JOURNAL OF MATERIALS SCIENCE **37** (2002) 2163–2166

# Metallization development for AlN/W cofired substrate at low temperature

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In this paper, metallization properties of AlN/W cofired substrate sintered at 1650°C were studied. The adhesion strength between W and AlN ceramic was improved by some methods, which including addition of several kinds of oxides mixture or metallic particles into W thick film ink. When $MgO\text{-}Al_2O_3\text{-}SiO_2$ was used, glass bonding increased the adhesion strength and when metallic particles were added, W conductor resistance decreased obviously. © *2002 Kluwer Academic Publishers*

## 1. Introduction

Being a promising candidate substrate material, Aluminum Nitride (AlN) ceramic has been widely studied and developed in the past few years. It includes AlN powder fabrication, AlN ceramic sintering, thin film (Ti, Mo, W, Cu) or thick film (Ag, Ag-Pd, Cu, Mo, W) metallization and AlN/W multilayer cofired substrates. Nowadays, because of the emergence of the MCM technology, high density ceramics multilayer module are becoming the key technique to accomplish high density electronic packaging. Normally, AlN/W multilayer substrate is cofired at a high temperature above 1800°C. Many attempts [1–3] have been made to lower the sintered temperature in order to utilize AlN ceramic widely, but fewer works have been put on the metallization characters of the AlN/W substrates cofired at low temperature (1650°C). In our previous paper [4], the effects of oxide additives on sheet resistance of W thick film conductor for W/AlN cofired body sintered at 1850°C has been studied. In this paper, low temperature (1650°C) cofired AlN/W substrates was developed, the adhesion strength and thick film conductor resistance were improved by two methods, added (1) oxides mixture and (2) metallic particles into W thick film inks.

## 2. Experiment procedure

Fig. 1 shows the schematic of AlN/W multilayer body manufacture process. AlN and W particles have an average size of 1.0 and 1.7 μm, respectively.

Tensile pull test [5] was used to view the W/AlN adhesion strength, W thick film resistance was measured by four probe method, X ray diffraction was utilized to identity the crystalline phase at AlN/W interface, the microstructures were characterized with scanning electron microscopy (SEM). The relative density of AlN ceramic become 99% sintered at 1650°C with a heating rate of 5°C/min and soaking for 4 hours when appropriate amounts (5–8 wt%) of ($Y_2O_3\text{-}CaO\text{-}B_2O_3$) were added in AlN as sintering aids, and its thermal conductivity reached 100 W/mK [6].

## 3. Results and disscussion

Table I shows the adhesion strength and W thick film resistance, from which we can see that when pure W ink (no additives) was used, W-AlN adhesion strength was very low, not more than 20 Mpa, and W film resistance is 30 mΩ/□. When some oxides and metallic additives were added into W thick film inks, the adhesion strength increased and W resistance decreased clearly.

### 3.1. Pure W thick film ink

Tungsten (W) belongs to the refractory metals and it is impossible to reach theoretic density without sintering aids with the sintering temperature below 1800°C. Sintered at 1650°C for 4 hours, its relative shrinkage of free sintered W film was merely 70%. For AlN/W

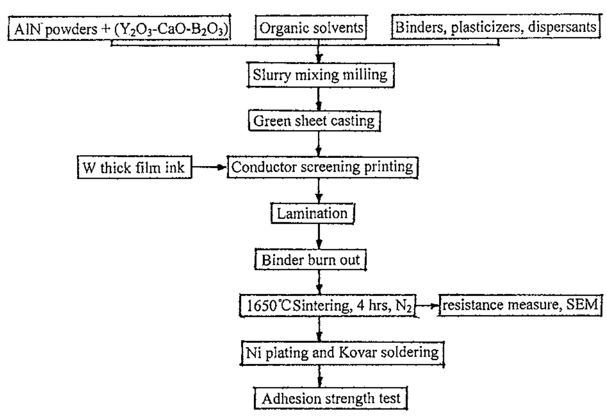


*Figure 1* Schematic of the multilayer body manufacture process.

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TABLE I The adhesion strength and W thick film resistance (6 specimens for each condition)

| Composition of W ink | Adhesion strength (Mpa) | W film resistance (mΩ/□) |
|---|---|---|
| pure W | | |
| Free sintered W film | | 45 |
| AlN/W Cofired | <20 | 30 |
| W + 8 wt% ($Al_2O_3$-MgO-$SiO_2$) | 40–45 | 20 |
| W + 5 wt% Mo | 25–30 | 17–20 |
| W + 5 wt% Ni | 25–29 | 21–24 |
| W + 5 wt% Co | 30–35 | 15–17 |

cofired substrates, liquids appear below 1500°C when appropriate amounts of $B_2O_3$ and CaO oxides were added into AlN green sheet as sintering aids [7]. In this case, if AlN/W multilayer substrates sintered together, the densification rates of W were lower than those of AlN. In-plane stresses developed at the interface of W film and AlN during its constrained sintering, constrained sintering led to defective packages which including cracking at AlN/W interface. Constrained sintering was present by Choe [8] and Bordia [9], the analysis and experiments showed that the film develops a in-plane stress very early in the heating period, and crack is prone to form at metal/ceramic interface or in one film in this process. The crack at AlN/W interface showed in Fig. 2 reduced adhesion strength.

When W thick film was cofired with AlN at 1650°C, in-plane press stresses developed in W film because

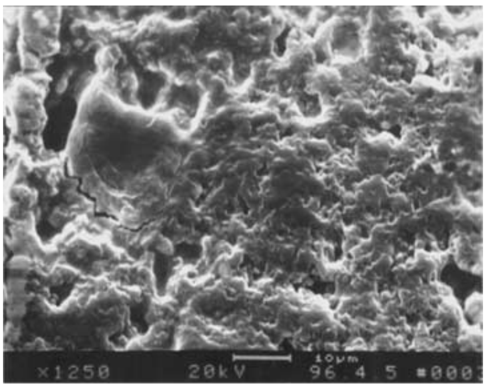



*Figure 2* Crack left at AlN/W interface.

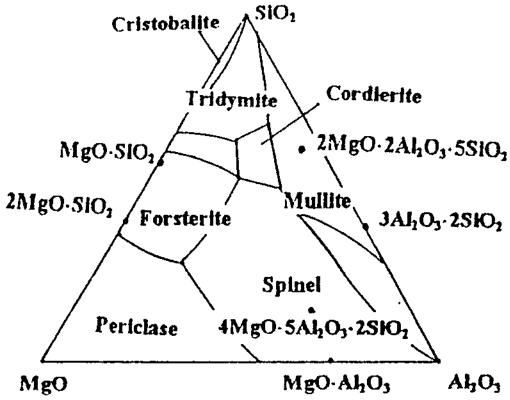



*Figure 4* Phase diagram of magnesia-alumina-silica.

AlN shrinks faster than that of W film, normally this stresses is useful to the densification of W film. That's why the resistance of W film is smaller (30 mΩ/□) than that of free sintered film (45 mΩ/□). But this stresses is not big enough to make W film sintered completely, so there are many pores in W film (Fig. 3).

## 3.2. Oxide mixture

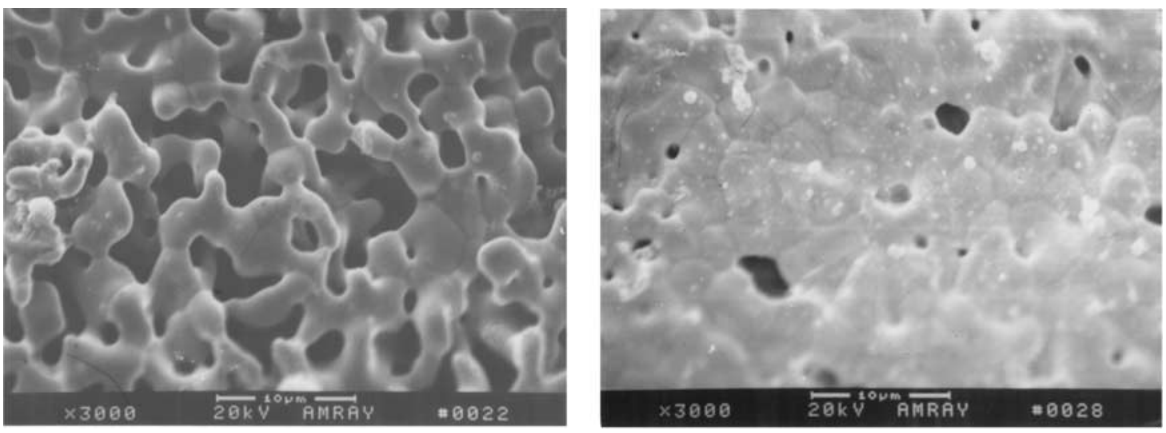
The oxide mixture composition was MgO, 18–25 wt%, $Al_2O_3$, 18–22%, $SiO_2$, 50–55%, $B_2O_3$, 1%. Fig. 4 shows the phase diagram of magnesia-alumina-silica.

During cofiring processes, glass and cordierite phase were formed, glass softened and penetrated into W particles boundaries, so W particles rearranged and the grain growth occurred by the solution-precipitation mechanism. Finally glass phase moved toward W/AlN interface by the influence of gravity, capillary action and squeeze action. Glass was squeezed from the W particles because of the growth of W grain size. In the cool-down period, it solidified and existed at AlN/W interface (Fig. 5).

Fig. 6 indicates that there are cordierite and $Al_6Si_2O_{13}$ phase at W/AlN interface. From Fig. 5b we can see that glass phase diffused into the boundaries of AlN particles. Besides glass diffusion, chemical reaction maybe existed:

$$SiO_2 + AlN \text{ - - - - } Si_3N_4 + Al_2O_3$$

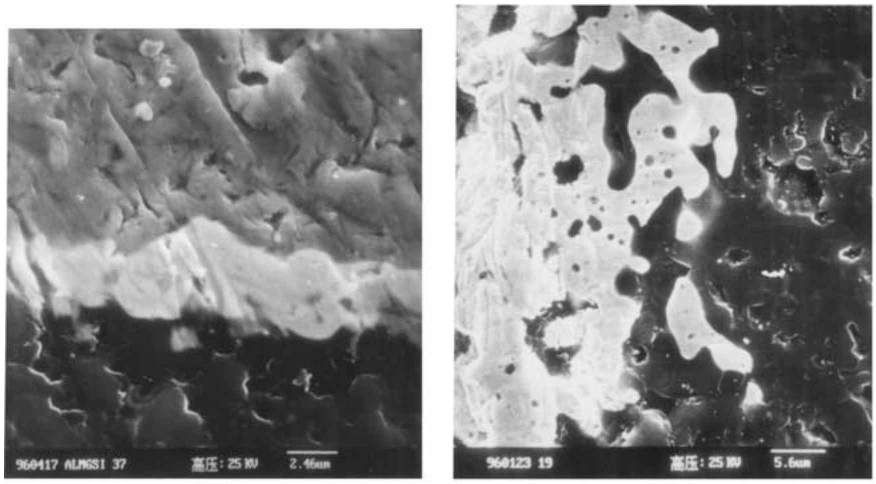
$$Al_2O_3 + MgO \text{ - - - - } MgAl_2O_4$$




(a) Pure W ink

(b) W + oxides

*Figure 3* Surface of W film after cofired at 1650°C.



(a) (b)

*Figure 5* Glass layer at AlN/W interface.

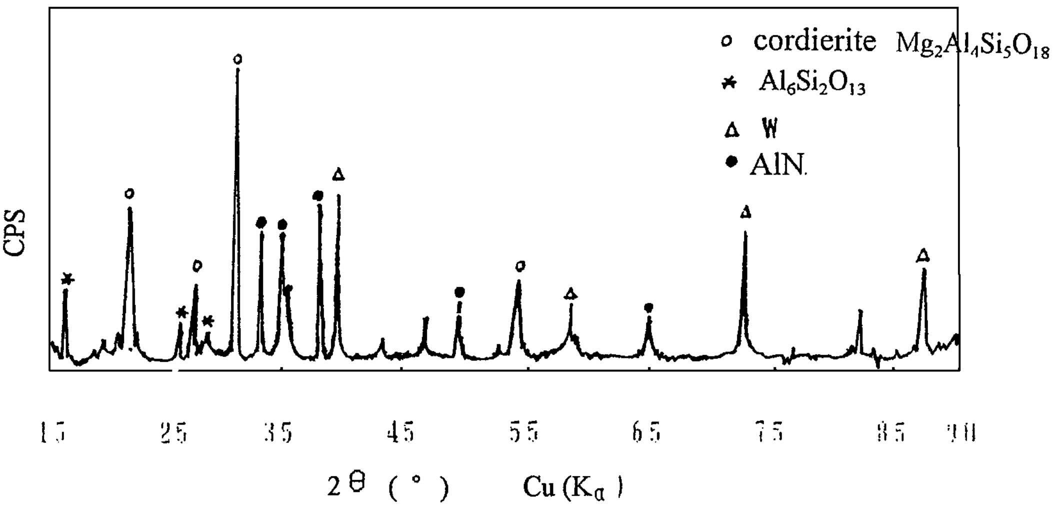
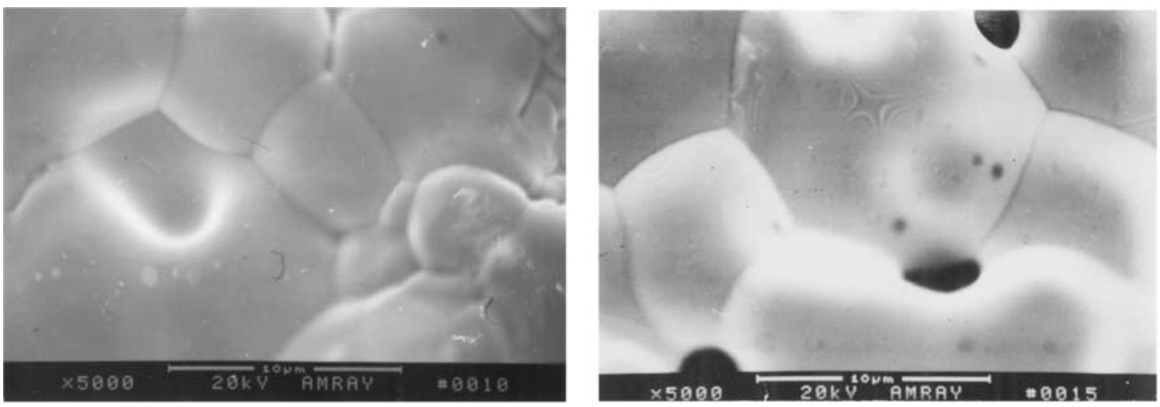



*Figure 6* XRD at W/glass/AlN interface.



(a) W + Co (b) W + Mo

*Figure 7* Surface of cofired W film.

Owing to the glass layer existed at interface or glass diffused into AlN ceramic, W/AlN adhesion strength improved obviously, and the glass phase improved the sinter ability of W film, lesser pores were found in W film (Fig. 3b), in this case the resistance of W film reduced.

## 3.3. Metallic additives

Table I shows that when metallic particles such as Mo, Ni, Co were added into W ink, the resistance of W film decreased, and the adhesion strength of metallization increased a little. Metallic additives increased the sinter ability of W thick film because of its lower melt point than that of W, fewer pores left in W film (Fig. 7) resulted in the decrease of W conductor resistance. From that point of interface stress, when metallic additives used, the densification rates of W increased, so the in-plane stresses at AlN/W interface reduced, this led to the increase of adhesion strength.

## 4. Conclusion

For the AlN/W body cofired at 1650°C, the metallization adhesion strength was improved by some methods, which including addition of several kinds of oxides mixture or metallic particles into W thick film ink. When MgO-$Al_2O_3$-$SiO_2$ was added into W thick film ink, the adhesion strength was increased by glass bonding. When metallic particles were added, W conductor resistance decreased obviously. Reducing the densification rate between the metal film and ceramic is an effective method to improve electronic package properties. The effects of oxides, metallic particle and W particle size on the metallization characters are to be studied.

## Acknowledgments

This project was sponsored by Cao Guangbiao High Technical Development Fund of Tsinghua University and China National Natural Science Fund.

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*Received 11 November 1999*
*and accepted 11 April 2000*