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Ultra-heat resistant interconnection for wide band gap semiconductors

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Abstract

Power electronics play an important role in the generation-storage-distribution conversion cycle of the electric energy. Wide band gap semiconductors such as SiC and GaN have attracted many researchers recently because both of their excellent energy conversion efficiency and of capability of device downsizing. The performance of interconnection, especially die-attach, has one of the key role for power electronics devices. Among various proposals for die-attach materials and processes, Ag sinter joining is a promising approach for power semiconductors as well as for power LED, providing excellent heat-resistance to achieve stable joint structures beyond 200 °C. This paper summarizes the present status of the Ag sinter joining and of the new approach with Ag film bonding, both of which have developed by the authors' group.

1. Introduction

Power devices are currently being rapidly developed to fulfill the demands of high power density, high operation temperature and improved reliability. There are high expectations for wide band gap (WBG) power semiconductors, such as SiC and GaN devices, because they can operate in extreme conditions where Si power devices cannot work - in environments over 200 ºC, for example. Bringing out the full potential of WBG power devices requires completely new approaches covering all relevant technologies extending from structural design, electrical design, and packaging. With respect to packaging technology, innovations in materials, manufacturing techniques and reliability evaluation are inevitable.

Die-attach technology is one of the key technologies to establish WBG power devises. There are several candidate materials developed in the past decade for die-attach. High temperature lead-free solder has been under development though several candidates have been already proposed such as Bi alloys and pure Zn/Zn-Sn alloys as well as the conventional Au alloys [1-5]. Transient liquid phase bonding is also examined for off-eutectic Au or Ag alloys. In contrast, Ag sinter joining has attracted many researchers due to its excellent high temperature stability [2]. This paper reviews the current status of the Ag sinter joining and a new method utilizing stress migration effect for bonding, so called as stress migration bonding developed by the present authors [6, 7].

2. Ag sinter joining

Sinter joining with Ag nanoparticles under pressure is an attractive choice of die-attach [3-5]. Nevertheless, the high pressure beyond 5 MPa required for the joining may become a critical issue for thin and brittle semiconductor dies. In contrast, sinter joining with micron-sized Ag hybrid particle pastes provide a stable bonding structure at 200 ºC without applied high pressure [2, 8]. Figure 1 shows an example of a LED die-attach with the hybrid paste [8].

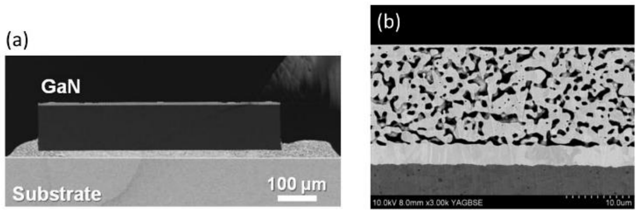

Fig.1 (a) GaN LED die-attach structure with Ag hybrid paste, and (b) sintered microstructure observed in cross-section of (a) [8].

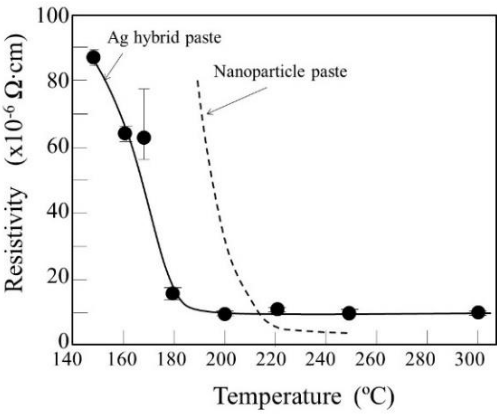

Fig. 2 Resistivity change of printed lines of Ag hybrid paste compared with nanoparticle paste as a function of sintering temperature [2].

The presence of oxygen plays a key role in cleaning the surface of Ag at around 200 ºC in air resulting in a successful low-temperature low-pressure Ag sintering joining [9]. Ag can clean its surface around 200 °C in air atmosphere. Fig.2 shows the resistivity change, which is a good scale of sintering, of printed Ag hybrid paste tracks as a function of sintering temperature [2]. The Ag hybrid paste lowers its resistivity even below 200 °C in contrast to the Ag nanoparticle paste being higher by 40 °C. Fig. 3 shows the effect of substrate metallization on the joint strength [10]. At 200 °C, Ag coating provides the highest strength due to Ag sintering ability in air. Thus, Ag sintering joining can be benefitted from the presence of oxygen, which is a great advantage as compared with other sintering materials.

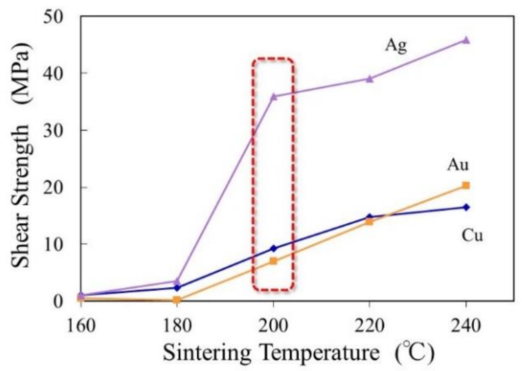

Fig. 3 Bonding shear strength as a function of temperature with Ag microflake paste on three substrates [10].

3. Ag film stress migration bonding

Recently, the Ag thin film stress migration bonding method has been developed, providing a perfect bonding without any voids performed in ambient pressure at 250 °C in air as shown in Fig.4 [6, 7, 11]. This joining has two key aspects. One is the reduction reaction of Ag oxides or of other Ag compounds on the surface of Ag at around 200 °C as mentioned above. The other is thermo-mechanical stress caused by thermal expansion mismatch between Ag plating layer and substrates, resulting in massive stress migration of Ag atoms from the bottom of the plating to the surface.

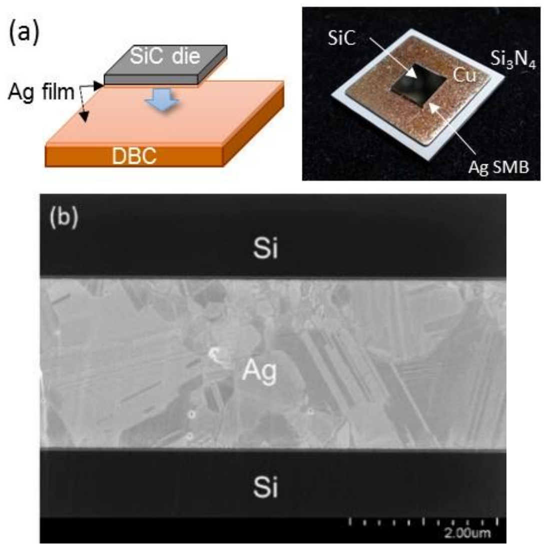

Fig. 4 (a) Schematics of stress migration bonding and (b) Si/Si bonded interface [7].

Fig. 5 shows bonding strength as a function of bonding temperature for various substrates [12]. 250 ºC is the best temperature for all substrates, which indicates the best stress migration condition while higher temperature joining makes unbalanced diffusion of Ag atoms resulting in severe void formation.

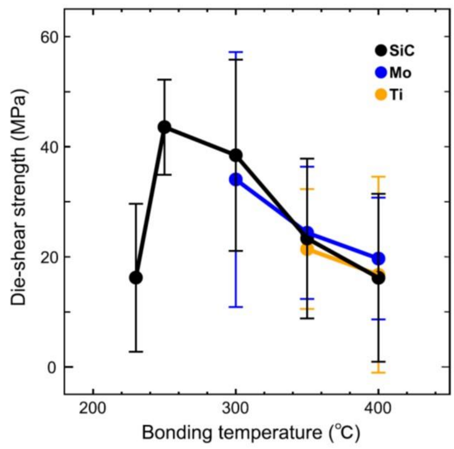

Fig.5 Die-shear strengths of the bonded samples for each substrate at various bonding temperatures [12].

3. Conclusions

This paper briefly describes the current status of Ag sinter joining and Ag film stress migration bonding. Ag has great advantages in both the surface reaction in air benefitting joining quality and the excellent electric/thermal properties. Ag sinter joining has already exhibited a great potential in the market as high temperature interconnection technology, while our Ag film stress-migration bonding is expected to provide an alternative route. Similar bonding methods using Cu or other metal materials instead of Ag would be explored as cost-effective interconnections in future.

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References

[1] K. Suganuma, S.-J. Kim, K.-S. Kim, JOM, 61, 64-71 (2009).
[2] K. Suganuma, S. Sakamoto, N. Kagami, D. Wakuda, K. -S. Kim, M. Nogi, Microelectron. Reliab., 52, 375-380 (2012).
[3] E. Ide, S. Angata, A. Hirose, K.F. Kobayashi, Acta Mater., 53, 2385–2393 (2005).
[4] K. S. Siow, J. Alloys Compd. 514, 6-19 (2012).
[5] T. Wang, X. Chen, G.-Q. Lu, G.-Y. Lei, J. Electron. Mater., 36, 1333-1340 (2007).
[6] T. Kunimune, M. Kuramoto, S. Ogawa, M. Niwa, M. Nogi, K. Suganuma, IEEE Trans. CPMT, 3, 363-369 (2013).
[7] C. Oh, S. Nagao, T. Kunimune, K. Suganuma, Appl. Phys. Letters, 104, 161603 (2014).
[8] M. Kuramoto, S. Ogawa, M. Niwa, K.-S. Kim, K. Suganuma, IEEE Trans. CPMT, 33, 801-808 (2010).
[9] M. Kuramoto, S. Ogawa, M. Niwa, K.-S. Kim, K. Suganuma, IEEE Trans. CPMT, 1, 653-659 (2011).
[10] S. Sakamoto, S. Nagao, K. Suganuma, J Mater. Sci. Mater. Electron, 24, 2593-2601 (2013).
[11] T. Kunimune, M. Kuramoto, S. Ogawa, T. Sugahara, S. Nagao, K. Suganuma, Acta Mater., 89, 133-140 (2015).
[12] C. Oh, S. Nagao, K. Suganuma, J. Mater. Sci. Mater. Electron, 26, 2525-2530 (2015).