology; (b) Ni X-ray mapping.

also apparent for bonding at 950°C, as shown in Fig. 14(b). The diffusion depth of Ni is up to 10 μm into the Cu foil, and the concentration of Ni in the Cu matrix near EN/Cu interface exceeds 3%, as indicated in Fig. 15. Decrease of the amount of Ni in the EN layer with temperature is attributed to the formation of low Ni-containing metastable phases, such as Ni₃P and Ni₁₂P₇ at 910°C and 950°C, respectively, as shown in Fig. 7. The compositions of the metastable Ni-P phases fall within the Ni₃P-Ni₁₂P₇ peritectic range in the Ni-P phase diagram. The peritectic temperature of 970°C for these metastable phases within the Ni₃P-Ni₁₂P₇ peritectic range is higher than the eutectic temperature of 880°C for the original EN compositions within the Ni-Ni₃P eutectic range. It is argued that the Ni-P liquid solidified to form the Ni₃.₅₅P (or Ni₁₁.₂P₇) at the bonding temperature due to the decreasing of the amount of element Ni in the Ni-P liquid. As a result, the metastable phases with higher peritectic temperature will make the application temperature of the joint higher than that of melting for the original EN composition before bonding.

One might argue the behaviors of yttrium in the bonding since some amounts of yttrium are detected in the concentration profiles, as shown in Figs. 9, 10, and 15. However, it should be pointed out that the detected yttrium originally added to promote the AlN sintering is enhanced due to the presence of Al-Y-O compounds within the AlN substrate, while no Y enrichment is ever observed near the interfacial region. Thus it appears that yttrium cast no significant effect on the measured adhesion strength for the present study.

Although the formation of solid solution between Ni and Cu ensures a strong joint in the EN/Cu interface, the weakness in the AlN/EN interface itself makes the adhesion strengths of samples bonded at 910°C and 950°C only around 3.19 ± 0.99 and 4.76 ± 4.23 MPa, respectively. The large variation of adhesion strength in the 950°C-bonded case is due to the fact that some bonded samples appear to lose adhesion directly after being taken out of the hot press chamber. This could result from the negative effect of lack of Ni-P liquid in the AlN/EN interface to wet the AlN ceramic under the bonding conditions with high temperature and pressure. The wetting angle of Cu on the EN-metallized AlN at 1150°C is estimated around 125°, as shown in Fig. 16. It is smaller than that of pure Cu on AlN, which is around 150°, as observed by Rhee [5]. This indicates that Ni-P addition in Cu has positive effects for the wetting of liquid Cu on AlN, although the wetting angle is still large for a normal good wetting. It should be pointed out that the wettability of liquid Ni-P on AlN is not yet known. Besides, the affinity of Ni-P metastable compounds with AlN and the mismatch of coefficients of thermal expansion between them are not well understood. However, one thing that can be confirmed is that the thermal stress initiated from the bonding temperature to room temperature can not be neglected.

C. Edges Trimming Effects

Edges trimming of the as-bonded samples by grinding can be regarded as a mechanical damage exerted by an external force. All kinds of stresses, such as tensile, compressive,
and/or shear, may be introduced during trimming. The AlN/EN interface with discontinuity of elastic modulus across the metal/ceramic joint is subject to the concentrated stress under the action of external stresses. The stress cycle by trimming introduces the damage in the AlN/EN joint before adhesion testing. Moreover, the differences in the grinding rates between AlN, EN, and Cu will make zones of step or indentation along each interface on the trimmed surfaces in edges, especially in the AlN/EN interface, which is also the site of stress concentration. This renders the cracks easier to initiate and propagate along the AlN/EN interface when bonded samples fail. As a result, two types of phenomena are observed from the pull test of the trimmed samples: One is the decrease of adhesion strength from around 10 MPa for the untrimmed samples to around 6 MPa for the trimmed samples bonded at 600°C, and the other is the enlarged variation in the measurement of adhesion strength around ±6 MPa at 700°C, as shown in Fig. 17.

D. Surface Roughness Effects

In metal/ceramic joining, surface roughness is a critical parameter to ensure the bonding successful. The effects of surface roughness on the strength in the joint were reported elsewhere [26]. It is claimed that the increase in the adhesion strength of the Cu-metallized AlN is attributed to the rough surface after etching which provides sites for mechanical interlocking. Fig. 18 shows the comparison of the adhesion strengths among etched, polished, and as-received samples. The average adhesion strength of etched samples has a higher value than that of as-received ones bonded at 600°C and 700°C, while the average adhesion strength of polished samples is the lowest among them. It is interesting to point out that the maximum adhesion strength for etched samples reaches 14 MPa on average, which is nearly two times larger than that in the Cu-sputtered AlN as reported in the literature [1]-[4]. Although there exist deviations in the measurement of adhesion strength, it is apparent that the adhesion strength can be enhanced if the AlN substrate is etched properly in advance before electroless plating and following bonding, as revealed in this study.
Fig. 18. The adhesion strengths of bonded assembly for as-received, etched, and polished AlN, which were bonded with Cu foil after EN metallization.

Almost all failure of etched and polished samples bonded at both 600°C and 700°C occurred in the AlN/EN interface. It is apparent that the mirror-like surface of the polished AlN without any mechanical interlocking with the EN film exhibits a poor adhesion strength in the AlN/EN interface. Even after cooling from 700°C, no measurable adhesion strengths of polished samples are obtained, because the intrinsic bonding strength of the atoms between EN and AlN can not overcome the effects of mismatch of coefficients of thermal expansion (CTE) on the AlN/EN interface. For the as-received AlN case, it is argued that the large macroscopic irregularity in the AlN/EN interface offers a compression exerted from the metal side (high CTE) to hold the extrusions of the rough surface on the ceramic side (low CTE) as the sample is cooled from the bonding temperature, as exhibited in Fig. 19, which results in an additional shear strength offset in the adhesion test. In addition, the surface roughness of the macroscopic rough surface will tend to detour the crack, which propagates originally along the AlN/EN interface, toward the metal matrix (e.g., EN). Moreover, some weak contacts in the EN/Cu interface resulting from the difficulty of the deformed Cu foil to conform to the macroscopic rough surface of the EN-metallized AlN will act as the initial sites or the path for the cracks propagating in the as-received case, as shown in Fig. 8(a). Thus, the whole path of crack is through the AlN/EN, EN/Cu interfaces and EN film itself. On the other hand, the etched AlN reserves the mirror flat morphology in the macroscopic view, which is produced by polishing before etching, despite the many small etched holes that were observed microscopically on the macroscopic flat surface after etching, as reported by Chang et al. [27]. In fact, the EN film grown from the etched holes anchors with the etched AlN surface to exhibit a good mechanical interlocking. This results in a higher adhesion strength for the etched samples than the as-received ones.

On the basis of the above discussion, schematic diagram of interfacial morphologies in the as-received, polished, and etched AlN-derived bonding assembly is presented to illustrate the crack propagation during fracture. Fig. 20 pinpoints the distinctions of fracture behavior under various pretreatment of the AlN substrate, which in turn result in the variation in the measured adhesion strength of the bonded assembly, as revealed in this study.

IV. CONCLUSIONS

1) The electroless Ni (EN) plating method was employed to metallize the AlN ceramic substrates. The EN-plated AlN substrate was bonded with the Cu foil to form a sandwich-like AlN–EN/Cu/EN–AlN assembly by hot pressing in vacuum. The bonding of EN-metallized AlN and Cu is conducted through solid-state diffusion and liquid phase through both wetting and diffusion.

2) A maximum adhesion strength of the AlN–EN/Cu/EN–AlN assembly bonded between 600°C and 700°C is around 10 MPa. The adhesion strength of the joint depends on the characteristics of two different interfaces of AlN/EN and EN/Cu. If the bonding temperature is lower than 600°C, the solid solution reaction through the interdiffusion between Cu and EN is slow, and the adhesion strength is controlled by the EN/Cu interface. If the bonding temperature is higher than 700°C, the residual stress induced in the AlN/EN interface due to the mismatch of CTE of AlN and EN will reduce the adhesion strength of the joint, and the adhesion strength thus depends on the EN/Cu interface. An optimum bonding temperature is observed between 600°C and 700°C, where the contribution of the mechanical interlocking in AlN/EN
interface and the solid-state diffusion bonding in the EN/Cu interface to the adhesion strength of joint are competitive.

3) The adhesion strengths of the bonded samples are highest with etched AlN, with as-received next, and with polished the least. This is due to the combined effects of both surface roughness and surface morphology of the AlN ceramics.

4) Mismatch of coefficients of thermal expansion between AlN and EN induces a residual stress in the AlN/EN interface. As the least. This is due to the combined effects of both surface with etched AlN, with as-received next, and with polished that of polished one, the introduced residual stress tends to initiate and to propagate a crack along the polished AlN/EN interface to fracture the joint. However, it also produces a compression from the metal side to tightly hold onto the rough surface of the as-received AlN ceramic. This results in a higher adhesion strength of bonded samples for the as-received AlN than that of the polished one.

5) Although the surface roughness of the as-received and etched AlN appears to be the same, the adhesion strength of the bonded sample is higher for the etched AlN than the as-received one due to the different surface morphologies. The etched surface of AlN with micro-etched holes provides the anchor sites for interlocking with the EN film, and higher adhesion strength in the joint is achieved.

REFERENCES


Chang-Daw Young is a graduate student in the Department of Materials Science and Engineering, National Tsing Hua University, Taiwan. His current work involves metallization of aluminum nitride substrate through electroless plating and solid-state bonding.

Jens-Gong Duh received the B.S. degree in nuclear engineering from National Tsing Hua University, Taiwan, and the Ph.D. degree in materials engineering from Purdue University, West Lafayette, IN. He is a Professor in the Department of Materials Science and Engineering, National Tsing Hua University, Taiwan. During 1987-1988 he was a Visiting Scientist at Cornell University Ithaca, NY. His technical interests include electron microscopy, interfacial phenomena of materials, ceramic thin-film processing, and surface modification of ceramics.