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# Effects of Various Heating Rate and Sintering Temperatures on the Microstructural and Die-Shear Strength of Sintered Ag-Cu Nanopaste

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**Abstract**

Electronic devices used in high temperature applications needs to dissipate a large amount of heat and capable to withstand the high temperature. In order to ensure these electronic devices working efficiently in such extreme environment, the die-attach quality in the first level electronic packaging need to be seriously consider. Hence, nanopaste was introduced to attach a semiconductor die onto a substrate. Nanopaste is a mixture of metallic nanoparticles and organic additives (binder, surfactant, solvent). In this study, 80 wt% of Ag nanoparticles and 20 wt% of Cu nanoparticles with average diameter of 40-90 nm, and 50-60 nm, respectively, was combined with commercial V-006A binder, and ethylene glycol as surfactant. Next, the mixture was inserted in vacuum oven at 70$^{o}$C. To identify the mechanical properties, two polished Cu plates (4.0 cm x 0.7 cm) was joint by stencil printing Ag-Cu nanopaste and sintered in horizontal tube furnace at various sintering temperature (380, 350, 300, 260, 230$^{o}$C), dwell time of 30 min and different ramp rate (5, 10, 15, 20, 25, 30°C/min). The bonding strength was measured by performing lap shear test using an Instron universal testing system with a crosshead speed of 0.5 mm/min. The highest bonding strength recorded was 12.77 MPa, at sintering temperature of 260$^{o}$C and 25$^{o}$C/min ramp rate.


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*Keywords:* die-attach; Ag-Cu nanopaste; bonding strength

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## 1. Introduction

Electronic devices used in high temperature applications (>500°C) for example in jet engines, automotive electronics and many more, need to fulfill these main requirements, namely i) able to operate in extreme environments and ii) able to withstand very high operation temperature [1]. Still, the main concern of these high temperature electronic devices is the reliability issue. The reliability of these devices depends on the die-attach quality in the first level interconnection of an electronic packaging. Die-attach not only provides an electrical interconnection and mechanical fixation between a die and a substrate but also create a path for heat generated by semiconductor to dissipate as well [2], [3].

Nanopaste is a mixture of metallic particles and organic compounds, namely binder, surfactant and solvent. These elements are coalesced together by sintering stage using much lower sintering temperature compared to micrometer scale particles (micropaste), due to its nanoscale particles [4]. Desirable bonding quality can be achieve by introducing nanopaste as one of the die-attach systems, because its eliminates die-shifting issue [5], [6] and produces reliable joint than other types of die-attachment system [7], [8]. Organic additives are needed in nanopaste formulation as they serve different purposes. Binder is used to bring all metallic particles together and prevents cracking, surfactant used to avoid agglomeration while solvent to ensure the viscosity of binder.

However, nanoscale particles are susceptible to form agglomeration and aggregation due to their fine particle sizes [9]. Agglomeration can be re-dispersed before sintering stage because the particles are bind together by weak forces, such as Van Der Waals, while aggregation on the other hand, cannot re-dispersed as the particles are strongly bonded together by metallic force [10]. Aggregation need to be avoided because large aggregated particles possess less driving force for sintering, hence, reducing the densification rate [11].

One of the strategies to prevent aggregation of the nanoparticles is via rapid ramping of heating rate during sintering processing when die-attachment is being performed. By rapidly raising the sintering temperature, surface diffusion does not have sufficient time to occur, thus prevent aggregation from happened. As a result, nanopaste with denser microstructure will be formed. In this work, microstructure of Ag-Cu nanopaste bonding quality on various heating rate at different sintering temperature was investigated and reported.

## 2. Experimental Details

Commercial Ag and Cu nanoparticles purchased from Skyspring Nanomaterials Inc., Houston, USA with average particle sizes of 40-90 and 50-60 nm, respectively, were used in this study. The nanopaste was formulated by mixing 80 wt% of Ag and 20 wt% of Cu nanoparticles with organic compounds consist of a commercial binder (V-006A, Heraeus Inc.) and a surfactant [ethylene glycol, EG, (MW 40 000) from Merck]. This mixture was then put in a vacuum oven at 70°C for 3 hours to evaporate the solvent. After that, the prepared nanopaste was stencil printed onto a pre-cleaned soda lime glass substrate with an area of 1.0 x 1.0 $cm^2$ and thickness (t) of 50.8 μm. To identify the mechanical properties, two polished bare Cu substrates with dimensions of 4.0 cm x 0.7 cm x 4.0 mm (length x width x thickness) were joint by stencil printing of the Ag-Cu nanopaste with a joint area of 0.7 x 0.7 $cm^2$.

The samples were then inserted into a Lenton horizontal tube furnace and heated from room temperature to a a set of various sintering temperatures (380, 350, 300, 260, and 230°C). Different heating rates (5, 10, 15, 20, 25, 30°C/min) were used in to achieve each of the sintering temperature. All of the samples were dwelled for 30 min in the furnace before they were cooled down and withdrew from the furnace for characterization.

Polarizing microscope (MT9430) was also used to characterize the surface morphology of the joint surface. Thermogravimetric analysis (TGA) measurements performed in air were conducted from 35 to 400°C at a rate of 10°C/min using a Perkin Elmer Pyris Diamond system, to study the thermal properties of Ag-Cu nanopaste in various heating rate and temperature. The bonding strength was measured by performing lap shear test using an Instron universal testing system (Model 5582) [12] with a crosshead speed of 0.5 mm/min.

## 3. Results and Discussion

Fig. 1 shows the image of detached bare Cu plates sample after lap shear test. From visual observation, it can be seen that the sintered Ag-Cu nanopaste is still attached and detachment starts to occur towards the end of the Cu substrates