# Adhesion Strength and Microstructural Evaluation in Electroless Ni-P Metallized AlN Substrate

Chung-Daw Young and Jenq-Gong Duh

***Abstract*— The adhesion strength of the electroless Ni (EN)-plated AlN substrates is studied through investigation of the microstructural morphologies at the AlN-EN interfaces. Etching sites around the Al-Y-O compounds on the etched AlN substrate provide the anchor acceptors for interlocking the EN film to achieve a high adhesion strength. Separation of the EN film from the AlN substrate under the action of force leaves the fracture cracks propagating along the AlN/EN interface, cutting through the anchors and making the fragmental EN films around the etching sites resided on the AlN fracture surface. However, the polished AlN substrate lacks the interlocking sites and fails to obstruct the cracks propagating along the AlN/EN interface, and thus results in a poor adhesion strength. An appropriate adhesion strength of 13.7 MPa with a small standard deviation ($\pm$2.3 MPa) can be obtained for the previously etched and 10 $\mu$m thick EN-plated AlN substrate.**

***Index Terms*— Adhesion, electroless plating, fracture crack, interlocking.**

## I. Introduction

ELECTROLESS Ni (EN) plating has been an important coating technology in many engineering applications due to various physical characteristics, such as hardness, uniformity, wear resistance, corrosion resistance, and the ability of coating on the non-conductive surface [1]. Recently, EN has attracted interests for application in electronics industry because of its excellent solderability, conductivity and receptivity to brazing, wire, and die bonding. In addition, the capability of acting as the diffusion barrier, as well as providing high aspect ratio in metallizing pin through hole (PTH) and via renders profits on the microelectronic packaging. Furthermore, through metallization, such as protect finishing, barrier coating, and underplating for electrical connection and mechanical bonding, multilayered three-dimensional (3-D) circuits construction can be performed.

The process of EN plating is described as an autocatalytic electrochemical reaction without external current applied [2]. In other words, the Ni ions selectively reduce only at the surface of a catalytic substrate from the aqueous solution, followed by the continuous deposition through the catalytic action of the deposit itself. The surface of substrate, especially the insulating regions, needs sensitization and activation in the chloride-Pd and Sn ions based solutions [3], [4] in advance for successful EN deposition.

Aluminum nitride (AlN), one of important ceramic insulators with high thermal conductivity [5]–[7], is considered as a substrate material to replace alumina ($Al_2O_3$) for application in electronic packaging industry. In fact, AlN with good mechanical strength, low dielectric constant, no toxicity and a thermal expansion coefficient close to that of silicon has rendered it an excellent substrate material. Surface metallization of AlN substrate is necessary for the mounting and connection of electronic devices to perform the signal transport, power supply and heat dissipation functions. EN plating is one of such metallization approach, which possesses a great deal of advantages, such as cost-effectiveness and mass production capability. This method has been widely used and investigated in patterning the circuits on plastic and $Al_2O_3$ [8]–[12] printed wiring boards (PWB's). However, only a few investigations were related to the AlN substrates [13], [14]. The critical requirement for the application of the EN-metallized AlN is to ensure an appropriate adhesion strength of the deposited EN film on the AlN substrate. In this work it is intended to investigate the relationship of the interfacial morphologies and the bonding mechanism at the interface between the EN film and the AlN substrate. In addition, the dependence of the adhesion on the thickness of the EN film is discussed.

## II. Experimental Procedures

### A. Sample Preparation

The commercial yttrium-contained aluminum nitride (SH-15, TOKUYAMA SODA CO., LTD., Japan) with the size of $1 \times 1 \times 0.025$ in$^3$ was used as the substrate. The as-received AlN substrate with the surface roughness (Ra) around 300 nm was analyzed by a surface profilometer (ALPHA-STEP 250, TENCOR, U.S.A.). The scan rate is 50 $\mu$m/s and scan length is 2 mm. The AlN substrates with different surface morphologies were prepared through the SiC grinding and diamond polishing, and then by the 4 wt% NaOH solution etching for 180 min to obtain the surface roughness around 15 and 300 nm, respectively.

### B. Electroless Ni-P Plating

The electroless Ni-P films were plated on the sensitized and activated surfaces of the as-received, polished and etched AlN

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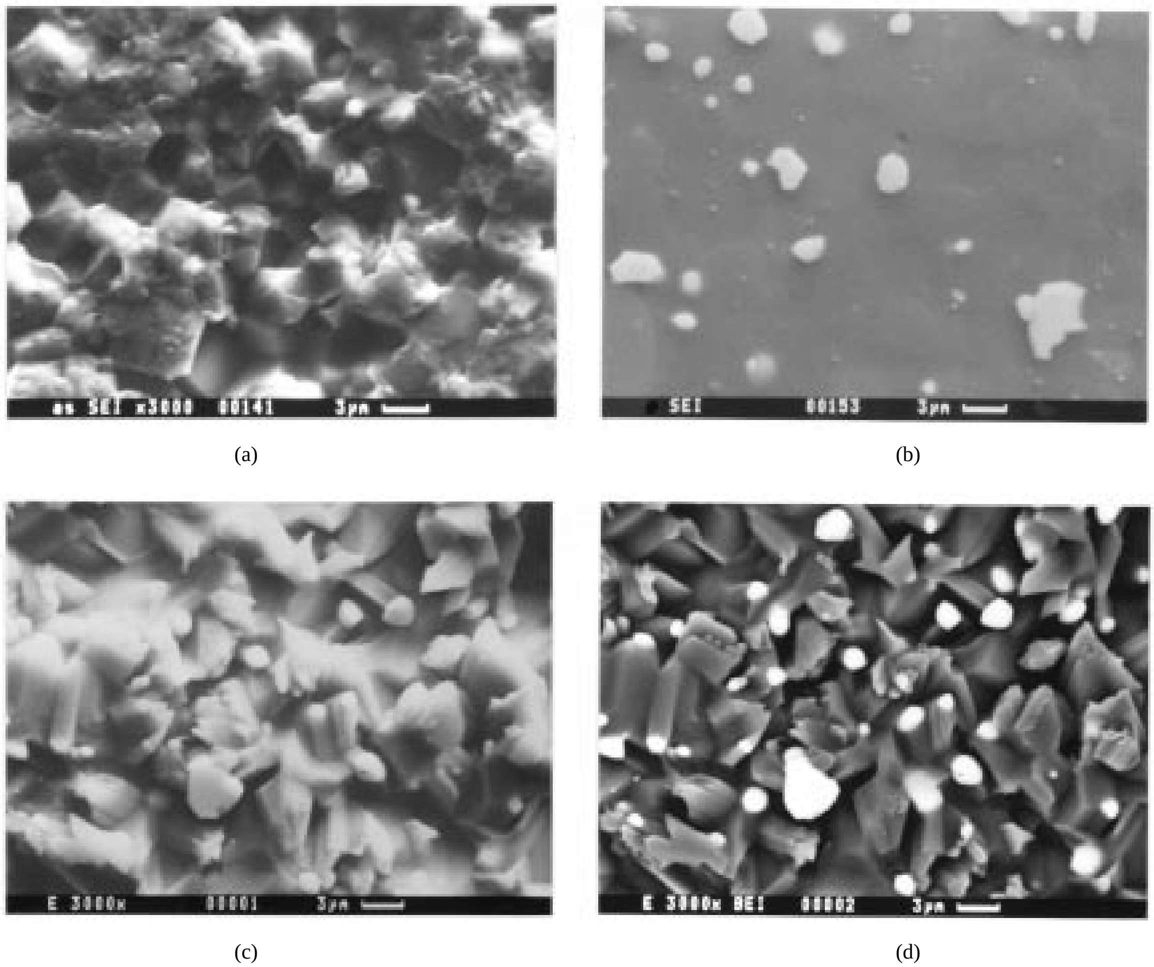



Fig. 1. Surface morphologies of: (a) as-received, (b) polished, (c) etched AlN substrate, and (d) corresponding BEI of (c).

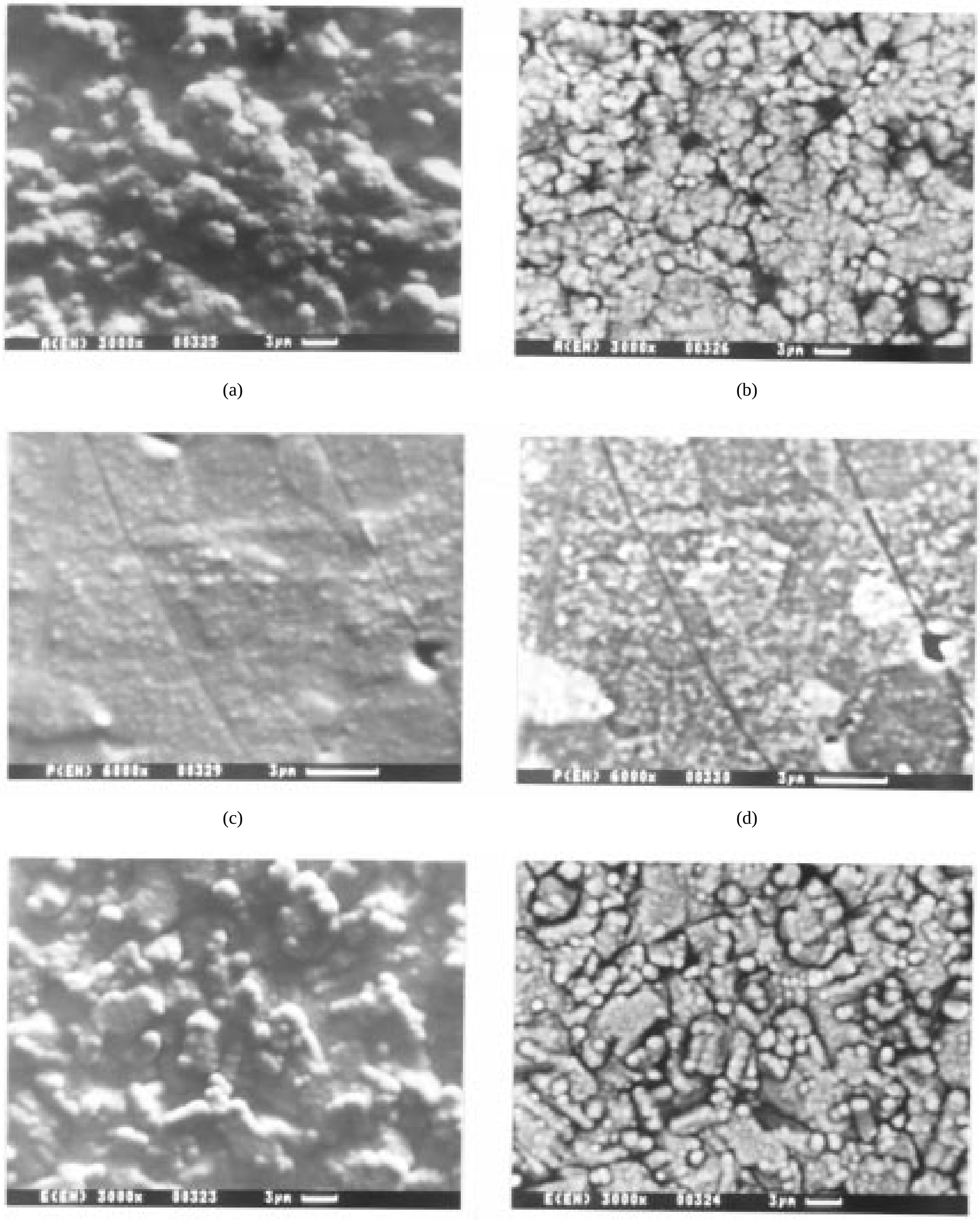
substrates. Each liter of sensitization and activation solutions contains 16 g $SnCl_2{\cdot}2H_2O$–30 ml HCl and 0.1 g $PdCl_2$–8 ml HCl, respectively. The dipping time was 10 min. After each sensitization and activation steps, the AlN substrates were rinsed with the deionized (D.I.) water for 10 min. to remove the excess Sn and Pd species. The electroless Ni-P plating bath included the Ni source: 20g/l $NiSO_4{\cdot}6H_2O$, reducing agent: 27g/l $NaH_2PO_2{\cdot}$ $H_2O$, complexing agent: 16g/l $Na_2H_4C_3O_4{\cdot}6H_2O$ and the pH adjuster: a reaction grade $H_2SO_4$ acid. The pH value of the plating bath was initially adjusted and maintained at 4.6 at room temperature before the EN plating. The EN solution was heated to 70 °C, and the activated AlN substrates were then put into the EN plating bath for 10 and 120 min to deposit the thin and thick EN films, respectively.

### C. Adhesion Strength Measurement

The adhesion strength of the EN-plated AlN substrate was measured with a pull-off tester (SEBASTAIN FIVE, QUAD, U.S.A.). The Aluminum pull stud was adhered by epoxy on the EN-plated AlN substrate and both were fixed and pressed together by a clamp for curing at 150 °C for 1 h. The adhesion strength measurement was accomplished at room temperature under the air atmosphere with a pull rate of 2.58 kgf/s. The diameter of the nail head of the pull stud is 3.58 mm. As the EN film was pulled off from the AlN substrate, the adhesion strength was calculated by dividing the exerted force by the bonded area of the stud nail head.

### D. Microstructural Evaluation

The morphologies of the free surfaces of the AlN substrates and the plated EN films, and the fractured surfaces of the EN/AlN interface were examined by scanning electron microscopy (SEM) (CAMSCAN, England) through a secondary electron image (SEI). A backscattered electron image (BEI) analyzer is equipped to differentiate the compositional distribution taking advantage of the different reflective ability of backscattered electrons to different elements. The BEI also assist to further observe the surface topography due to its apparent contrast across the physical boundaries on surfaces. The EN-plated AlN substrates were mounted vertically in epoxy, and then cut, ground, polished and carbon coated for the cross sectional viewing. The composition of the EN film was quantitatively analyzed by energy dispersive X-ray spectroscopy (EDX) (EXCEL, LINK, England). The phases of the EN film and the AlN substrate before and after the pull-off testing were identified by X-ray diffraction (XRD) (DMAX-B, RIGAKU, Japan).

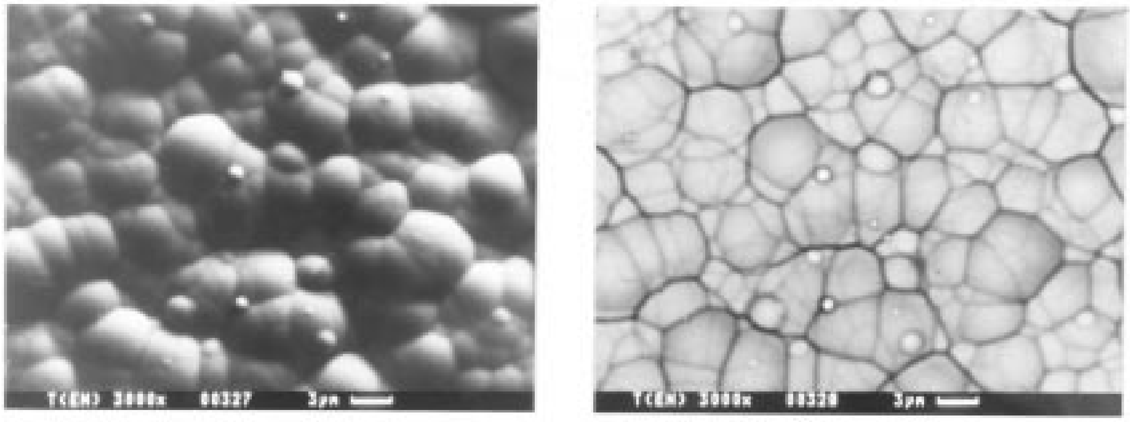


(a) (b) (c) (d) (e) (f)

Fig. 2. Surface morphologies and corresponding BEIs of electroless Ni-plated AlN substrates for (a) and (b) as-received, (c) and (d) polished, (e) and (f) etched AlN substrates.

## III. Results and Discussion

Surface morphologies of the AlN substrates with different surface treatments, including as-received, polished and etched, are shown in Fig. 1(a)–(c), respectively. The as-received AlN substrate has a rough surface on which a blurred layer is above the equiaxed AlN grains. The surface roughness (Ra) is 0.31 $\mu$m, as shown in Table I. After polishing, the surface becomes smooth and has the Ra around 15 nm. The white grains in the AlN matrix are Al-Y-O compounds, which are the reacted products from the raw materials of AlN powders and the sintering aids. They were previously identified by XRD as $AlYO_3$ and $Al_5Y_3O_{12}$ [15]. On the contrary, the alkali-attacked AlN grains on the etched surface of Ra 0.3 $\mu$m appears irregular and have sharper edges than those on the as-received one, despite both substrates have similar surface roughness. However, the Al-Y-O compounds with higher




(g) (h)

Fig. 2. (*Continued.*) Surface morphologies and corresponding BEIs of electroless Ni-plated AlN substrates for (g) and (h) thicker EN film on etched AlN substrate, respectively.

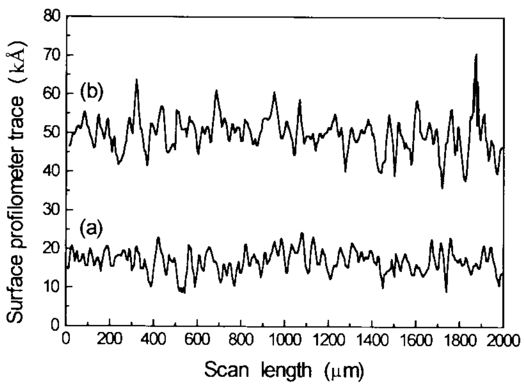



Fig. 3. The surface profilometer traces of the: (a) as-received AlN substrate and (b) EN film plating for 10 min.

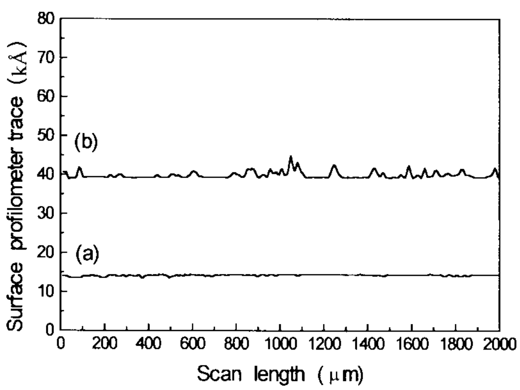



Fig. 4. The surface profilometer traces of the: (a) polished AlN substrate and (b) EN film plating for 10 min.

resistance against the etching behavior retain the original round form. Some AlN grains connecting to Al-Y-O compounds exhibit column shape because that the Al-Y-O grains act as the etching resistors in the AlN granular end. The distribution of these Al-Y-O compounds on the etched AlN surface is clearly observed through the BEI morphology due to the larger atomic weight of elemental Y in Al-Y-O compounds than that of elemental N in AlN, as shown in Fig. 1(d). Details of the related etching behaviors have been reported elsewhere [16].

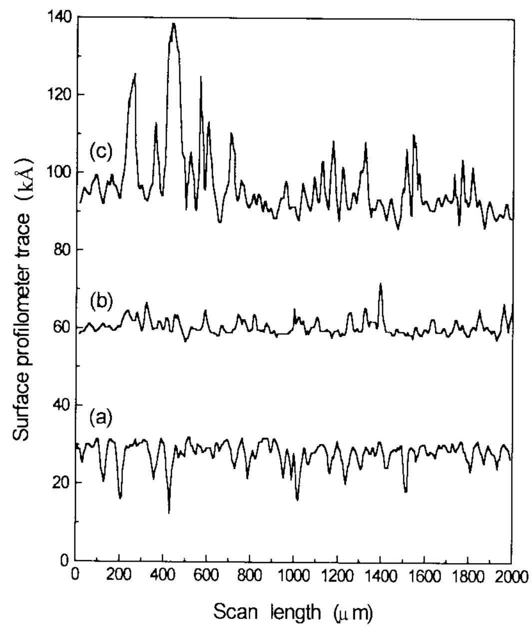



Fig. 5. The surface profilometer traces of the: (a) etched AlN substrate, (b) EN film plating for 10 min and (c) EN film plating for 2 h.

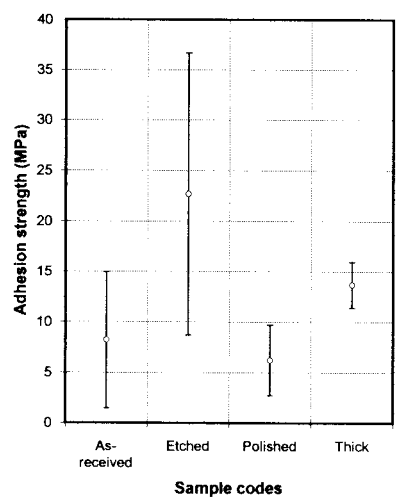



Fig. 6. Adhesion strength of samples A (as-received), P (polished), E (etched), and T (thicker EN film).

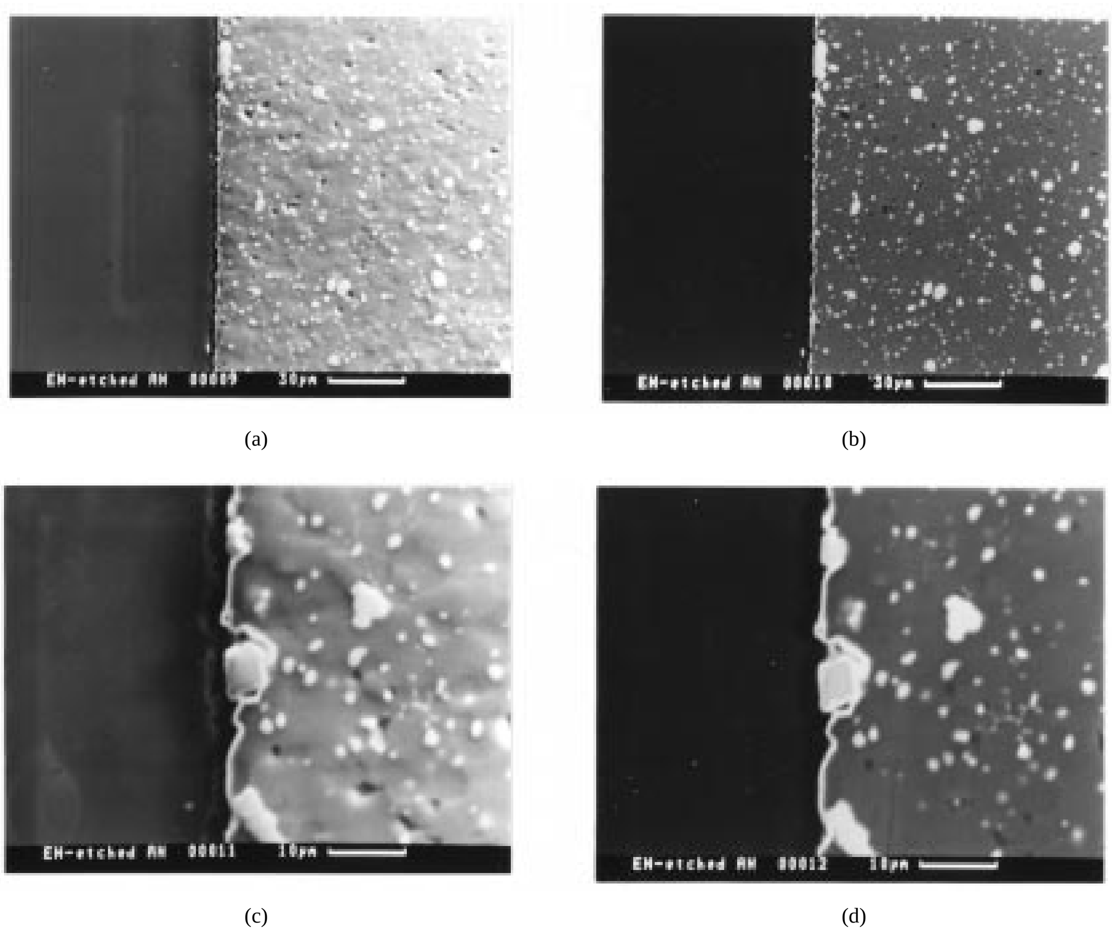



Fig. 7. Cross-sectional view of the EN film on the etched AlN substrate: (a) SEI micrograph, (b) corresponding BEI of (a), and (c) and (d) higher magnification pictures of (a) and (b), respectively. The EN film well contours AlN and penetrates into AlN surface around Al-Y-O compounds to form anchors.

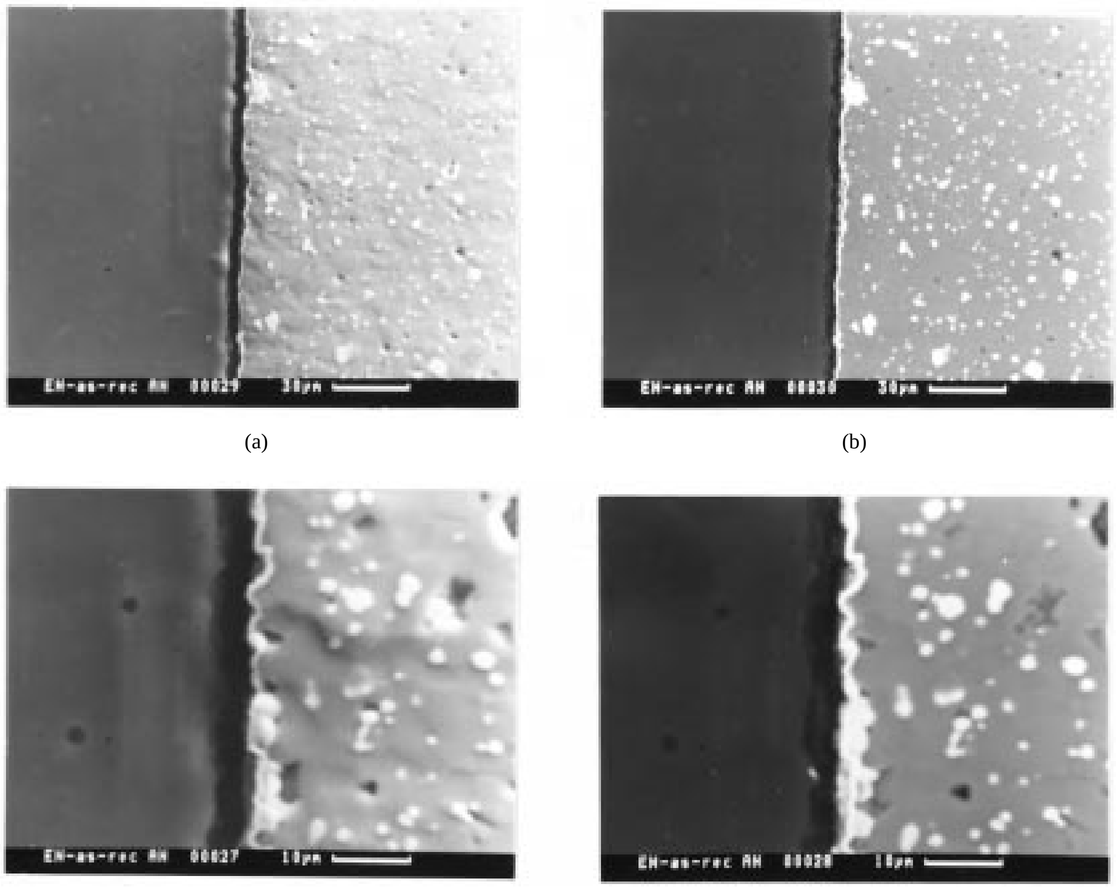
### *A. EN Surface Morphology*

Thin EN film containing 11.3 wt% elemental P analyzed by EDX is plated on the AlN substrates for 10 min. For the as-received AlN, the EN particles smaller than 1 $\mu$m distribute randomly over the rough substrate. Fig. 2(a) and (b) show the SEI and BEI, respectively, of the surface morphologies of the EN film. By BEI, the shape of EN particles on the film surface is more clearly observed than by SEI, especially in the shaded and concave area. On the polished AlN surface, the EN film is composed of tiny particles, which are much smaller than those on the as-received AlN surface. The SEI and BEI of the EN surface are indicated in Fig. 2(c) and (d). As compared with the as-received case, the EN film plated on the etched AlN surface exhibits a similar particle size distribution. However, the larger EN particles tend to align locally and linearly, as shown in Fig. 2(e) and (f), which reflects the sharp edges of the irregular and etched AlN grains. The length of these linear aggregate is smaller than 5 $\mu$m. It is likely that the sharp granular edges on the etched AlN substrate have more chance than the concave sites to attract the Ni and P species to deposit during the plating. The EN particle deposition enhanced on the sharp edges of the AlN grains results in the morphology of the larger EN particles distributing locally and linearly. The phenomena is not observed for the plating on the as-received and the polished AlN substrates.

As the plating time increases to 120 min to deposit a thicker EN film on the etched AlN substrate, the enormous EN particles coalesced from small ones are observed, as shown in Fig. 2(g) and (h). The large and wide boundaries between the coalesced particles, as well as the small the narrow subboundaries inside are evident. The size of the coalesced particle is as large as 6–7 $\mu$m.

It is believed that the EN particles are rather fine in the initial plating stage. The EN species (Ni and P) continuously precipitate from the plating solution onto the EN surface to form the growing EN particles. The subsequent particle coalescence accompanies particle growing at the expense of the smaller EN particles in order to lower the surface energy. In other words, the behavior of the particle coalescence is dynamic. Besides, the extrusive sites of the EN film have the tendency to retain the EN species, thus the particle coalescence is further promoted. Due to the particle coalescence and the different particle growing rates on rough surface, the distribution of particle size increases with the plating time.

From a macroscopic view, the surface profilometer trace of the EN film partially reflects the particle growing and coalescence outlook. Fig. 3(a) and (b) show the typical surface



(a) (b) (c) (d)

Fig. 8. Cross-sectional view of the EN film on the as-received AlN substrate. (a) SEI micrograph, (b) corresponding BEI of (a), and (c) and (d) higher magnification pictures of (a) and (b), respectively. The EN film well contours the rough AlN, but no apparent anchors are formed.

profilometer traces of the as-received AlN substrate and the deposited EN film, respectively. After the EN plating, the amplitude of the surface profilometer trace enlarges slightly and the surface roughness increases from 0.31 to 0.38 m. This implies that the extrusion sites on the AlN surface enhance the EN deposition. The wave form of the trace is basically pulse-like. Fig. 4(a) and (b) show the typical surface profilometer traces of the polished AlN substrate and the adherent EN film, respectively. The trace for the EN film only consists of the upward peaks. This also reflects the different growing rates of the EN particles. The surface roughness increases from 0.015 to 0.070 $\mu$m after the EN plating. Fig. 5(a)–(c) represent the typical surface profilometer traces of the etched AlN substrate, the thin and the thick EN films, respectively. Again, the formation and amplification of the upward peaks in the traces take place in proportion to the plating time. The values of the surface roughness for the etched AlN substrate, the thin and the thick EN films are 0.30, 0.15, and 0.56 $\mu$m. It is interesting to point out that downward peaks instead of upward peaks show up in the surface profilometer trace of the etched AlN substrate. This indicates that the etching holes on the AlN surface are filled up by the EN species first and the following deposition of the EN species accompanied by the particle coalescence prefers the extrusion sites of the EN film.

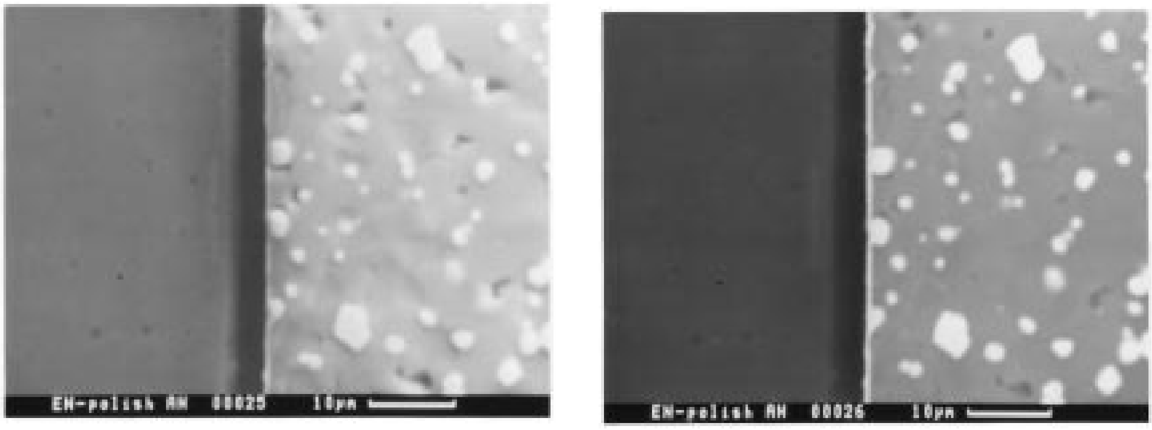
TABLE I
SURFACE ROUGHNESS (Ra) FOR VARIOUS AlN SUBSTRATES AND PLATED EN FILMS (UNIT: $\mu$m)

| | As-received | Polished | Etched | |
|---|---|---|---|---|
| AlN substrate | 0.31±0.02 | 0.015±0.001 | 0.30±0.05 | |
| Plated EN film (plating time) | 0.38±0.03 (10 min) | 0.070±0.016 (10 min) | 0.15±0.01 (10 min) | 0.56±0.02 (2 hr) |

Values of the surface roughness for various AlN substrates and adherent EN films are listed in Table I.

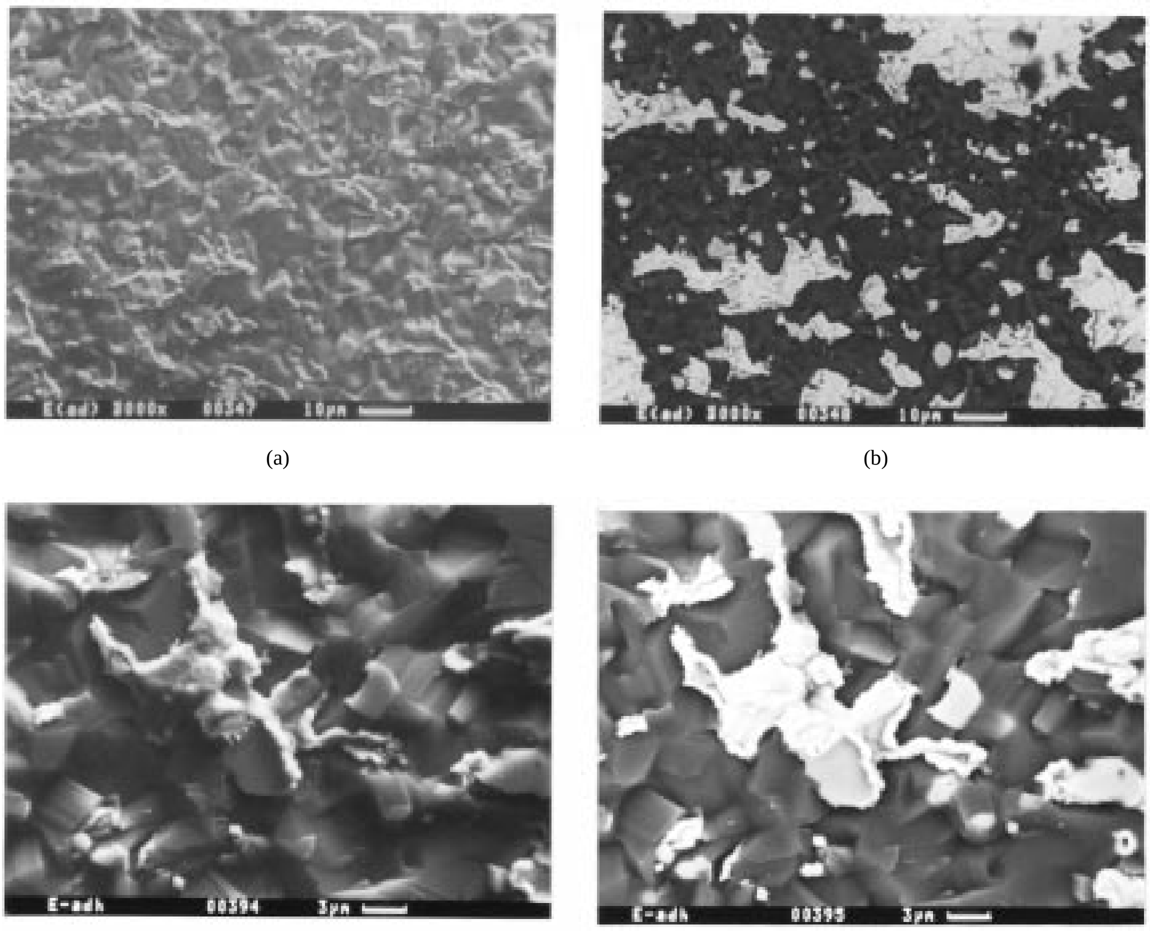
### *B. Effect of Surface Morphology of AlN Substrate*

The adhesion strength of the EN film on the AlN substrate is evaluated by the pull-off test, as indicated in Fig. 6. The samples designated as A, P, and E indicate that the AlN substrates used in the electroless Ni-P plating are as-received, polished and etched, respectively. The plating time is 10 min. Among these, the sample E has the highest average adhesion strength, with the sample A next and the sample P the lowest. It was proposed that the mechanical interlock is the major bonding mechanism of joining the electroless Ni-P film and the substrate [17]. Adhesion strength of the EN film is, therefore,




(a) (b)

Fig. 9. Cross-sectional view of the EN film on the polished AlN substrate. (a) SEI micrograph, (b) corresponding BEI of (a). The EN film well contours the smooth AlN substrates and no anchors are formed.



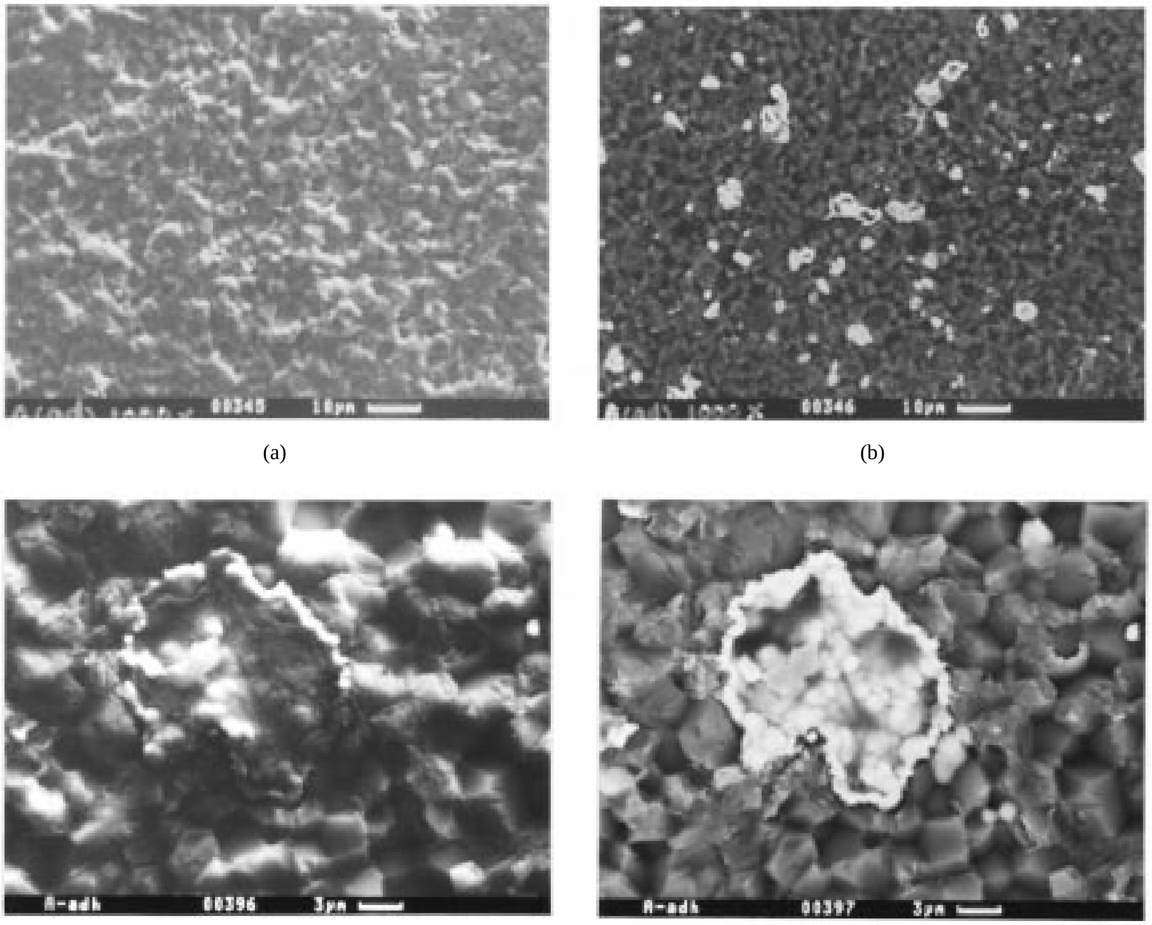

(a) (b)

(c) (d)

Fig. 10. Fractured surface of the EN-plated etched AlN substrate after pulling-off. (a) SEI micrograph, (b) corresponding BEI of (a), and (c) and (d) higher magnification pictures of (a) and (b), respectively. Large areas of the residual EN films are visible around the Al-Y-O compounds and irregular in shape.

determined by the surface morphologies of the AlN substrates. For further evidence, details of the interfacial morphologies in the EN/AlN joints are investigated as follows.

The cross-sectional view of the sample E is shown in Fig. 7. The thickness of the EN film is around 1 $\mu$m. The white grains in the AlN matrix are the Al-Y-O compounds as described before. The EN film penetrates into the AlN substrate along the grain boundary around the Al-Y-O compounds. Some Al-Y-O compounds are further surrounded by the EN film. However, this penetration phenomenon is not observed in the cross sectional view of samples A and P, as shown in Figs. 8 and 9. It is believed that the grain boundaries between



(a) (b)

(c) (d)

Fig. 11. Fractured surface of the EN-plated as-received AlN substrate after pulling-off: (a) SEI micrograph, (b) corresponding BEI of (a), and (c) and (d) higher magnification pictures of (a) and (b), respectively. A few residual EN films are left on the AlN fracture surface and exhibit round shapes.

Al-Y-O compounds and AlN grains are susceptible to be etched by the alkaline NaOH solution due to the higher energy associated with the grain boundaries. The etching sites on the AlN substrate act as acceptors for the EN anchors to tightly interlock the EN film. Thus, failure occurs only when the interfacial cracks propagate through and cut off the anchors to separate the EN film and the AlN substrate. The interlocking mechanism by the EN anchors is one of the major reasons for the good adhesion of the EN film on the etched AlN substrate as compared with those on the as-received and polished ones.

More information can be obtained from the cross-sectional view in Figs. 7–9. As identical to the Ra values in Table I, the EN film appears rougher for both the etched and the as-received AlN substrates than for the polished, while the wavy form of the EN film exhibits angularity for the EN plating on the etched AlN substrate as compared to the as-received, as shown in Figs. 7 and 8. In contrast to Fig. 1(c), the angularity comes from the sharp edges of the etched AlN grains. Rough interface has higher resistance than the smooth one to inhibit the cracks propagation along the interface. It is argued that the residual thermal stress, which generates from the thermal expansion mismatch of two bonded materials, changes from the interfacial shear stress to the partial shear-partial compressive one as interface becomes rough [17]. The angular interface, furthermore, has higher crack propagating resistance than the round one. Thus, the propagation of a crack is more difficult along the EN/etched-AlN interface than along the EN/as-received-AlN interface. Since the sharp edges of the AlN grains exist at the EN/etched-AlN interface, the tip of a interfacial crack must adjust its propagating direction in larger curvature to continuously propagate along the EN/etched-AlN interface. Otherwise, the crack will go forward into the EN

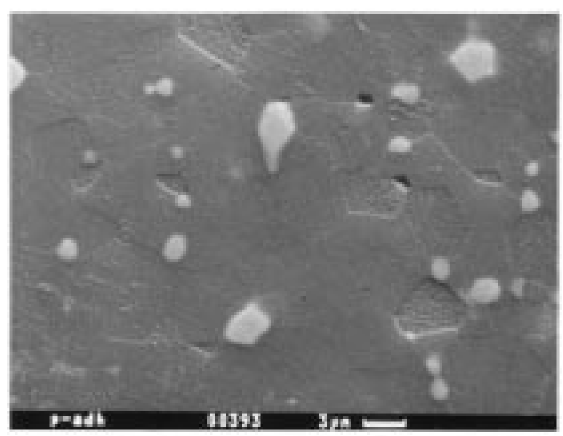
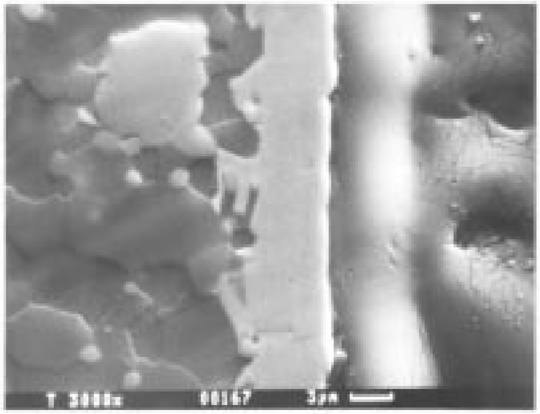
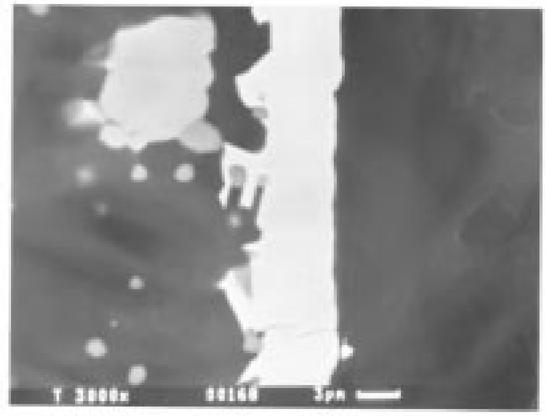


Fig. 12. Fractured surfaces of the EN-plated polished AlN substrates after pulling-off. No residual EN film is visible on the AlN fracture surface.




(a)

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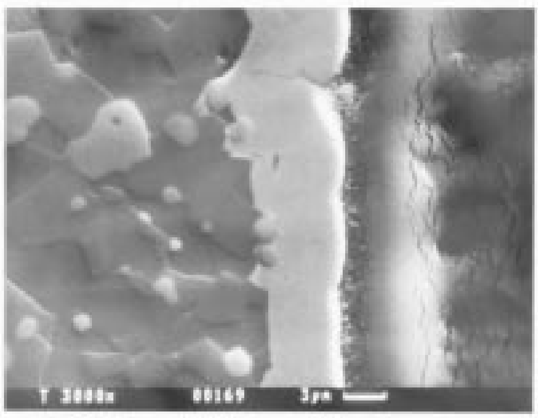
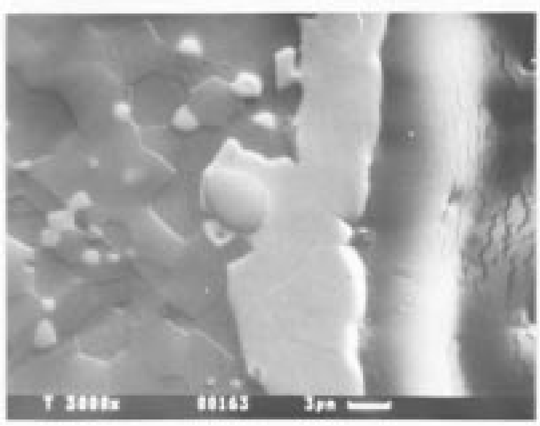



(c)


(d)

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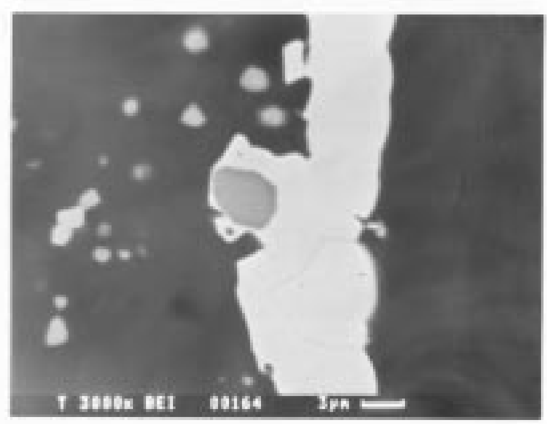
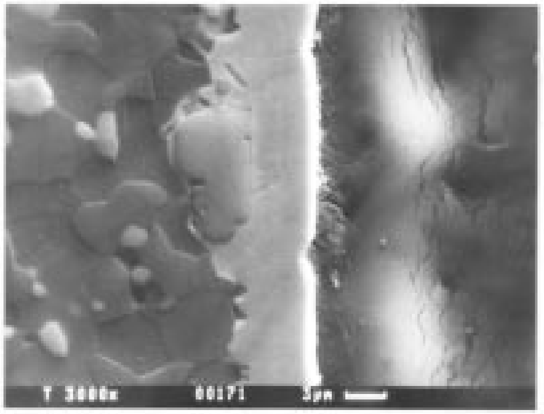



(f)

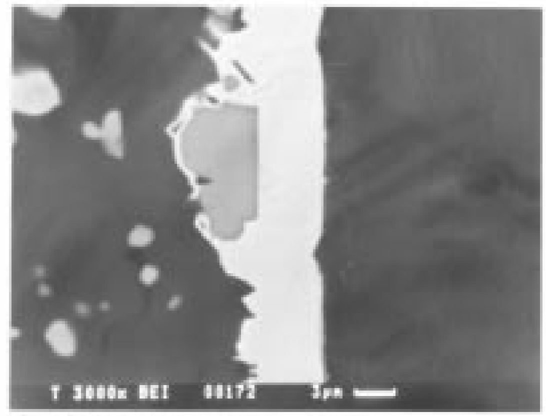
Fig. 13. Morphologies of the cross-sectional views of the thick EN films on the etched AlN substrates: (a), (c), (e), (g), (i), and (k) SEI micrographs, and (b), (d), (f), (h), (j), and (l) corresponding BEI of (a), (c), (e), (g), (i), and (k), respectively.

bulk and result in residual EN films on the AlN fracture surface after a pull-off testing.

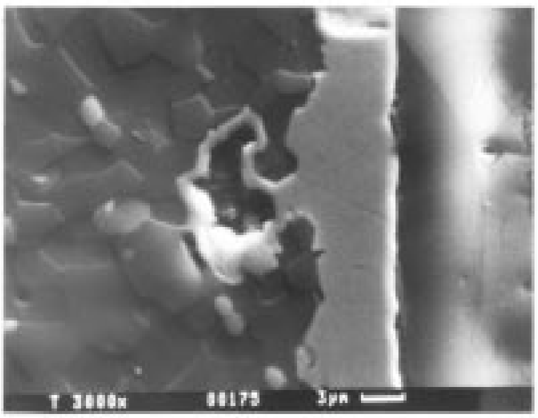
The interlocking between the EN film and the etched AlN substrate can be revealed by surveying the AlN surface of the fractured interface (AlN fracture surface). For the etched case, the irregularly shaped residual EN films distribute over the AlN fracture surface after the pull-off test, as shown in Fig. 10. The residual EN films locates around the Al-Y-O compounds with a size of 5–20 $\mu$m. In contrast with the cross sectional view in Fig. 7, it is argued that these EN residues are the fractured anchors that penetrate deeply into the AlN surface and thus tightly interlock with the AlN substrate. For the as-received case, the residues of the fractured EN film are also observed on the AlN fracture surface occasionally, as shown in Fig. 11. However, these residual EN films are not located around the Al-Y-O compounds, instead they reside on the open



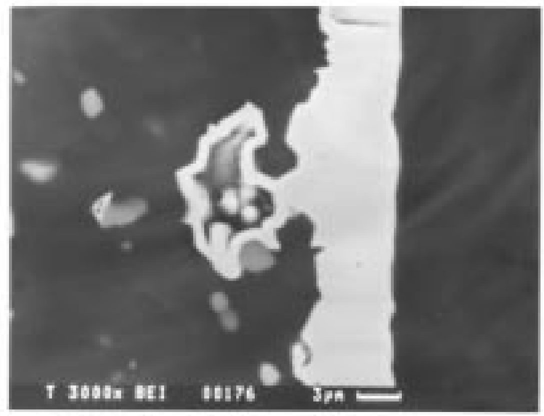

(g)




(h)




(i)

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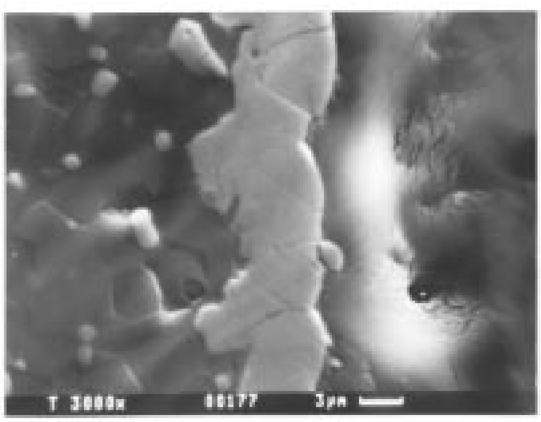


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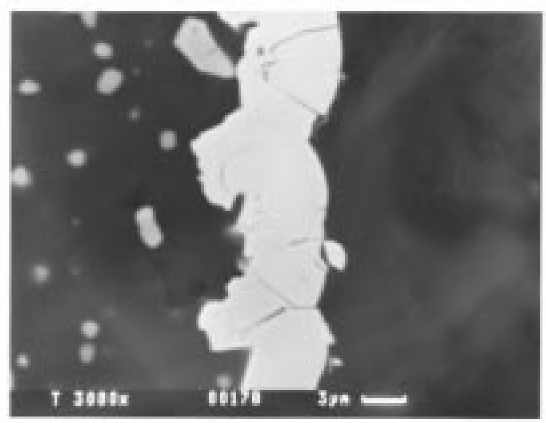


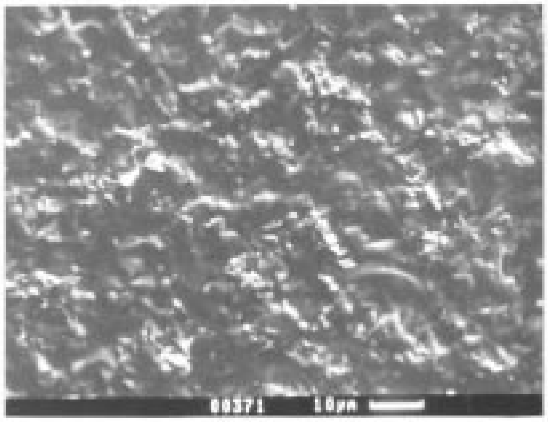

(l)

Fig. 13. (*Continued.*) Morphologies of the cross-sectional views of the thick EN films on the etched AlN substrates: (a), (c), (e), (g), (i), and (k) SEI micrographs, and (b), (d), (f), (h), (j), and (l) corresponding BEI of (a), (c), (e), (g), (i), and (k), respectively.

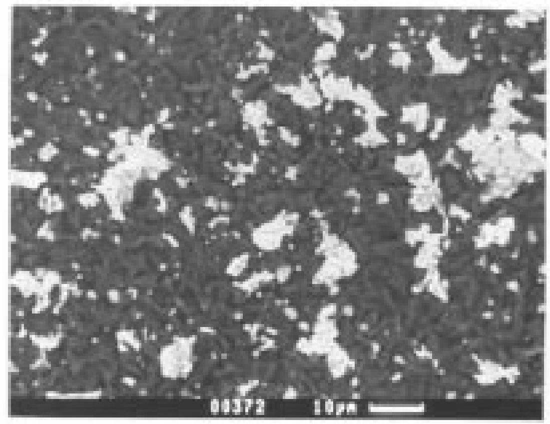
pores of the as-received AlN substrate. The open pores are, in fact, another kind of anchors. The density of the open pores on the as-received AlN substrate is lower than that of the etching sites around the Al-Y-O compounds on the etched AlN substrate. Thus, the EN film possesses higher adhesion strength on the surface of the etched AlN substrate than on the as-received. The polished AlN substrate without rough surface nor etching sites as the anchor acceptors exhibits the poorest EN adhesion ability. It was shown that the AlN fracture surface for the polished case is as similar as the polished surface before plating. As indicated in Fig. 12, no residual EN films adhere on the AlN fracture surface.

### C. Effect of Thickness of EN Film

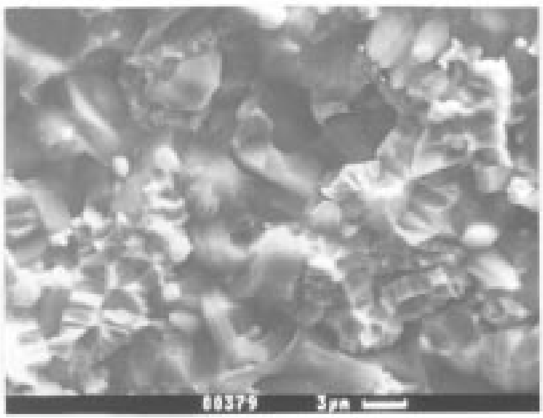
To investigate the thickness effect of the EN film on the adhesion strength, samples T, in which the EN film is plated



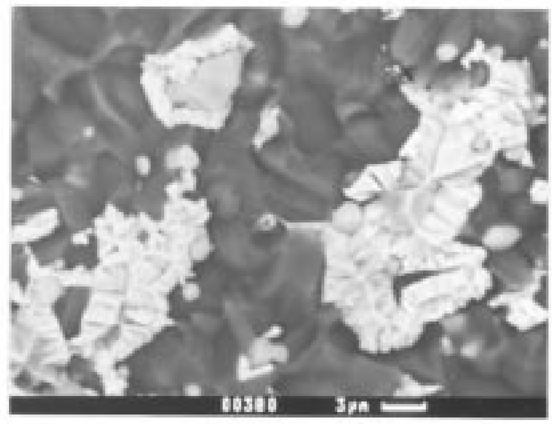

(a)




(b)




(c)




(d)

Fig. 14. Fractured surface of the etched AlN substrate with thick EN film plated on the EN film after pulling off test: (a) SEI micrograph, (b) corresponding BEI of (a), and (c) and (d) higher magnification pictures of (a) and (b), respectively.

on the etched AlN substrates for 2 h to increase the thickness of the EN film to 10 $\mu$m, are prepared. As described before, the sample E has the highest adhesion strength among all of these EN metallized AlN substrates, as shown in Fig. 6. However, the sample T which has the second higher adhesion strength but lower deviation shows the best performance.

Fig. 13 shows the morphology of the cross sectional views of the sample T. Similar to the sample E, mechanical interlocking is the major bonding mechanism between the EN film and the AlN substrate. The interlocking includes many types, such as the penetration of the EN film into the boundaries between the AlN grains and the Al-Y-O compounds [Fig. 13(a)–(d)], the surrounding of the EN film around the Al-Y-O grains [Fig. 13(e)–(h)], the accommodation of the EN film to the rough surface of the etched AlN substrate and, in some occasion, the deposition of the EN film inside the open pores on the AlN free surface [Fig. 13(i) and (j)]. The shapes of the anchors to achieve the mechanical interlock are diversified. In addition, from the cross-sectional view, the EN film in the sample T consists two types of microstructure. The first is the small particle layer plated directly on the AlN surface in the initial plating stage. The thickness of the layer is 1–3 $\mu$m. The second layer with coalesced large particles grown from the first layer constructs the major part of the thick EN film. The large EN particle, due to the dynamic coalescence, exhibits a corn shape, as shown in Fig. 13(k) and (l), where the sharp end toward the AlN, while the broaden end directs to the EN surface.

The interlocking mechanism of the bonding is also reflected on the AlN fracture surface of the thick EN-plated etched AlN substrate. The residual EN films distributing over the AlN fracture surface of the EN/AlN interface are shown in Fig. 14. The Al-Y-O compounds imbedded inside the AlN substrate have the residual EN films around. As observed from the cross-sectional view before, the grain boundaries around the Al-Y-O compounds can be easily etched and thus provide the anchor acceptors to interlock the EN film and the AlN substrate.

The shape of these residual EN films is as irregular as that in the sample E. However, the surface of the residual EN film appears faceted, which is not identical to that of the as-plated film. It is argued that the strength at the EN/AlN interface is worse than that of the EN film itself. However, when hindered by the EN anchors, detouring of the propagation of the interfacial crack through the EN film, generally along the interface between the layers of the small and the coalesced particles, is much easier. The EN fracture finally results in

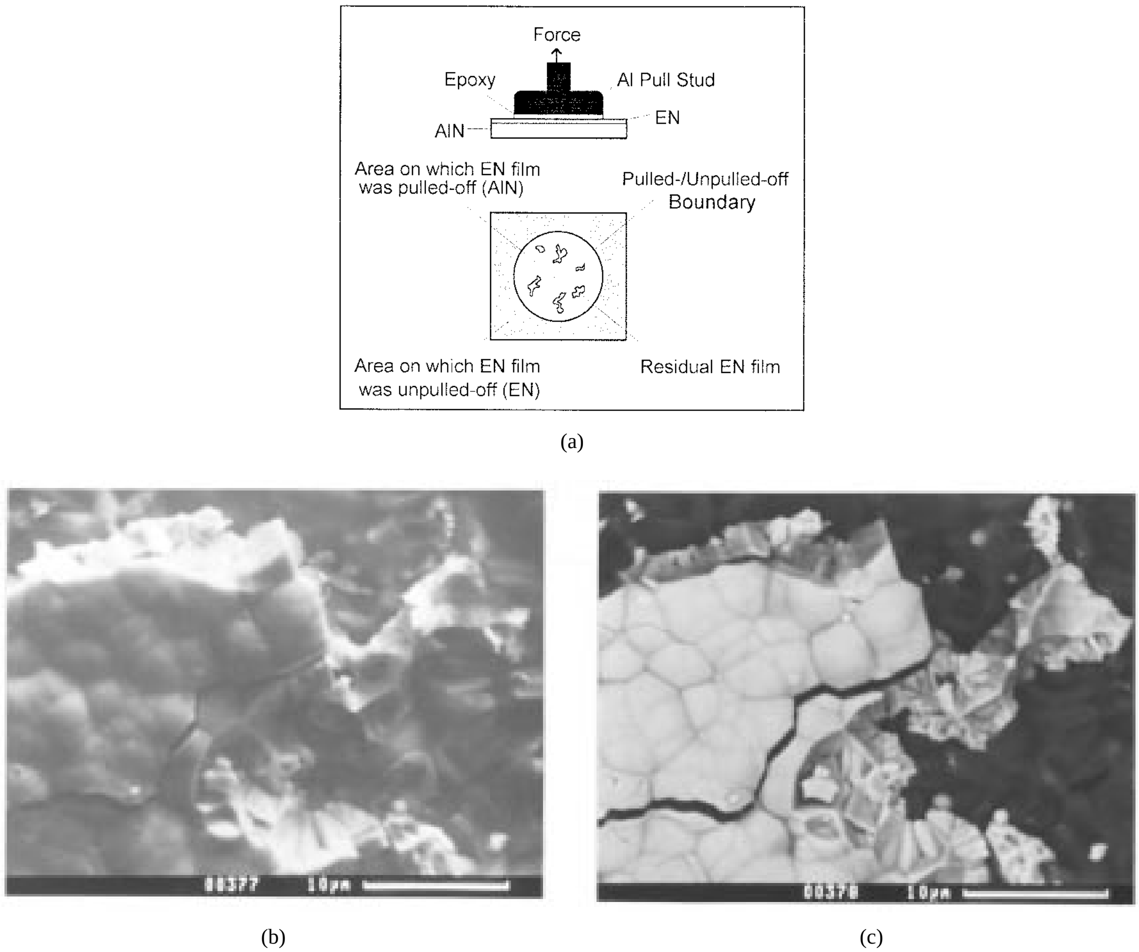



Fig. 15. The boundary between the pulled-off and unpulled-off areas in EN film. Cracks inside the unpulled-off EN film are mainly propagating along the particle boundaries: (a) Schematical diagram, (b) SEI micrograph and (c) BEI micrograph.

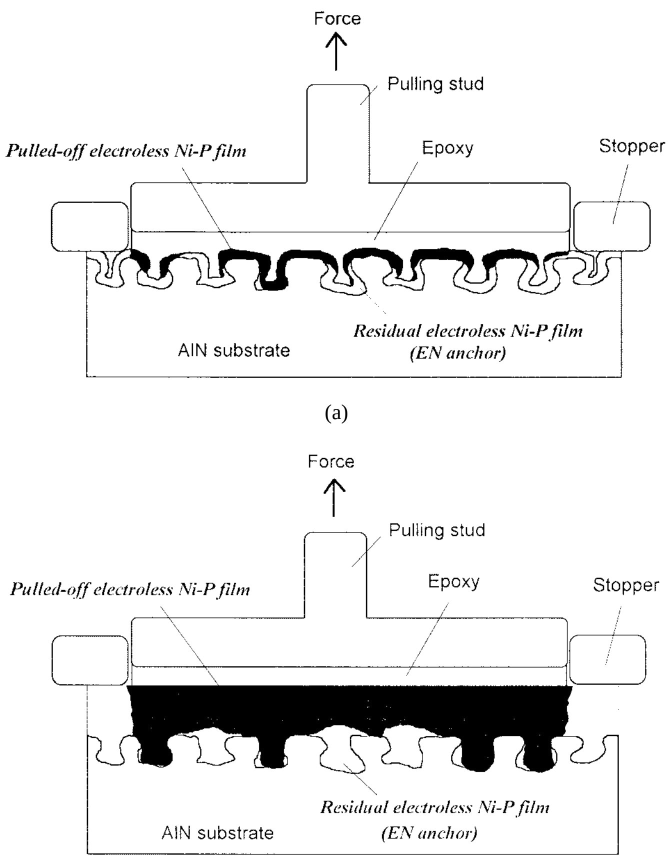
faceted residual EN films on the AlN fracture surface. An observation in Fig. 15 indicates the boundary across which the EN film is intended to be pulled off on one side but not on the other side. The faceted films adjacent to the unpulled-off EN film are the fractured residual EN films. By the way, cracks along the wide boundaries between the coalesced particles were also observed. This indicates that the boundaries are easy path for the cracks to initiate and to propagate.

A schematic diagram to indicate the different fracture mechanisms of the EN-plate AlN substrates for the samples E and T is shown in Fig. 16(a) and (b), respectively. The major difference in fracture between the samples E and T is that the former has a fracture path cutting through the EN anchors mainly along the epoxy/EN interface, while the latter totally through the EN film.

Finally, for the sample E, the EN film is too thin to cover up the surface topography of the etched AlN substrate. There exists similar anchor acceptors on the EN surface above the etching sites for the epoxy to penetrate, as those on the etched AlN surface for the EN film. The interlocking behavior, therefore, penetrates through the EN film and then acts indirectly between the AlN substrate and the adhesive epoxy. The force exerting from the pulling stud not only pulls off the thin EN film, but also breaks the AlN bulk. In addition to the adhesion strength of the EN film on the AlN substrate, the measured adhesion strength possibly reflects the influence of the bulk strength of the AlN substrate. In fact, fracture through the AlN substrate, which is thus broken into two pieces after the pull-off testing, has been observed. On the contrary, the intimate contact between the EN film and the epoxy is difficult because that the bubble may be trapped inside the anchor acceptors and forms an interfacial crack at the epoxy/EN interface. The interface between the epoxy and the EN film becomes another fracture path for the crack to initiate and to propagate. The diverse fracture path explains the highest adhesion strength and large standard deviation of the sample E.

## IV. Conclusion

1) Various surface morphologies of aluminum nitride (AlN) substrates are prepared by polishing and by dilute NaOH solution-etching. AlN substrates are then metallized by electroless Ni (EN) deposition in acid plating bath. Adhesion strength of the EN-plated AlN substrates is evaluated by the pull-off test.
2) The etching sites around the Al-Y-O compounds act as the anchor acceptors to interlock the EN film mechanically. The sharp edges of the etched AlN grains obstruct




(b)

Fig. 16. Schematic diagrams to show the fracture mechanisms of the EN-plated AlN substrates under the pull-off testing for samples: (a) E and (b) T, respectively.

the crack to propagate along the EN/AlN interface and the highest adhesion strength for the EN-plated etched AlN substrate is achieved. However, the polished AlN substrate with smooth surface has the worst adhesion strength for the EN plating.

3) Among all the EN metallized AlN substrates, the thick EN-plated etched AlN substrate with a higher adhesion strength of 13.7 MPa and lower deviation around ±2.3 MPa shows the best performance.

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