Sintering Cu Bonding Paste that can be Sintered without Pressure

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1 Abstract

We developed a sintering Cu bonding paste that can be cured without pressure at 225°C in an H_2 atmosphere. The die-shear adhesive strength with an adherend of Cu, Ni, Au, or Ag is at least 40 MPa. After sintering, the thermal conductivity of the sintered Cu bonding layer is 180 $W \cdot m^{-1} \cdot K^{-1}$. The sintered Cu bonding after a thermal cycle test (TCT) of 2000 cycles in the temperature range from −40 to 200°C showed a bonding reliability that is the same as, or better than, sintered Ag bonding or high lead solder. With its high thermal conductivity, high bonding reliability, good productivity, and reasonable cost, this sintering Cu bonding paste is likely to be an ideal bonding material for application in power electronics.

2 Characteristics of the New Product

- The product is sintered without any pressure (225°C, in hydrogen) to produce a highly heat-resistant, highly reliable metal bonding.
- The product produces a low-porosity sintered body of Cu with a high level of thermal conductivity (> 180 $W \cdot m^{-1} \cdot K^{-1}$).
- The sintered body consists entirely of Cu, and contains no environmental hazardous substances.

3 Background of the Development

Enhancing the operating temperature of a power device simplifies the cooling device and reduces the required number of device chips. This leads to smaller, lighter, and cheaper power modules. Accordingly, power device manufacturers are promoting development according to roadmaps that show the targets for improvements in the operating temperature of power devices.[1)] The highest operating temperature of power device elements (junction temperature, $T_{j,\,max}$) was 125°C in 1990 and 150°C in 2005. In 2016, power device elements for which the highest operating temperature was 175°C were released. Moreover, studies have begun concerning the operation of compound semiconductor (SiC and GaN) devices in the temperature range from 200 to 250°C.

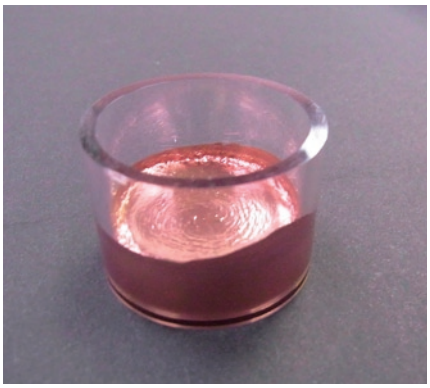
High-lead solder shows high levels of bonding reliability among conventional solder materials, and has therefore been widely used for power devices. Despite its high lead content, this material is exempted from the RoHS Regulations.[2)] High-lead solder, however, poses the problem of insufficient power cycle reliability during operation at $T_{j,\,max} \geq 175°C$.[3)] Another problem is that it forms a thermal bottleneck due to its lower thermal conductivity compared to other components.

4 Technical Details

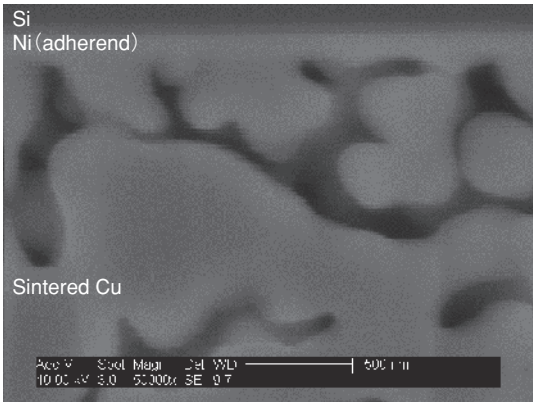
We developed a sintering Cu bonding paste that allows pressure-less bonding. This material can be sintered at 225°C or higher without any pressure in a hydrogen atmosphere. Although it needs hydrogen for the sintering, hydrogen reduces and removes oxide film from the adherend surface, thereby allowing bonding to Cu, Ni, and Pd in addition to Au and Ag. The thermal conductivity of this paste is 180 $W \cdot m^{-1} \cdot K^{-1}$, which is sufficiently high relative to 35 $W \cdot m^{-1} \cdot K^{-1}$ of high-lead solder, and therefore allows heat from power device chips to rapidly dissipate. In a thermal cycle test in the temperature range from −40°C to 200°C, in terms of bonding reliability, this paste performed better or equal to sintering Ag bonding paste and high-lead solder. In a power cycle test at $T_{j,\,max}$ = 175°C, this paste showed better power cycle reliability than that of high-lead solder. Furthermore, the raw materials of this paste are available at more reasonable prices than those of the sintering Ag bonding paste, and this paste contains no environmentally hazardous substances (unlike high-lead solder). This sintering Cu bonding paste provides high levels of productivity, high levels of heat conductivity, and high levels of bonding reliability, all at a reasonable price. Sintering Cu bonding paste is expected to provide an ideal bonding material for power electronics.

Table 1 Comparison of die-bonding properties among sintering Cu bonding paste, sintering Ag bonding paste, and high-lead solder

Items		Sintering Cu bonding paste	Sintering Ag bonding paste	High-lead solder
Bonding conditions	Environment	H_2	Air	H_2 or HCOOH
	Bonding pressure	No pressure	Press (20 MPa)	No pressure
	Temperature	225−300 ℃	300−350 ℃	350 ℃
Adherent materials		Cu, Ni, Au, Ag, Pd	Ag, Au	Cu, Ni, Au, Ag
Properties of bonding layer	Thermal conductivity	180 $W \cdot m^{-1} \cdot K^{-1}$	280 $W \cdot m^{-1} \cdot K^{-1}$	35 $W \cdot m^{-1} \cdot K^{-1}$
	Power cycle reliability	> 40000	—	38000
	Thermal cycle reliability	> 2000	> 2000	> 2000
Material cost		Reasonable	Expensive	Cheap
Environmental friendliness		OK	OK	Pb



Appearance of the sintering Cu bonding paste



Cross sectional SEM of the bonding interface

Figure 1 Appearance of the sintering Cu bonding paste and an SEM image of the bonding interface

5 Future Business Development

- Application to large-area chips equivalent to or exceeding 10 mm × 10 mm (currently 7 mm × 7 mm)
- Development of materials curable in non-combustible gases (existing materials can be sintered only in 100% hydrogen)

[References]

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3) S. Kim, K.-S. Kim, S.-S. Kim, K. Suganuma and G. Izuta, "Improving the Reliability of Si Die Attachment with Zn-Sn-Based High-Temperature Pb-Free Solder Using a TiN Diffusion Barrier,"J. Electron. Mater., vol.38, no.12, pp.2668-2675, 2009.