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How to determine surface roughness of copper substrate for robust pressureless sintered silver in air

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ABSTRACT

It is significant to attach power devices on low-cost copper (Cu) substrates by pressureless silver-sintering in air. The Cu surface in direct-bond-copper (DBC) substrates could have a wide range of surface roughness due to the various processing techniques. It is crucial to find out how the surface roughness influences the bonding strength of the sintered-silver (Ag) die-attachment. In this study, we did die-attach on Cu substrates with surface roughness R_a = 0.15–8.41 μm and R_z = 1.22–50.97 μm by pressureless sintering of nanosilver paste in air. When the surface roughness (R_a of 0.65 μm) is slightly larger than the silver nanoparticles (diameter of 0.6 μm), the high shear strength in excess of 50 MPa was achieved, likely due to both strong metallic bonds and mechanical interlock. This work could help to prepare DBC substrates with optimized surface roughness to accommodate the viscosity, the particle size, and the sintering shrinkage of the silver paste for well using the sintered-Ag die-attach technology.

1. Introduction

With the development of wide-band-gap devices targeting for high-temperature and high-power applications, die-attachment by low-temperature sintered-silver was increasingly used as an alternative to solders or epoxies, due to its high-performance and high-reliability [1–4]. It has been reported that the strong die-attach on low-cost copper (Cu) surface can be obtained by pressureless silver-sintering in air, which has great significance in power electronics [4]. The Cu surface could have a wide range of surface roughness due to the various processing techniques for bonding Cu sheets on ceramic insulation layer during DBC substrate manufacturing [5–8]. The surface roughness is typically characterized using arithmetical mean surface roughness (R_a) and maximum roughness depth (R_z). In general, relatively smooth surfaces with $R_a < 5$ μm and $R_z < 20$ μm can be obtained by eutectic-bonding, active-metal-brazing (AMB), and metal-casting-direct-bonding (MCB) method etc. [5–7], while cold-spray typically generates very rough surfaces with R_a of 5–20 μm and R_z of 20–60 μm [8]. It has been reported that the surface roughness greatly influences the bonding strength of sintered-Ag die-attachment [5–7]. Buttay *et al.* [5,6] obtained higher bonding strength using substrates or devices with a smoother surface. Wereszczak *et al.* [7], however, reported higher bonding strength using substrates with a rougher surface. Therefore, it is crucial to find out the effects of surface roughness on the bonding strength of sintered-Ag die-attachment.

In this study, we did die-attach on Cu substrates with different surface roughness using nanosilver paste pressureless sintered in air. The findings helped us to achieve the high bonding strength in excess of 50 MPa in the case of surface roughness R_a slightly larger than the Ag particles, by likely generating full contacts for strong metallic bonds and mechanical interlock. The results presented in this study could help to prepare DBC substrates with optimized surface roughness for well using the Ag-sintering die-attach technology.

2. Materials and methods

Samples were fabricated by attaching Ag-plated silicon dice (3×3 mm^2) using sintered nanosilver paste (average diameter of Ag particles is 0.6 μm) on Cu substrates with different surface roughness. The surface roughness was measured using an optical surface profilometer (Zygo, NewView™ 9000). The surface

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roughness on die was $R_a = 0.2$ μm and $R_z = 1.5$ μm. The surface roughness on Cu substrates were obtained as $R_a = 0.15–8.41$ μm and $R_z = 1.22–50.97$ μm by polishing with 60–2000 grits sandpapers. After polishing, the Cu substrates were cleaned with diluted hydrochloric acid (2 mol/L) and ethanol to remove the native Cu oxidation. Then a 50 μm-thick nanosilver paste was screen-

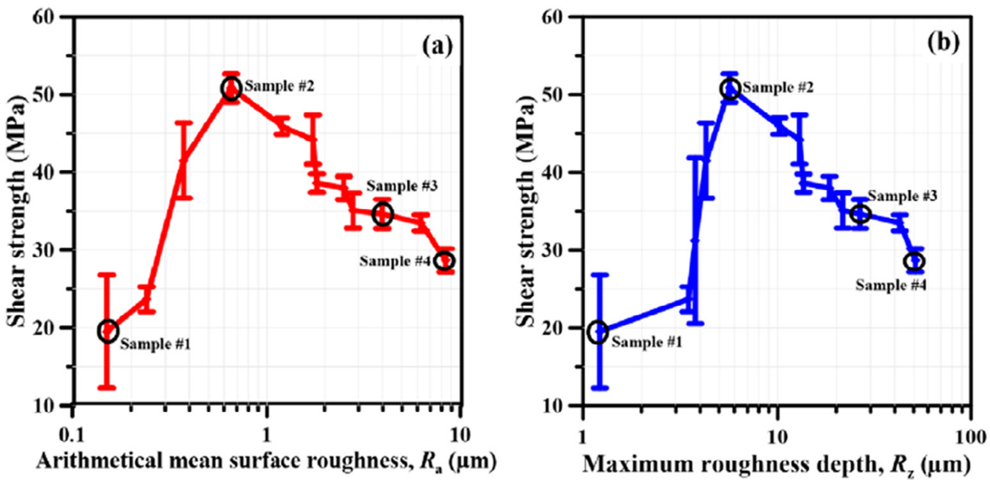

Fig. 1. Relationship between die-shear strength and surface roughness (a) R_a and (b) R_z.

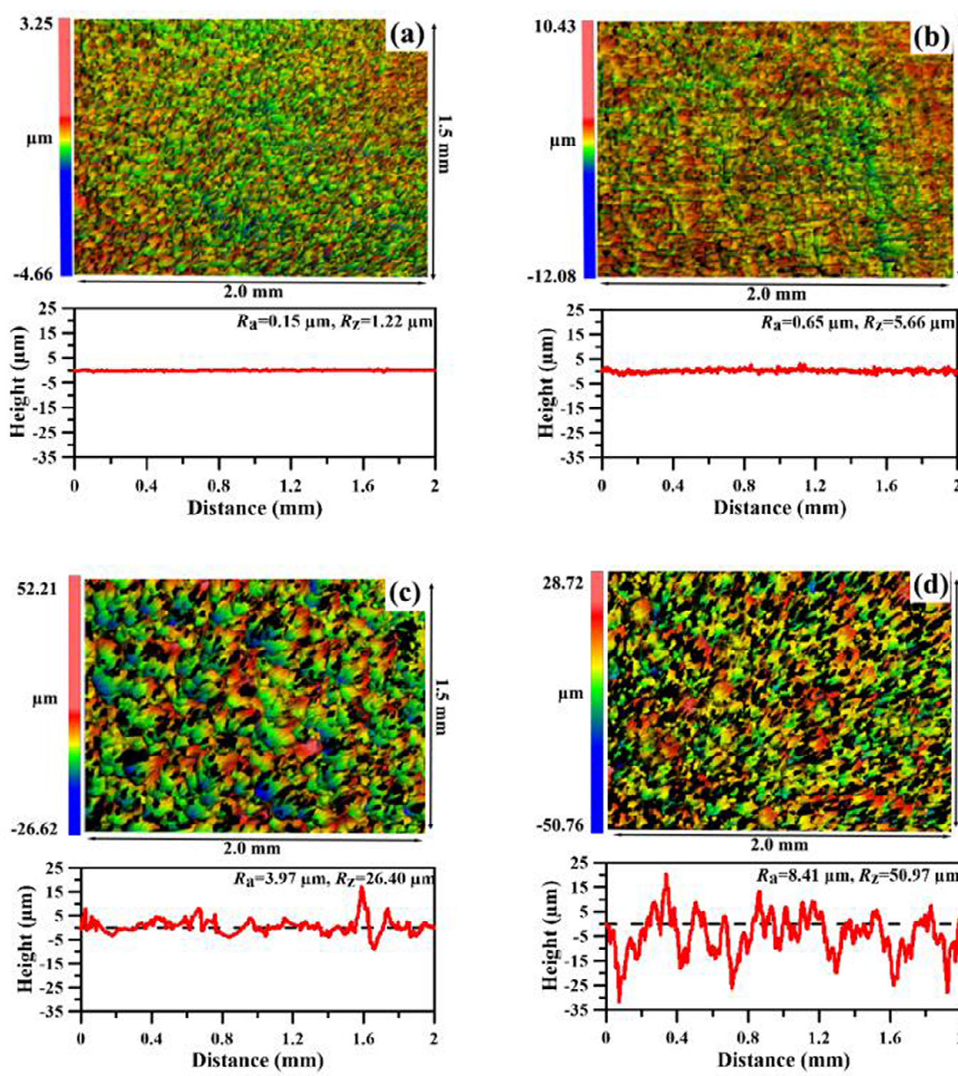

Fig. 2. Surface roughness of Cu substrates: (a) sample #1, (b) sample #2, (c) sample #3, and (d) sample #4.