

Effects of oxide additives on sheet resistance of W thick-film conductor

TONGXIANG LIANG, WENZHEN SUN, Y.-H. WANG, H.-D. LI, Q.-L. WU*, Y.-J. YAN*

*Department of Materials Science and Engineering and *Institute of Materials Research, Tsinghua University, Beijing, 100 084, P. R. China*

A multilayer AlN–W cofired body has been developed using the pressless sintering technique. Effects of additives, such as Y_2O_3 , CaO, La_2O_3 , MgO, Al_2O_3 and SiO_2 , on the sheet resistance of W conductor were studied. The sheet resistance of the W conductor increases with increasing additives in the W paste. However, the oxides can be divided into two groups. The effect of the first group on sheet resistance is different from that of the second group.

1. Introduction

Aluminum nitride (AlN) has several attractive properties for use as an electronic packaging material, such as high thermal conductivity, high electrical resistivity and thermal expansion coefficient matched with silicon. Recently, multilayered cofired AlN–W substrates used for microelectronic circuits, were developed [1, 2]. Obviously, for cofired multilayered substrates low conductor resistivity is the most important factor. Many factors influence conductor resistivity, for example sintering temperature, size and distribution of W particles, frit in W paste etc. The resistivity behaviour of thin film has been studied by several workers, but little is known about the behaviour of thick-film resistivity.

This paper focuses on the effects of oxides on the W conductor sheet resistance in the W–AlN multilayered cofired body.

2. Experimental procedure

A multilayered AlN–W cofired body was developed by means of tape casting technology; its fabrication process is shown in Fig. 1. The substrate was made from AlN and W powders with average particle sizes of about 1 and 2 μm , respectively. The multilayered body was made by laminating tape-cast AlN green sheet screen-printed with W thick-film paste. After the binder was burnt out, the laminated body was fired at 2123 K in flowing N_2 for 2 h.

In order to promote the AlN–W interfacial adhesion strength, 5–25 wt % oxides were introduced into W paste, these oxides included Y_2O_3 , CaO, MgO, Al_2O_3 etc. The constitution of the W paste is shown in Table 1.

The sheet resistance of the W conductor was examined after cofiring using a four-probe resistivity detector. The adhesion strength was measured by

nailhead pull test of pins soldered onto 2 mm Ni-plated square pads.

The microstructure was observed by scanning electron microscopy (SEM).

3. Results and discussion

Fig. 2 shows the relation between fired W sheet resistance and oxides additives. It indicates that first, the fired W conductor sheet resistance increases when oxides are added to W paste, e.g. it increases from 12 to 25 $\text{m}\Omega\text{cm}^{-1}$ for the W paste with 10 wt % Y_2O_3 added; second, the effect of the content of oxide additives on the fired W conductor sheet resistance is different. Y_2O_3 , CaO, La_2O_3 , etc., are defined as group one oxides. For oxides in this group, increasing their content increases the conductor sheet resistance; but for group two oxides, such as Al_2O_3 , SiO_2 and MgO, the increase of oxides additives content has no obvious influence on the W sheet resistance.

Fig. 3 shows the W conductor surface morphology after cofiring. As indicated in Fig. 3a, the continuum of the fired W surface was distributed by some oxides of group one; there are some oxides or other phases residual in the surface of the W conductor. While in Fig. 3b, there are no oxides found in the W surface, although the oxides of group two were added to the W paste.

It had been concluded that W powder did not react with AlN powder at the sintering temperature [3]. Metallization of AlN is more difficult than that of Al_2O_3 because of less secondary phases in AlN and because of the lower self-diffusion coefficient of AlN. For cofiring AlN–W substrates, the high adhesion strength (> 20 MPa) of W on AlN substrate is attributed to mechanical interlocking of W and AlN during cofiring [2]; but for post-sintering, metallization of AlN is obtained mainly by glass-bonding and/

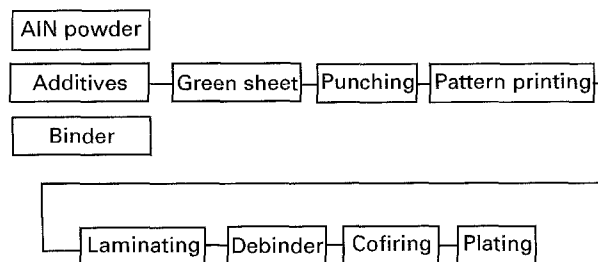


Figure 1 The AlN-W multilayered cofired body fabrication process.

TABLE I The constitution of W paste

| Sample No. | Constitution |
|------------|---|
| 0 | Pure W |
| 1 | W-Y ₂ O ₃ |
| 2 | W-Y ₂ O ₃ -CaO (Y ₂ O ₃ :CaO = 2:1) |
| 3 | W-Y ₂ O ₃ -La ₂ O ₃ (Y ₂ O ₃ :La ₂ O ₃ = 2:1) |
| 4 | W-Y ₂ O ₃ -La ₂ O ₃ -CeO (Y ₂ O ₃ :La ₂ O ₃ :CeO = 1:1:1) |
| 5 | W-Al ₂ O ₃ -MgO (Al ₂ O ₃ :MgO = 1.5:1) |
| 6 | W-MgO-SiO ₂ -Al ₂ O ₃ (MgO:SiO ₂ :Al ₂ O ₃ = 1:1:2) |

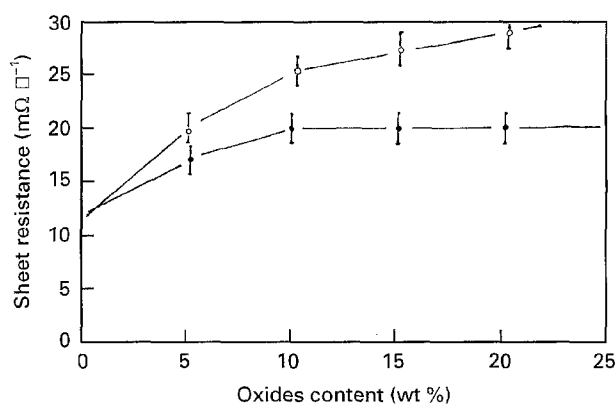


Figure 2 Effects of oxides on W sheet resistance: (○) Nos 1-4, (●) Nos 5 and 6.

or chemical reactive-bonding. In this paper, the adhesion strength is improved when small amounts of oxides are added into the W paste. The adhesion strength goes up to 65 MPa with 15 wt % Y₂O₃ as frit, but the strength value is only 30 MPa when the W paste has no oxides introduced into it.

For group one, there are some oxides in W paste residual on the surface of the fired W conductor. These oxides result in an increase of W sheet resistance. On the other hand, oxides such as Y₂O₃ near the AlN-W interface may react with surrounding AlN particles and form Y₄Al₂O₉, YAlO₃ (YAG) as shown by the model in Fig. 4a. Formation of an AlN-YAG-Y₂O₃ network improves the adhesion strength.

Fig. 5 shows the AlN surface after the W conductor layer was removed. For No. 5 W paste (W-Al₂O₃-MgO), there is a glass phase existing at AlN grain boundaries. This indicates that Al₂O₃ and MgO forms glass and glass aggregates at the AlN-W interface.

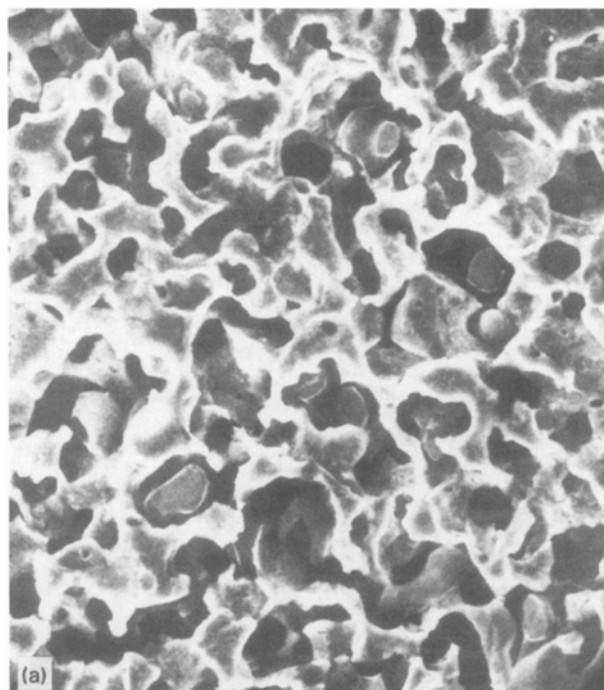
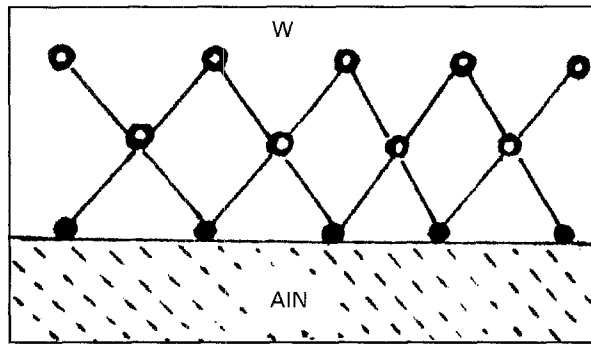
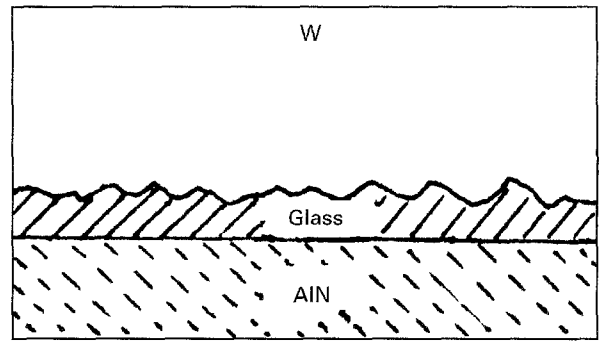


Figure 3 The W morphology after cofiring (1850 °C, 2 h): (a) No. 2 paste, and (b) No. 5 paste (see Table I).

When the oxides in group two are used, these oxides (Al₂O₃, MgO) can form glass in the course of cofiring. For No. 5 W paste the relative phase diagram is given in [4]. During cofiring the glass melts and flows from the W layer to the AlN-W interface under the influence of gravity and capillary action, and solidifies in the period of cool-down. The glass wets the AlN substrate and surrounds the W particles near the substrate, mechanically locking the W film to the AlN substrate. The base of the tungsten film is cast in glass and bonded by the glass to the AlN substrate. The final microstructure is shown in Fig. 4b. Glass aggregates near the AlN-W interface; there are little residual



(a)



(b)

Figure 4 Model of AlN–W interfacial microstructure: (a) group one oxides in W paste, and (b) group 2 oxides in W paste. (O) Y_2O_3 , (●) YAG.

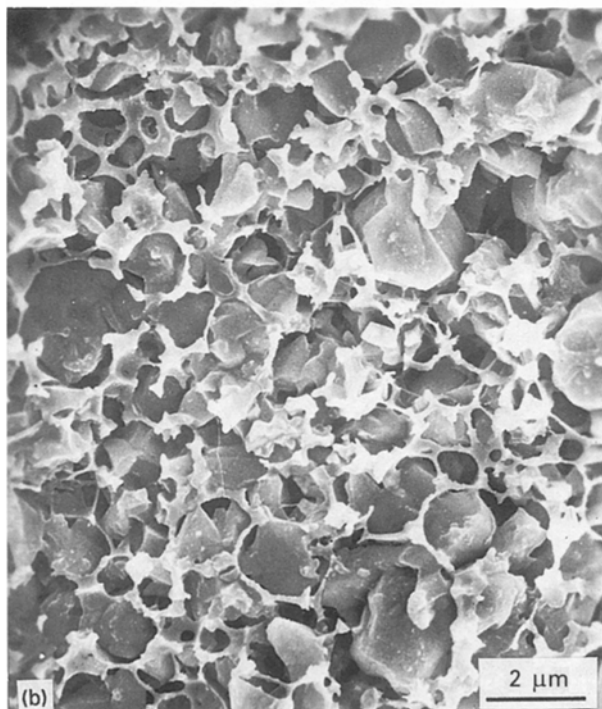
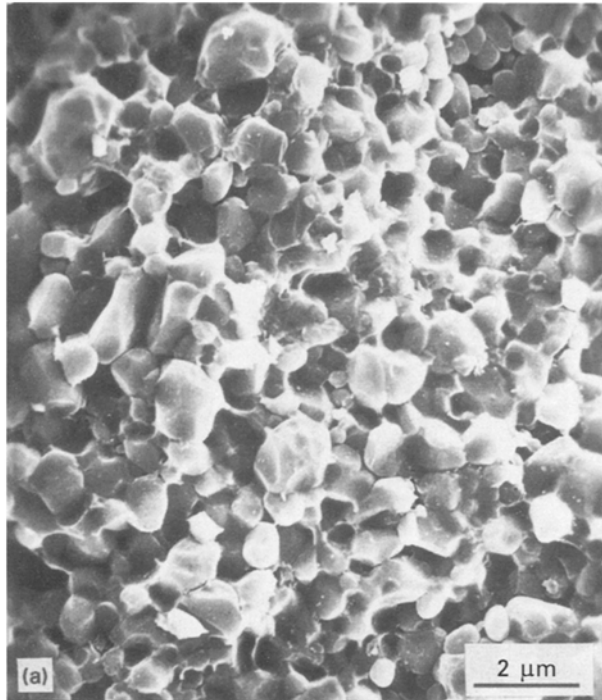


Figure 5 AlN surface after W conductor layer was removed: (a) No. 2 W paste, and (b) No. 5 W paste.

oxides in the W conductor layer. For this reason, the sheet resistance is independent of the oxides additives content.

4. Conclusions

An AlN–W cofired multilayered body has been developed. The conclusions obtained in this research work are summarized as follows:

1. The W sheet resistance achieved is $12 \text{ m}\Omega \square^{-1}$.
2. Different kinds of oxides have different influences on the behaviour of W sheet resistance.
3. Oxides additives can be divided into two groups.

For group one, oxides such as Y_2O_3 , CaO do not form a glass phase during the cofiring process. These oxides are residual on the surface of the fired tungsten conductor, resulting in an increase of W sheet resistance. Increase of the content of oxides results in increasing conductor sheet resistance; while for group two, the content of oxides has no obvious influence on fired W sheet resistance. Al_2O_3 , MgO and SiO_2 belong to this group.

References

1. YASUHIRO KUROKAWA, CETIN TOY and W. D. SCOTT, *J. Am. Ceram. Soc.* **72** (1989) 612.
2. Y. H. CHIAO and K. YANG, in *Cofire Metallization of Aluminum Nitride Substrates*, ISHM '92 Proceedings 19–21 October 1992, San Francisco, CA, pp. 88–93.
3. J. C. SCHUSTER and H. NOWOTNY, *J. Mater. Sci.* **20** (1985) 2787.
4. A. GRANON, P. GOEURIOT and F. THEVENOT, in *J. Europ. Ceram. Soc.* **13** (1994) 365.

Received 23 June 1995

and accepted 18 March 1996