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Property measurements on spray formed Si-Al alloys

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Abstract: A novel Si-Al alloy was prepared by spray forming process for electronic packaging. Property measurements on spray-formed Si-Al alloys after hot pressing were carried out. The results indicate that the alloys (Si-(30%−40%)Al) have advantageous physical and mechanical characteristics, including low coefficient of thermal expansion (6.9×10^{-6}−8.7×10^{-6}/K), high thermal conductivity (118−127 W/(m·K)), low density (2.421×10^3−2.465×10^3 kg/m^3), high ultimate flexural strength (180−220 MPa) and Brinell hardness (162−261). The alloys are easy to machine to tight tolerances using standard machine tools and they can be electroplated with gold finishes and soldered with Sn-Pb alloy without any difficulty.

Key words: spray forming; Si-Al alloy; electronic packaging material; coefficient of thermal expansion

1 Introduction

Si-Al alloys (Si-(30%−50%)Al, mass fraction), prepared using the spray forming process, achieve homogeneous and isotropic properties. Their advantageous physical characteristics, such as low coefficient of thermal expansion (6.8×10^{-6}−11×10^{-6}/K), high thermal conductivity (120−149 W/(m·K)), and low density (2.42−2.51 g/cm^3), make these alloys particularly attractive for packaging electronic circuitry[1−7]. Furthermore, the alloys are easy to machine to tight tolerance using standard machine tools and they can be electroplated with gold, silver or nickel finishes without difficulty. Being non-toxic, they do not require any special handling[8−10]. Therefore, exploitation and application of the alloy have extensive prospect. A family of Si-Al alloy (Al-27%Si, Al-42%Si, Al-50%Si, Al-60%Si, Al-70%Si) has been developed for electronic applications by spray forming process in Osprey Metals Ltd.[11−12]. Nowadays, these alloys have been produced in large scale and applied in RF packages, microwave packages, carrier plates for high frequency circuits and microwave amplifier modules etc. Si-Al alloys (Al-50%Si, Al-60%Si, Al-70%Si) have been prepared by spray forming process or powder metallurgy method in some institutes and universities in China[13−16].

In this study, Si-Al alloys were studied through measuring physical properties (coefficient of thermal expansion, thermal diffusivity and specific heat), mechanical properties (ultimate flexural strength and Brinell hardness), and electroplating and soldering tests. From thermal diffusivity and specific heat, it is possible to reliably calculate thermal conductivity of the alloys.

2 Experimental

The experimental materials were spray formed Si-Al alloys (Si-30%Al, Si-40%Al) after hot pressing. The preforms were prepared on spray forming equipment developed by Beijing General Research Institute for Non-ferrous Metals and Jinzhou Metallurgic Technology Institute (model SF720). The densification process was conducted on hot-pressed sintering furnace developed by Beijing General Research Institute for Non-ferrous Metals. Coefficients of thermal expansion (CTE) measurements were conducted on Formastor-Digital in Beijing Research Institute of Mechanical & Electrical Technology. Thermal diffusivity measurements were conducted in No.703 Institute in Beijing. Specific heat values were determined on Netzsch DSC204 in University of Science & Technology Beijing. Electro-

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plating tests were conducted in No.55 Institute in Nanjing. Soldering tests, the 3-point bending and Brinell hardness measurements were conducted in Beijing General Research Institute for Non-ferrous Metals. Microstructures of Si-Al alloys were observed on NEOPHOT-2 type Optical Microscope and CAMBRIDGE-2 type Scanning Electronic Microscope. The density of the alloys was tested by draining means.

3 Results and discussion

3.1 Microstructure of spray formed Si-30%Al alloy

It can be seen that the microstructure of as-deposited preforms is fine and homogenous. The primary silicon phases distributed in aluminium matrix evenly are fine and irregular, whose size is in the range of 10−40 μm. There are porosities in the alloys because of characteristics of spray forming process, as shown in Fig.1(a). Fig.1(b) shows metallograph of spray formed Si-30%Al alloy after hot pressing, which is different from that of as-deposited preforms. There aren't porosities in the hot-pressed alloy. Moreover, the primary silicon and aluminium matrix realign. The primary silicon congregates in microzone under the stress, and aluminium matrix flows into the porosities and connects in harness.

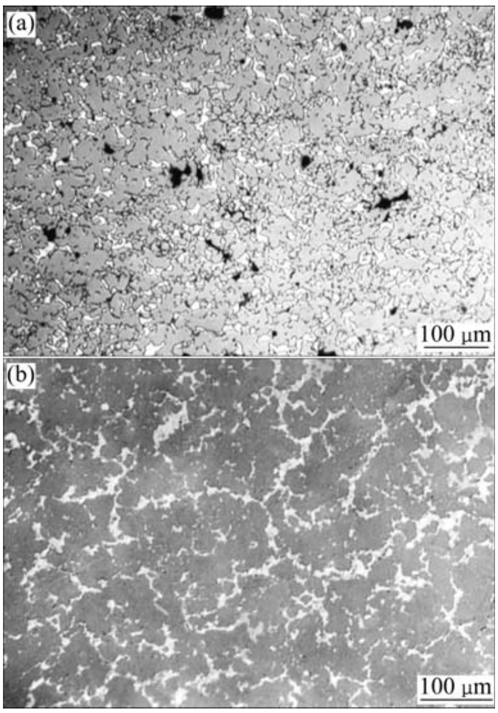

Fig.1 Microstructures of spray formed Si-30%Al alloy: (a) As-deposited; (b) After hot pressing

3.2 Physical properties of spray formed Si-Al alloy

Coefficients of thermal expansion (CTE) measurements were made on samples of Si-30%Al and Si-40%Al alloys. Fig.2 shows CTE of Si-30%Al and Si-40%Al alloys. It can be seen that CTE of Si-40%Al alloy increases with increasing temperature before 400 ℃, however, CTE of Si-40%Al alloy at 500 ℃ is lower than that at 400 ℃. From Fig.2, it can also be seen that CTE of Si-30%Al alloy increases with increasing temperature before 300 ℃, however, CTE decreases with increasing temperature from 400 ℃ to 500 ℃. As seen in Fig.2, CTE of the alloys increases with increasing aluminium content at the same temperature.

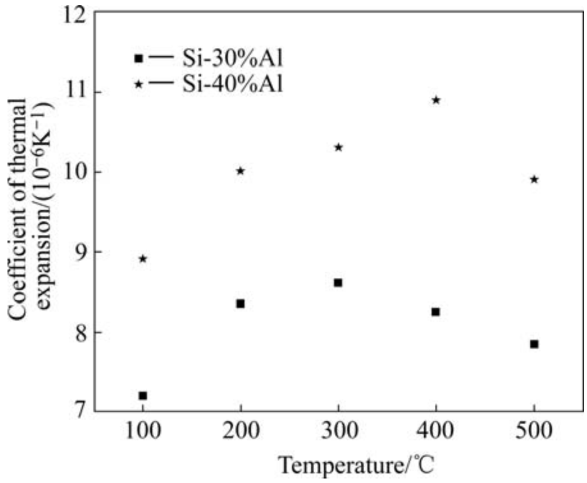

Fig.2 Coefficient of thermal expansion of spray formed Si-Al alloys after hot pressing

Thermal conductivities of the alloys were computed over the measured temperature range from the specific heat capacity and thermal diffusivity measurements. Specific heat capacity (c_p) measurements were made on samples of Si-30%Al and Si-40%Al alloys over a temperature range of 50−500 ℃, as shown in Fig.3. It can be seen that c_p values of Si-Al alloys increase with increasing temperature and aluminium content.

Thermal diffusivity measurements were made on

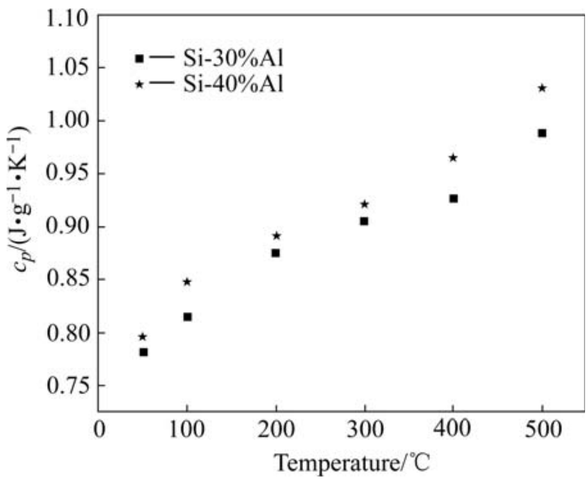

Fig.3 Heat capacity of spray formed Si-Al alloys after hot pressing

samples of Si-30%Al and Si-40%Al alloys over the same temperature range (50−500 ℃), as shown in Fig.4. It can be seen that thermal diffusivity values of Si-Al alloys decrease with increasing temperature and silicon content.

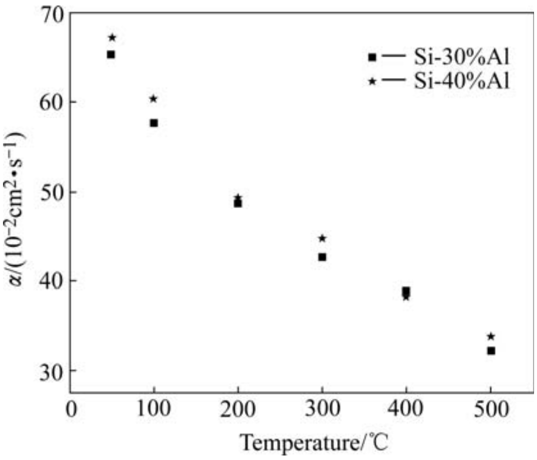

Fig.4 Thermal diffusivity of spray formed Si-Al alloys after hot pressing

From the specific heat capacity and thermal diffusivity measurements, the thermal conductivity values of the alloys were computed, as shown in Fig.5. The derived thermal conductivities similarly drop with increasing temperature and silicon content.

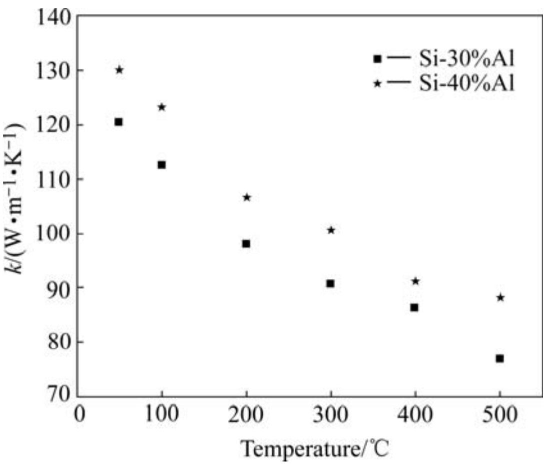

Fig.5 Thermal conductivity of spray formed Si-Al alloys after hot pressing

Drainage is adopted in density measurements of spray formed Si-Al alloys after hot pressing. Three specimens were measured for each alloy, and the average values are listed in Table 1. It can be seen that the average density of Si-30%Al alloy is 2.421×10^3 kg/m^3 and that of Si-40%Al alloy is 2.465×10^3 kg/m^3. The values of this parameter measured are attractive for light mass of the devices.

Table 1 Density of spray formed Si-Al alloys after hot pressing

Alloy	Average density/(10^3kg·m^{-3})
Si-30%Al	2.421
Si-40%Al	2.465

3.3 Mechanical properties of spray formed Si-Al alloy

Table 2 lists the measurements of the ultimate flexural strength of Si-Al alloys after hot pressing. It is shown that the average value of the ultimate flexural strength of Si-30%Al alloy is 180 MPa and that of Si-40%Al alloy is 220 MPa. For the alloys that could be reliably measured, the ultimate flexural strength decreases with increasing silicon content because the alloy becomes more brittle.

Table 2 Ultimate flexural strength of spray formed Si-Al alloys after hot pressing

Alloy	Average ultimate flexural strength/MPa
Si-30%Al	180
Si-40%Al	220

Table 3 lists the measurements of Brinell hardness of spray formed Si-Al alloys after hot pressing. It can be seen that the average value of Brinell hardness of Si-30%Al alloy is 261 and that of Si-40%Al alloy is 162. The hardness increases with increasing silicon content because the primary silicon is an unyielding phase.

Table 3 Brinell hardness of spray formed Si-Al alloys after hot pressing

Alloy	Average Brinell hardness
Si-30%Al	261
Si-40%Al	162

3.4 Electroplating and soldering tests

SEM photograph of densified Si-Al alloy after gold plating is shown in Fig.6. It is shown that appearance of

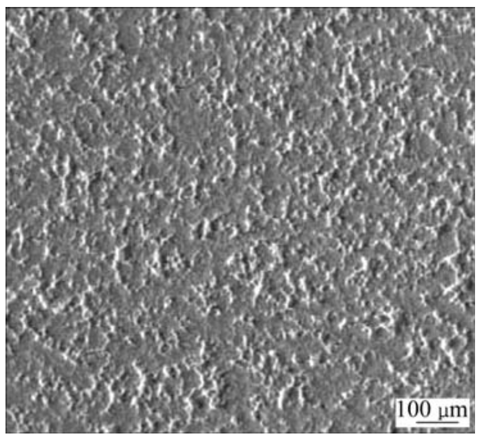

Fig.6 SEM photograph of densified Si-Al alloy after gold plating

uniform film is perfect. When the alloy was held at 450 ℃ for 120 s in atmosphere according to GJBl420A, the film didn't change color and bubble. When the alloy was pressed in vacuum according to GJB548-1041, ratio of leaking is less or equal to 5×10^{-3} Pa·cm^3/s.

Interphase of the film is shown in Fig.7. It can be seen that the film combines the primary silicon or aluminium matrix well. The thickness of the nick layer ranges between 2 and 10 μm. Nick layer is coated with gold whose thickness is in the range of 2−4 μm. For diffusion of atoms, diffusion layer between nick layer and the primary silicon or aluminium matrix is about 2 μm, and the layer between nick layer and gold layer is in the range of 1−3 μm. It is shown that the alloy could be plated easily.

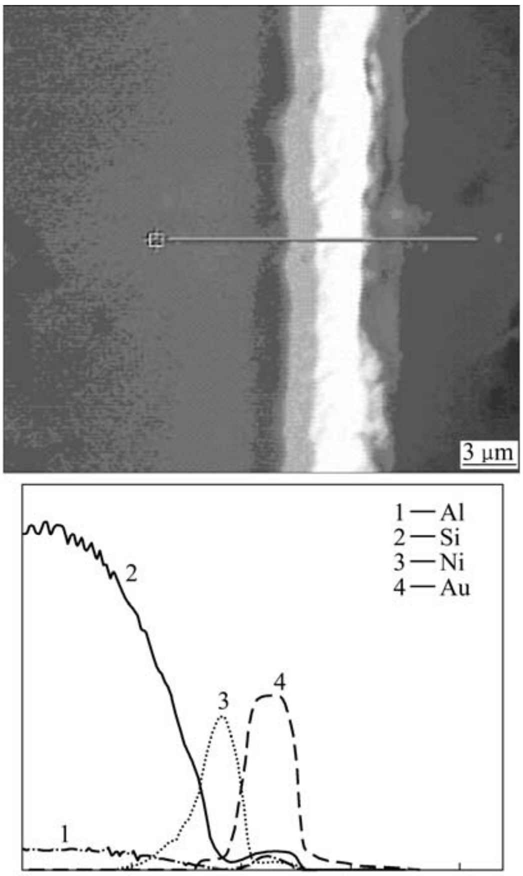

Fig.7 SEM photograph and element distributions of plating of Si-Al alloy

After electroplating tests, the alloy was soldered with Sn-Pb alloy. There isn't porosities and flaws in the weld joint, as seen in Fig.8. Diffusion layer is in the range of 6−9 μm according to interdiffusion of stannum or plumbum atoms with gold atoms, which makes the phases integrate firmly. It is shown that the alloy can be infiltrated and soldered easily.

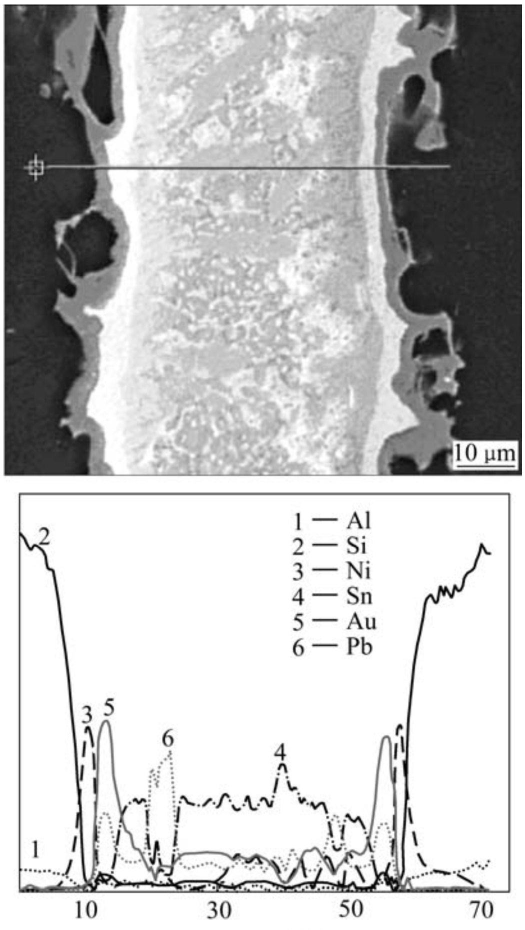

Fig.8 SEM photograph and element distributions of solderable coating of Si-Al alloy

4 Conclusions

1) Spay formed Si-Al (Si-(30%−40%)Al) alloys exhibit attractive properties, i.e. low coefficient of thermal expansion (6.9×10^{-6}−8.7×10^{-6}/K), low density (2.421×10^3−2.465×10^3 kg/m^3), high thermal conductivity (118−127 W/(m·K)), high ultimate flexural strength (180−220 MPa) and high Brinell hardness (162−261).

2) Spay formed Si-Al alloys could be electroplated with gold easily according to standard technology. During soldering tests, it can be seen that the alloy could be soldered without any difficulty.

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