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**Electronic packaging**<br>
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<sup>b</sup> Department of Materials Science and Engineeri **Y.** Liu <sup>a, \*</sup>, L. Pu <sup>a</sup>, Y. Yang <sup>b, c, \*\*</sup>, Q. He <sup>b</sup>, Z. Zh<br>
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c **Y.** Liu <sup>a, \*</sup>, L. Pu <sup>a</sup>, **Y. Yang** <sup>b, c, \*\*, **Q.** Hend  $\frac{b}{b}$  Department of Materials Science and Engineering, Beijing In  $\frac{b}{b}$  Department of Mechanical Engineering, City University of H Coepartment of Material</sup> Accepted 7 July 2020<br>
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SINBIINZN-based high-entropy alloy (HEA) was studied as a low reflow temperature s Or *indeptomagional Congregional Congre* was studied as a low reflow temperature solder with melting<br>bout 52° after reflow at 100 °C for 10 min. The intermetallic<br>asured to be ripening-control with a low activation energy<br>reaction rate is very slow, leading to t

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becoming critica by will nee to sell and the predimic and economical in the chronic particular constrained to be coming critically important to sustain the future computational applications, it is important to growth in microelectronics i physical and economical mind, etection (packaging tetimology is solic eccenteris, bondendarely and epotenting protations, it is important to by growth in microelectronics industry. The trend in miniaturization applied to Examing critical proportion of uses and the distribution and protection applied to related packaging term in minical protection is moving from 2D IC to 3D inte-<br>for very-large-scale-integration is moving from 2D IC to 3D growth in introductionits industry. The tiend in initiaturization<br>of very-large-scale-integration is moving from 2D IC to 3D inte-<br>grated circuit (IC) [1–3]. The latter has various chips stacking<br>vertically, which require y. The trend in initial<br>and applied to related packar<br>noving from 2D IC to 3D inte-<br>temperature of these dever<br>has various chips stacking<br> $\frac{1}{100}$  Follow to develop ind<br>aleopment of new technologies<br>point solders will packaging technology will need to use a inerarchy of solider appropriate soliders with a method of C), middle (200 °C), and solders with a method of C) wetting temperature solders will work together, so biomedical device Joints. In other words, low (around 100 °C),<br>high (300 °C) wetting temperature solders v<br>that different components can be stacked a<br>moment, we have the high-Pb  $Pb_{95}Sn_5$  solder<br>point and the eutectic SnAg solder for the

if the interlactar reaction rate is very slow, leading to the<br>ing point HEA solder has potential applications in a<br>lly for biomedical devices.<br>ed by Elsevier Ltd. This is an open access article unde<br>license (http://creativ Faction Tate is very slow, leading to the formation of a very<br>A solder has potential applications in advanced electronic<br>dical devices.<br>T Ltd. This is an open access article under the CC BY-NC-ND<br>license (http://creativeco mg point that solid has potential applications in advanted electronic<br>ed by Elsevier Ltd. This is an open access article under the CC BY-NC-ND<br>license (http://creativecommons.org/licenses/by-nc-nd/4.0/).<br>about 150 °C [6,7] Its in advanced ecclome<br>
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about 150  $\degree$ C [6,7]. It would be b<br>dering temperature furthermore<br>g to its<br>crease of electronics diversity, we<br>soft electronics, biomedical device<br>applications, it is important to have<br>ization<br>applied to related packagi wer the sol-<br>elopment of<br>on. For these<br>rature solder<br>the working<br>low melting<br>low melting<br>low melting<br>ased solders<br>we have no<br>C, not to say<br>be applied to<br>an no longer<br>research on about 150 °C [6,7]. It would be better if we could lower the sol-<br>dering temperature furthermore to 100 °C. Moreover, as the in-<br>crease of electronics diversity, we are seeing the development of<br>soft electronics, biomedic we could lower the sol-<br>  $^{\circ}$ C. Moreover, as the in-<br>  $\dot{ }$ ing the development of<br>
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How to develop industrial applicable Sn-based low melting<br>
point solders will be problematic. Eutectic binary Sn-based solders<br>
have been studied for decades; however, so far we have no Frow to accetiop matistria application and predicts binary Sn-based foot solders have been studied for decades; however, so far we have no appropriate solders with a melting point below 180 °C, not to say solders with a me point solders will be problematic. Latectic binary sin-based solders<br>have been studied for decades; however, so far we have no<br>appropriate solders with a melting point below 100 °C that can be applied to<br>biomedical device such as through-Si-Via and microbumps. More importantly, the 3D<br>
C packaging technology will need to use a hierarchy of solder appropriate solders with a melting point below 100 °C, not to say<br>
C packaging technology will moment, we have the high-Pb Pb<sub>95</sub>Sn<sub>5</sub> solder for the high melting multicomponent solder is essential. Multicomponent alloys have point and the euctic SnAg solder for the middle melting point (the Me) (HeA), especially in

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LOW melting point solders based on Sn, Bi, and In elements<br>
Y. Liu<sup>a</sup>

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erials Science and Engineering, Beijing Institute of Technology, Be-<br>
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# Atomic insights of Cu nanoparticles melting and sintering behavior in Cu\\Cu direct bonding Materials and Design<br>
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Atomic insights of Cu nanoparticles melting and sintering behav<br>
Cu—Cu direct bonding<br>
Rui Wu, Xiuchen Zhao, Yingxia Liu \*<br>
School of Materia Atomic insights of Cu nanoparticles m<br>
Cu—Cu direct bonding<br>
Rui Wu, Xiuchen Zhao, Yingxia Liu \*<br>
School of Materials Science and Engineering, Beijing Institute of Technology, Beijing,<br>
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Rui Wu, Xiuchen Zhao, Yingxia Liu \*<br>
School of Materials Science and Engineering, Beijing Institute of Technology, Beijing, China<br>
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Cu—Cu direct bonding<br>
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of Cu nanoparticles during the direct bonding process. The melting points of<br>are simulated to be from 963 K to 1298 K. The smaller the diameter of the nano-<br>e same sintering temperature, the sintering time for 2 nm nanopar are simulated to be from 963 K to 1298 K. The smaller the diameter of the nano-<br>esame sintering temperature, the sintering time for 2 nm nanoparticles is less<br>articles. Based on these atomic insights, if we can synthesis C ide same sintering temperature, the sintering time tor 2 nm hanoparticles is less<br>articles. Based on these atomic insights, if we can synthesis Cu nanoparticles as<br>bonding temperature and time can be reduced further.<br>Elsev articles. Based on these adomic misgnis, it we can synthess of nanoparticles as<br>bonding temperature and time can be reduced further.<br>Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://<br>creat bonding temperature and time can be reducted further.<br>
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Interior Content Cont traditional solder joints, Cu—Cu direct interconnection has better scal-<br>ability, better conductivity, thermal conductivity, and resistance to<br>electromigration [4]. However, because the Cu surface is easy to be ox-<br>idized traditional solder joints, Cu—Cu direct interconnection has better scalability, better conductivity, thermal conductivity, and resistance to electromigration [4]. However, because the Cu surface is easy to be oxidized and traditional solder joints, Cu—Cu direct interconnection has better scal-<br>ability, better conductivity, thermal conductivity, and resistance to<br>electromigration [4]. However, because the Cu surface is easy to be ox-<br>idized traditional solder joints, Cu—Cu direct interconnection has better scal-<br>ability, better conductivity, thermal conductivity, and resistance to<br>electromigration [4]. However, because the Cu surface is easy to be ox-<br>idized traditional solder joints, Cu—Cu direct interconnection has better scal-<br>ability, better conductivity, thermal conductivity, and resistance to<br>electromigration [4]. However, because the Cu surface is easy to be ox-<br>idized In the magnetic of and the mail conditions were star-<br>
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https://doi.org/10.1016/j.matdes.2020.109240<br>0264-1275/© 2020 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

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# Ultra-thin intermetallic compound formation in microbump technology by the control of a low Zn concentration in solder



Materialia

Yingxia Liuª\*, Li Puª, Andriy Gusakʰ, Xiuchen Zhaoª, Chengwen Tanª, K.N. Tu¢

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# A B S T R A C T

Diffusion<br>
The contract the state of the same of the formed IMC was Cu<sub>5</sub>Zn<sub>8</sub> with a thickness only about 0.36  $\mu$ m, which is much thinner IMC growth kinetics than the IMC in nowaday packaging technologies. We systematically studied the IMC growth kinetics and built and built 3D IC up a model to explain the extremely slow IMC growth rate. The growth kinetics of the reaction is non-parabolic We report here the extremely slow intermetallic compound (IMC) growth kinetics in the reflow reaction between a Sn-based solder of SnBiIn-2 at.% Zn and Cu. The solder has a melting point about 90 °C, and after reflow for and the activation energy is about  $23.8 \pm 1.6$  kJ/mol. The non-parabolic kinetics is related to the lateral grain growth in IMC during the reactive diffusion along the moving grain boundaries. Our theoretical model shows that the growth rate of  $Cu<sub>5</sub>Zn<sub>8</sub>$  compound should be proportional to the square root of Zn initial concentration in solder and a low Zn concentration in the solder will lead to a very slow IMC growth rate. The finding could be applied to control IMC thickness in 3D integrated circuit (3D IC) with micro-bump technology.

# 1. Introduction

As Moore's law of miniaturization in Si technology is approaching its physical and economic limit, 3D IC has been regarded as the most promising technology to sustain the law in the future  $[1-3]$ . 3D IC is achieved by stacking multiple chips using TSV (through-Si-via) and microbumps. There are three different size solder joints in the 3D ar chitecture, including Ball Grid Array (about 760–200  $\mu$ m), Controlled Collapse Chip Connection (C-4 joints about 100  $\mu$ m) and microbumps (about 20  $\mu$ m). In the future, the density of input/output connections in packaging will increase, so the size of  $\mu$ -bump might be scaled down to 10  $\mu$ m, 5  $\mu$ m, or even only 1  $\mu$ m [4–6]. This scaling trend will lead to serious reliability concerns and challenges in microbumps.

One of the main challenges is to control IMC thickness in microbumps. This is because the diameter of microbumps has been reduced more than 10 times from the C-4 joint, so the volume of solder will be reduced more than 1000 times [7]. Under the same reflow time, if we assume both the traditional solder balls and microbumps have the same IMC growth rate, the percentage of IMC would be much higher in microbumps. Furthermore, the IMC growth rate in small size solder bumps will be remarkably higher due to surface diffusion during interfacial re action [8]. Actually, the solder layer in microbumps could transform completely into IMC after just aging for 24 h at 180 °C [9]. IMC is brittle in nature, and the high percentage of IMC will lead to the embrit-(about 20 *pm*<sub>1</sub>). In the nuture, the energiest of MC will be celebrate on the state solution of the scale down to However, the IMC growth rate packing the packing term of the  $\frac{1}{2}$ . This scaling term of will lead to

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tlement problem in microbumps [10]. In addition, during IMC growth, solder layer will be experiencing volume shrinkage, and volume shrinkage works together with electromigration would lead to early failures [11–13]. Therefore, it's essential to control the IMC growth rate in the interfacial reaction between the solder and under bump metallization (UBM) in microbumps.

In this study, we report a Sn-Zn solder containing very low concen tration of Zn solder that has an extremely slow reaction rate with Cu substrate. Some researchers have already investigated the effect of adding Zn to Sn-based solder to slow down the IMC growth kinetics [14–19]. However, the IMC growth rate in our work is much slower than the published results. Moreover, the reason of Zn effect to IMC growth kinetics is not systematically explained in those works, because Sn–Zn–Cu is a ternary system, and the reaction paths are complicated. Therefore, we developed a theoretical model for a systematic discussion of the competition among evolution paths in reactions between Cu with Sn-Zn solder. We explained that only a small amount of Zn can lead to the extremely slow reaction rate in IMC formation. The finding is important in the application of microbumps to advanced electronic packaging technology.

# 2. Experimental

SnBiIn-2 at.% Zn solder were prepared using high purity (>99.9%) Sn, Bi, In and Zn according to atomic ratio of Sn:Bi:In:Zn = 48:25:25:2. The ingots melted completely at around 300 °C in a vacuum induc-



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, Xiuchen Zhao <sup>a</sup>, Chengwen Tan <sup>a</sup>, K.N. Tu <sup>d</sup> Example 20 and the Complete Contract of the Co **ELSEVIER** journal homepage: www.elsevier.com/locate/mlblue<br> **Effect of adding Ag to the medium entropy SnBiIn alloy on intern**<br>
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Li Pu<sup>a</sup>, Yingxia Liu<sup>a,\*</sup>, Yong Yang <sup>b,c</sup>, Quanfeng He<sup>b</sup>, Ziqing Zhou **Effect of adding Ag to the medium entropy SnBiIn alloy on interme**<br> **COMPOUND formation**<br>
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<sup>a</sup> Dept. of Materials Science and Engineering, Beijing Institute of Technology, Beijing c<br>
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<sup>b</sup> Dept. of Mechanical Engineering, City University of Hong Kong **Li Pu<sup>a</sup>**, **Yingxia Liu**<sup>a,\*</sup>, **Yong Yang** <sup>b,c</sup>, **Quanfeng He**<sup>b</sup>, **Ziq**<br>
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Wetting reactions of the medium entropy allo **Consumed by the melting Choice of SnBiIn and SnBiInAg of Chengwen Tan<sup>a</sup>, K.N. Tu<sup>d</sup><br>
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Wetting** *s*<sup>c</sup>, Quanfeng He <sup>b</sup>, Ziqing Zhou <sup>b</sup>, Xiuchen Zhao <sup>a</sup>, Chengwen Tan <sup>a</sup>, K.N. Tu <sup>d</sup><br> *itute of Technology, Beijing, China*<br> *ig Kong, Hong Kong, Enina*<br> *if California, Los Angeles, USA*<br> **A B S T R A C T**<br>
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tigated. The melting points that is performology, *teams* Continuous, the pre-factor of diffusivity of Hong Kong, China<br>is ity of Hong Kong, Hong Kong, China<br>A B S T R A C T<br>Wetting reactions of the medium entropy alloy of SnBiln and SnBilnAg on Cu s mAg on Cu substrate have been investored.<br>
20<sup>2</sup> C. The reactions were performed at<br>
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2020 Elsevier B.V. All rights reserved. kinetics of interfacial intermetalic compound (IMM)<br>ed with activation energy about 11.1 kJ/mol for Sn<br>on of Ag has effectively reduced the IMC growth lived the pre-factor of diffusivity by increasing the  $\circ$  2020 Elsevie

As we enter the big data era, the trend in very-large-scale-<br>
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At the same time, the challenge in integration of electronic mate are stating and the same that according in the phase diagram<br>and the same time, the challenge in integration of electronic materi-<br>In = 42:28:30 in a vacuum ind<br>als has been greatly increased. Take the example of solder m At the same time, the Chamelege in Imegration of election the etchome Indeed and the sample of solder micro-<br>als has been greatly increased. Take the example of solder micro-<br>from the flip chip C-4 joint, the volume of so as ias been grady interaction. The interaction of solution, which can react with Cu to form solely and the comparison, The solution of sole is reduced more than 1000 times [1-4]. How to control IMC growth and limit the ing bump, will the callent through the callent in the sole of the system in the entropy. The effect of adding Ag to SnBiIn in reducing IMC formation is analyzed using PINC and the enter to increase its mixing entropy alloy (HE From the map time of solution that is restanted through the matrix and the map of the two solders. The precentage of IMC in micro-bump is critical, so new solder materi-<br>parecentage of IMC in micro-bump is critical, so ne than 1000 times  $[1-4]$ . Tow to control intergrowth<br>percentage of IMC in micro-bump is critical, so new<br>als are under consideration. High entropy alloy (HE<br>new, first reported in 2004, and it has attracted att<br>temperature temperature soldering applications [5–7]. The possible sluggish scope<br>diffusion kinetics in some HEAs might reduce the brittle interfacial<br>interf<br>IMC growth in solder joints [8]. So far, there are few reports<br>the stabout H Frequence solutions and the medical conduction in the distribution is compatible interface the brittle interface the soft content of the sole of the

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for 5 min, 10 min and 20 min, respectively. The cross-sections of<br>wetting samples were investigated by scanning electron micro-<br>scope (SEM) and energy dispersive X-ray spectroscope (EDX). The<br>interfacial IMC thickness was wetting samples were investigated by scanning electron microscope (SEM) and energy dispersive X-ray spectroscope (EDX). The interfacial IMC thickness was obtained from the SEM images by the software Image].<br> **3. Results a** scope (SEM) and energy dispersive X-ray spectroscope (EDX). The<br>interfacial IMC thickness was obtained from the SEM images by<br>the software Image].<br>**3. Results and discussion**<br>In order to identify the melting behavior of t **EXECT SNUTHET SOLUTE SOLUTE:**<br> **STATE:**<br> **STATE:**<br>

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Surface diffusion controlled reaction in small size microbumps<br>
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Institute of Materials Science and Engineering, Beijing Institute of Technology, Beijin **ELSEVIER** journal homepage: www.elsevier.com/locate/mlblue<br> **Surface diffusion controlled reaction in small size microbumps**<br>
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Yingxia Liu <sup>a,\*</sup>, Xiuyu Shi <sup>a</sup>, Haoxiang Ren <sup>a</sup>, Jian Cai<br>
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<sup>b</sup> Institute of Microelect **d reaction in small size microbump**<br> **ing Ren<sup>a</sup>, Jian Cai<sup>b</sup>, Xiuchen Zhao<sup>a</sup>, Chengwe<br>** *titute of Technology, Beijing, China***<br>** *ig, China***<br>** *A* **B S T R A C T<br>
We made head-shaped Cu-Sn solder joints with diameters abo** 

**Surface diffusion controlled r**<br>
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definition kinetics<br> Expression and diffusion frequency is calculated to be  $Q_S = 0.18 \pm 0.02$  eV/atom and diffusion frequency thermetallic alloys and compounds<br>  $\text{cm}^2/\text{s}$ .<br>
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Jure Surface diffusion. The scaling trend in chip technology, there is a scaling<br>
Similar to the scaling Share the scaling trend in chip technology, there is a scaling over under  $N_2$  environment af placed development of packaging technology, the size of solder joint shrinks from a packaging technology. The size of solder j Interfaces<br>
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trend in packaging technology. The size of solder joint shrinks form<br>
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several hundred microns to ab **Example 19** Four times and many every interest in the sealing the studied heat is a scaling the studied the chips up-side down to several hundred microns to about 20 µm and may eventually (SEM). For each bump size, we pio Similar to the scaling trend in chip technology, there is a scaling<br>
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several hundred mi sininal to the staing trend in clip technology<br>trend in packaging technology. The size of solder<br>several hundred microns to about 20  $\mu$ m an<br>shrink to several microns with the development<br>nology [1–3]. In the traditional Exercia mandred metroms to about 20  $\mu$ m and may ever-<br>shrink to several microns with the development of packagin<br>nology [1–3]. In the traditional flip chip C-4 solder joints, s<br>diffusion is neglected compared to grain b Exterimental section<br>
To fabricate the surface of 10 pm and the bottom and the bump size decreases to less than 20 µm, surface diffusion and<br>
The face diffusion in solder and the wind size diffusion in solder and the sect arrays of holes with diameter of 10  $µm$ , and 50  $µm$ , and 50  $µm$ , the CH and the parameter of 5.5  $µm$  Sharrays of holes with a thickness of the same solar of 5.5  $µm$  Sharrays of holes with a the parameter of 10 mm, in ever, when the bump size decreases to less than 20  $\mu$ m, surface dif-<br>
Fig. 1 shows the SEM cross-sectifusion becomes dominant. While surface diffusion in solid state<br>
solder joint reactions has been studied [4], surface

4.5 pm was electroplated in the holes, followed by electroplating<br>
4.5 m solid state in the gradient reactions has been studied [4], surface diffusion in solid state being reflowed. The gradient reflow reactions hasn't be Solder joint reactions has been studied [4], surface diffusion in solder in the grain size in<br>reflow reactions hasn't been analyzed. In this work, we study the<br>reflow ractions hasn't been analyzed. In this work, we study t Eventions hasn't been analyzed. In this work, we study the<br>
surface diffusion-controlled kinetics of wetting reaction in solder<br>
surface diffusion-controlled kinetics of wetting reaction in solder<br>
in a reflow the a sum o 1011 formation. To fabricate the head-shaped Cu-Sn solder joints, we made studies with this growt within growt<br>
array of holes with diameter of 10 μm, 20 μm, and 50 μm, in To<br>
the photoresist by lithography. Then, Cu laye more p<br>
Experimental section<br>
To fabricate the head-shaped Cu-Sn solder joints, we made<br>
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**K.N. TU**<br>
<sup>2</sup> School of Materials Science and Engineering, Beijing Institute of Technology, Beijing, Clubs Institute of Materials Science and Engineering, University of California, Los Angeles, USA<br>
A R T I C L E I N F O **CHEREN CUALTER CONSTRANT CUALTER CONSTRANT CUALTER CONSTRANT CUALTER (SPECIFY)**<br>
Egg China<br>
for Culifornia, Los Angeles, USA<br>
A B S T R A C T<br>
We made head-shaped Cu-Sn solder joints with diameters about 10 µm, 20 µm, an titute of Technology, Beijing, China<br>titute of Technology, Beijing, China<br>gg. China<br>A B S T R A C T<br>We made head-shaped Cu-Sn solder joints with diameters about 10 µm, 20 µm, and 50 µm and reflowed<br>the samples at 240 °C, 2 **grain after reflow, the classic model of scallop-type grain growth of Cu<sub>6</sub>Sn<sub>5</sub> does not apply. The clumber of california,** *tos Angeles, USA***<br>
We made head-shaped Cu-Sn solder joints with diameters about 10 µm, 20 µm, a** Itig Neri , Jiarl Cal , Atlutifieri Zilao , Ciferigwell 1 all ,<br>ig. China<br>grain of California, Los Angeles, USA<br>A B S T R A C T<br>We made head-shaped Cu-Sn solder joints with diameters about 10  $\mu$ m, 20  $\mu$ m, and 50  $\mu$ m Finding and Server Controlled model to explain a controlled model of  $\beta$  and  $\beta$  and titute of Technology, Beijing, China<br>
Ig. China<br>
A B S T R A C T<br>
We made head-shaped Cu-Sn solder joints with diameters about 10 µm, 20 µm, and 50 µm and reflowed<br>
the samples at 240 °C, 260 °C, and 280 °C for 60 s to 60  $\text{cm}^2\text{/s.}$ 20 μm, 20 μm, and 50 μm and reflowed 0 μm bumps, there is only one Cu<sub>6</sub>Sn<sub>5</sub> to the of Cu<sub>6</sub>Sn<sub>5</sub> does not apply. Also, the te. We proposed a surface diffusion-nodel, the diffusion activation energy factor to be  $D_{S0} =$ Sisic model of scallop-type grain growth of Cu<sub>6</sub>Sn<sub>5</sub> does not apply. Also, the<br>
e bumps has the faster growth rate. We proposed a surface diffusion-<br>
ne new kinetics. According to our model, the diffusion activation ene

be bumps has the faster growth rate. We proposed a surface diffusion-<br>ne new kinetics. According to our model, the diffusion activation energy<br> $\pm$  0.02 eV/atom and diffusion frequency factor to be  $D_{50} = 5.65 \times 10^{-3}$ <br>is the new kinetics. According to our model, the diffusion activation energy  $\pm$  0.02 eV/atom and diffusion frequency factor to be  $D_{SO} = 5.65 \times 10^{-3}$ <br>  $\odot$  2020 Elsevier B.V. All rights reserved.<br>
<br>
<br> **OVERT UNET ANC** ± 0.02 eV/atom and diffusion frequency factor to be  $D_{\text{SO}} = 5.65 \times 10^{-3}$ <br>
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Oven under N<sub>2</sub> environment after Ar<sup>+</sup> plasma pretreatment. We<br>
placed the chips up-side down to av  $\circ$  2020 Elsevier B.V. All rights reserved.<br>
oven under N<sub>2</sub> environment after Ar<sup>+</sup> plasma pretreatment. We<br>
placed the chips up-side down to avoid the influence of gravity<br>
on surface diffusion. The samples after reflo  $\circ$  2020 Elsevier B.V. All rights reserved.<br>
oven under N<sub>2</sub> environment after Ar<sup>\*</sup> plasma pretreatment. We<br>
placed the chips up-side down to avoid the influence of gravity<br>
on surface diffusion. The samples after reflo oven under  $N_2$  environment after  $Ar^+$  plasma pretreatm<br>placed the chips up-side down to avoid the influence of<br>on surface diffusion. The samples after reflow were polis<br>we observed the cross-sections by scanning electr Fig. 1 shows the SEM cross-sectional image of the pumps have the SEM cmin Universal image of the semi-<br>10 shows the SEM cross-sections by scanning electron microscope<br>10. For each bump size, we pick three bumps out of the oven under  $N_2$  environment after  $Ar^*$  plasma pretreatment. We<br>placed the chips up-side down to avoid the influence of gravity<br>on surface diffusion. The samples after reflow were polished and<br>we observed the cross-secti

oven under  $N_2$  environment after  $Ar^+$  plasma pretreatment. We<br>placed the chips up-side down to avoid the influence of gravity<br>on surface diffusion. The samples after reflow were polished and<br>we observed the cross-secti placed the chips up-side down to avoid the influence of gravity<br>on surface diffusion. The samples after reflow were polished and<br>we observed the cross-sections by scanning electron microscope<br>(SEM). For each bump size, we on surface diffusion. The samples after reflow were polished and<br>we observed the cross-sections by scanning electron microscope<br>(SEM). For each bump size, we pick three bumps out of the array<br>and measured the thickness of we observed the cross-sections by scanning electron microscope<br>(SEM). For each bump size, we pick three bumps out of the array<br>and measured the thickness of IMC by Image J.<br>**3. Results and discussion**<br>Fig. 1 shows the SEM (SEM). For each bump size, we pick three bumps out of the array<br>and measured the thickness of IMC by Image J.<br>**3. Results and discussion**<br>Fig. 1 shows the SEM cross-sectional image of the bumps after<br>being reflowed. The g and measured the thickness of IMC by Image J.<br> **3. Results and discussion**<br>
Fig. 1 shows the SEM cross-sectional image of the bumps after<br>
being reflowed. The grain size in the 50  $\mu$ m bumps is about 2–<br>
3  $\mu$ m after re **3. Results and discussion**<br>Fig. 1 shows the SEM cross-sectional image of the bumps after<br>being reflowed. The grain size in the 50  $\mu$ m bumps is about 2–<br>3  $\mu$ m after reflowed for 1 min and about 10  $\mu$ m after reflowed **Start of the SEM cross-sectional image of the bumps after** being reflowed. The grain size in the 50  $\mu$ m bumps is about 2–3  $\mu$ m after reflowed for 1 min and about 10  $\mu$ m after reflowed for 10 min. Under the same ref Fig. 1 shows the SEM cross-sectional image of the bumps after<br>being reflowed. The grain size in the 50 µm bumps is about 2–<br>3 µm after reflowed for 1 min and about 10 µm after reflowed<br>for 10 min. Under the same reflow ti The 21 shows the SEM closs-sectional image of the bumps atternal and<br>being reflowed. The grain size in the 50 µm bumps is about 2-<br>3 µm after reflowed for 1 min and about 10 µm after reflowed<br>for 10 min. Under the same re being tenowed. The grain size in the 30  $\mu$ m bumps is about 2-<br>3  $\mu$ m after reflowed for 1 min and about 10  $\mu$ m after reflowed<br>for 10 min. Under the same reflow time, the 20  $\mu$ m bumps have<br>bigger grains than 50  $\mu$ 

S put alter renowed for 1 film and about 10 pm alter renowed<br>bigger grains than 50 µm bumps. This trend is especially much<br>more prominent in 10 µm bumps. Almost all the 10 µm bumps<br>start to have only one grain, which is a for 10 nm, oner the same fellow thie, the 20  $\mu$ m bumps have<br>bigger grains than 50  $\mu$ m bumps. This trend is especially much<br>more prominent in 10  $\mu$ m bumps. Almost all the 10  $\mu$ m bumps<br>start to have only one grain, branch in 10 m bumps. Fins tiend is espectary intentions and the top university incomponent in 10 m, bumps start to have only one grain, which is about 10 µm in diameter within 1 min reflow. The above finding that IMC has more prominent in 10 pm bumps. Annost an the 10 pm bumps<br>start to have only one grain, which is about 10 µm in diameter<br>within 1 min reflow. The above finding that IMC has the fastest<br>growth rate in the smallest bump is u





![](_page_7_Picture_25.jpeg)

# 国家自然科学基金资助项目批准通知

刘影夏 先生/女士:

根据《国家自然科学基金条例》和专家评审意见,国家自然科学基金委员会( 以下简称自然科学基金委)决定批准资助您的申请项目。项目批准号:51901022, 项目名称: 应用于先进电子封装的低熔点高熵合金焊料焊接性与可靠性研究, 直 接费用:25.00万元,项目起止年月:2020年01月至 2022年 12月,有关项目的评 审意见及修改意见附后。

请尽早登录科学基金网络信息系统(https://isisn.nsfc.gov.cn),获取《 国家自然科学基金资助项目计划书》(以下简称计划书)并按要求填写。对于有修 改意见的项目,请按修改意见及时调整计划书相关内容;如对修改意见有异议,须 在电子版计划书报送截止日期前向相关科学处提出。

电子版计划书通过科学基金网络信息系统(https://isisn.nsfc.gov.cn)上 传,依托单位审核后提交至自然科学基金委进行审核。审核未通过者,返回修改后 再行提交;审核通过者,打印纸质版计划书(一式两份,双面打印),依托单位审 核并加盖单位公章,将申请书纸质签字盖章页订在其中一份计划书之后,一并将上 述材料报送至自然科学基金委项目材料接收工作组。电子版和纸质版计划书内容应 当保证一致。

请注意:依托单位应在邮寄纸质版计划书时,补交获资助的青年科学基金项目 、优秀青年科学基金项目和重点项目申请书的纸质签字盖章页(A4纸),其签字盖 章的信息应与电话书保持一致。自然科学基金委将对申请书纸质签字盖章页进 行审核,对存在问题的,允许依托单位进行一次修改或补齐。

向自然科学基金委补交申请书纸质签字盖章页、提交和报送计划书截止时间节 点如下:

1.2019年9月11日16点:提交电子版计划书的截止时间(视为计划书正式提交 时间);

2.2019年9月18日16点:提交电子修改版计划书的截止时间;

3. 2019年9月26日16点: 报送纸质版计划书(其中一份包含申请书纸质签字盖 章页)的截止时间。

4.2019年10月18日16点:报送修改后的申请书纸质签字盖章页的截止时间。

请按照以上规定及时提交电子版计划书,并报送纸质版计划书和申请书纸质签 字盖章页,未说明理由且逾期不报计划书或申请书纸质签字盖章页者,视为自动放 弃接受资助;未按要求修改或逾期提交申请书纸质签字盖章页者,将视情况给予暂 缓拨付经费等处理。

附件:项目评审意见及修改意见表

国家自然科学基金委员会 2019年8月16日

# 附件:项目评审意见及修改意见表

![](_page_10_Picture_166.jpeg)

通讯评审意见:

<1>具体评价意见:

一、请针对创新点详细评述申请项目的创新性、科学价值以及对相关领域的潜在影响。 项目拟研制高熵合金焊料解决低温度下集成电路的封装问题,既有创新性又有应用的迫切性。 研发的新材料对解决目前封装所需的低温焊料具有重要意义。

二、请结合申请项目的研究方案与申请人的研究基础评述项目的可行性。 研究方案可行,前期有很好的工作基础,材料体系基本确定,在本项目中进行组分优化、性能 测设等工作。申请人与领域前沿科学家有很好的合作关系,有利于项目的开展。优先支持。

三、其他建议

<2>具体评价意见:

一、请针对创新点详细评述申请项目的创新性、科学价值以及对相关领域的潜在影响。 申请人拟通过研究不同组分的高熵合金与熔点之间的关系,研究其焊接性能,并研究高熵合金 对金属间化合物反应动力学的影响,筛选出适合封装工业用的低温钎料。虽然,工程上钎料合 金的成分趋于简单,较多组元成分的钎料合金由于工艺过程中容易变化,从而不受工业界欢迎 。该项目研究工作值得尝试研究。

二、请结合申请项目的研究方案与申请人的研究基础评述项目的可行性。 申请者前期有一定的研究基础,项目具有一定的可行性。

三、其他建议

无。

<3>具体评价意见:

一、请针对创新点详细评述申请项目的创新性、科学价值以及对相关领域的潜在影响。 芯片封装技术正通过复杂化、高集成化来满足消费者对于电子产品性能日益苛刻的要求。该项 目提出采用低熔点高熵合金作为低温焊料,降低回流焊接时的温度来解决封装焊点小型化过程 中微凸点的金属间化合物生长动力学控制以及大尺寸封装翘曲度等问题,具有较好的创新性。 通过研究不同组分的高熵合金和熔点之间的关系,探寻高熵合金组分和结构及其熔点和焊接性 能之间的科学关联,筛选出适用于封装工业焊接用的低熔点高熵合金焊料,有利于降低传统焊 料熔点难题,为先进封装所面临的问题和挑战提供一种解决途径,具有较高的学术价值和科学 价值。同时,将回流焊接技术应用于制备低温焊料,改良助焊剂,高熵低温焊料利于克服未来 电子封装小型化、复杂化所带来的挑战,具有一定的实际应用意义。

二、请结合申请项目的研究方案与申请人的研究基础评述项目的可行性。 项目的研究内容较新颖,研究方案可行性高、具体完整,项目组的实验设备完善,申请者具有 较好的研究基础。

三、其他建议 建议基金委考虑对本项目予以资助。

修改意见:

工程与材料科学部

2019年8月16日