升温速率对复合钎料显微组织和力学性能的影响

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摘 要: 不同的钎焊工艺条件会对复合钎料中增强相颗粒(如 Ni, Ag, Cu 等金属颗粒)周围金属间化合物的形貌和尺寸产生影响, 而增强相颗粒周围金属间化合物的尺寸又会对复合钎料的力学性能产生影响。在共晶 Sn-3.5Ag 钎料中外加微米级铜颗粒制成复合钎料, 研究了不同的升温速率对复合钎料内部颗粒显微组织和力学性能的影响。结果表明, 复合钎料中铜增强颗粒周围存在着厚度不均的金属间化合物层, 不同的升温速率对这层金属间化合物的形貌基本没有影响, 只会对其厚度尺寸有影响。此外, 建立了不同升温速率与铜颗粒增强的 Sn-Ag 基复合钎料增强颗粒周围金属间化合物尺寸和力学性能的关系。

关键词: 升温速率; 复合钎料; 金属间化合物; 力学性能
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0 序 言

传统Sn-Pb 钎料凭借其合适的熔点、良好的钎焊工艺性能及力学可靠性等优势, 已在电子工业中服役了很长时间。但由于传统钎料中铅元素的毒性严重危害着环境及人类健康, 无铅钎料已成为各研究机构关注和研究的焦点。Sn-3.5Ag 共晶钎料作为含铅钎料的替代品之一已经得到越来越广泛的研究, 但仍存在着熔点偏高, 力学性能较差等问题。通常, 制备复合钎料的方法被认为是一种提高服役性能的有效方法, 特别是对于无铅钎料而言。通过内生或者外加法制成的复合钎料内部往往包含着由增强相颗粒形成的金属间化合物。

经过不同的焊接工艺、时效和再流等服役过程, 钎料/基体界面间及钎料内部金属间化合物的形貌会表现出不同的形态[1]。而界面处金属间化合物的脆性本质往往会影响钎焊接头的力学性能[2]。许多研究机构均致力于研究界面处金属间化合物的形貌[3]。不同的工艺条件下, Ni 颗粒增强的 Sn-3.5Ag 基复合钎料中 Ni 颗粒周围金属间化合物会有不同的形貌。这些金属间化合物的形貌与工艺条件有关, 特别是钎焊过程中的升降温速率[4]。钎焊过程中在钎料液相线温度以上停留的时间会影响钎料中金属间化合物的形貌, 特别是加热条件会对化合物形貌产生更大的影响[1]。

文中在共晶 Sn-3.5Ag 钎料中外加微米级铜颗粒制成复合钎料, 研究了在不同的升温速率工艺条件下, 铜增强颗粒的分布情况以及其周围金属间化合物的形貌和尺寸大小。此外, 对不同升温速率下制得的复合钎料的抗剪强度也进行研究。从而建立了不同升温速率与铜颗粒增强的 Sn-Ag 基复合钎料增强颗粒周围的化合物尺寸和力学性能的关系。

1 试验方法

采用外加法将微米级的 Cu 增强颗粒添加到Sn-3.5Ag 共晶钎料基体中形成复合钎料。Cu 增强颗粒的添加体积比例为 5%, 具体钎料成分配比见表 1。

表 1 钎料成分配比表
Table 1 Composition of solder

成分	体积分数(%)	质量 m/g	密度 ρ/(g·cm^{-3})
Sn-3.5Ag	95	5	7.36
微米 Cu 粉	5	0.3204	8.96

按表 1 称取适量的焊膏后, 将称量好的外加铜增强颗粒粉末倒入, 再用玻璃棒进行搅拌, 以保证外加粒子较均匀地弥散在钎料基体中。通过扫描电镜

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的观察分析，铜颗粒的平均粒径尺寸为 3～5 μm，如图 1 所示。

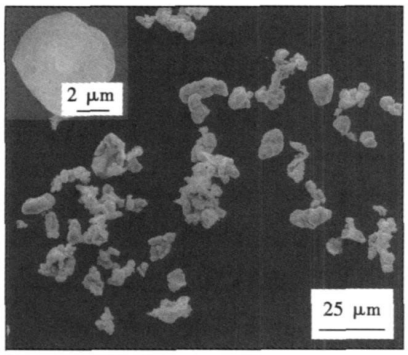

图 1 Cu 增强相颗粒形貌

Fig. 1 Microstructure of Cu reinforcement particles

采用单剪搭接接头进行钎焊试验以备显微组织观察和力学性能测试。钎焊接头的具体尺寸见图 2。如图所示，钎料搭接部分的面积为 1 mm^2，钎料的厚度控制在 0.1 mm。焊接前，接头首先需要经过 50%硝酸浸泡去除氧化物，再经过丙酮浸泡，吹干后备用。将涂好钎料的接头放置在模具中等待焊接。在钎焊的过程中采用恒定冷却速率，不同升温速率的工艺条件，并用 FLUKE54 型接触式温度计进行实时温度记录。图 3 为恒定冷却速率、不同升温速率下接头的钎焊温度变化曲线。如图所示，其峰值温度为 280 ℃，冷却介质为铝板，冷却速率平均约为 0.9 ℃/s。

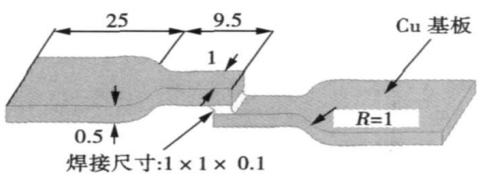

图 2 钎焊接头尺寸(mm)

Fig. 2 Dimension of soldered joint

钎焊后钎焊接头两侧外流的钎料要打磨干净以备抗剪强度性能测试。此外，进行显微组织观察的试样采用 800，1 000，2 000 号砂纸进行打磨，之后采用粒度 0.3 μm Al_2O_3，0.05 μm Al_2O_3，0.04 μm SiO_2 抛光液进行抛光。用光学显微镜及扫描电子显微镜对钎焊接头进行组织观察，采用 LOYYD 型抗拉抗剪强度测试仪测量钎焊接头的抗剪强度。通过以上不同的钎焊升温速率，以获得复合钎料中铜增强颗粒周围金属间化合物的不同形貌尺寸。

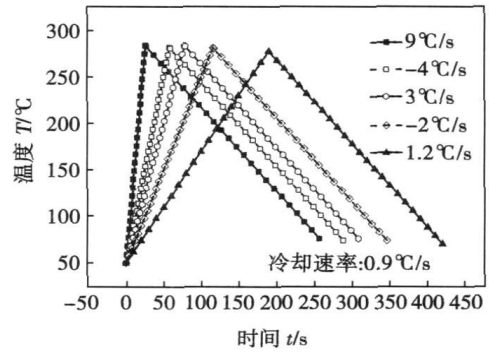

图 3 钎焊温度变化曲线

Fig. 3 Temperature profile for soldering

2 试验结果与讨论

2.1 不同升温速率对钎料内部铜增强颗粒周围金属间化合物形貌的影响

图 4 所示为在冷却速率恒定的条件下，不同升温速率钎焊工艺得到的复合钎料中铜颗粒增强相周围显微组织形貌。

如图所示，铜颗粒增强的复合钎料内部金属间化合物的显微组织形貌没有受到不同升温速率的影响。铜增强颗粒周围金属间化合物的形貌基本上呈现发射箭矢形态的向日葵状。

随着升温速率的降低，钎料在加热阶段有更多的时间吸收热量。与升温速率对应的，铜颗粒周围金属间化合物的厚度增加，尺寸也会变大。钎料内部的金属间化合物都有随热输入的增加而变厚的趋势。

根据不同升温速率钎焊工艺得到的显微组织，计算出增强颗粒及钎焊过程中增强颗粒周围形成的金属间化合物尺寸。升温速率与颗粒尺寸的关系如图 5 所示。升温速率较小的工艺条件下，得到的铜颗粒周围金属间化合物的平均尺寸越大，这是由于其升温速率过小，金属间化合物在铜颗粒表面形核的速度较慢，就很容易与钎料内部的 Sn 形成 Cu-Sn 金属间化合物层，铜颗粒反而被消耗得更多。另一方面，由于升温缓慢，金属间化合物在铜颗粒表面形成时铜增强颗粒不易分散，易产生团聚的现象。而升温速率相对较大的工艺条件，复合钎料中铜增强颗粒周围金属间化合物的平均尺寸相对较小，这是由于升温速率大，金属间化合物在铜颗粒表面形核的时间短，铜颗粒来不及反应，也不容易团聚，因而形成的尺寸相对较小。

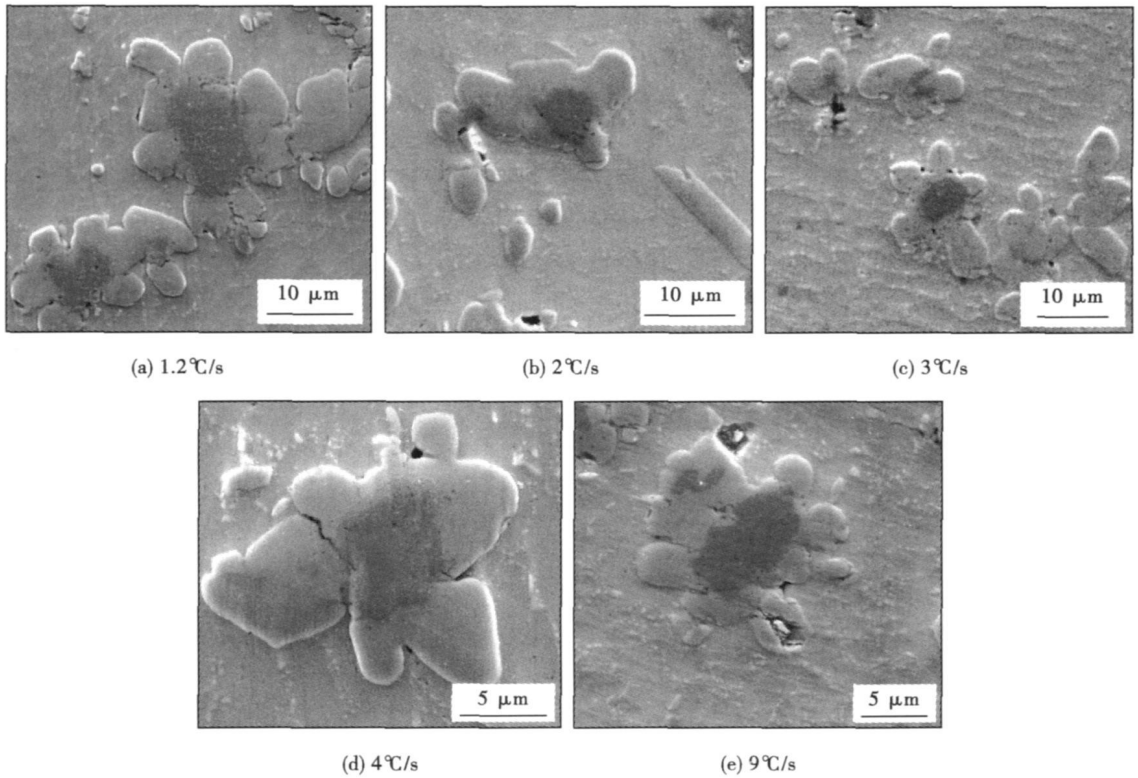

图 4　不同升温速率下增强颗粒显微组织形貌

Fig. 4　Microstructure of reinforced particles in different heating rate processes

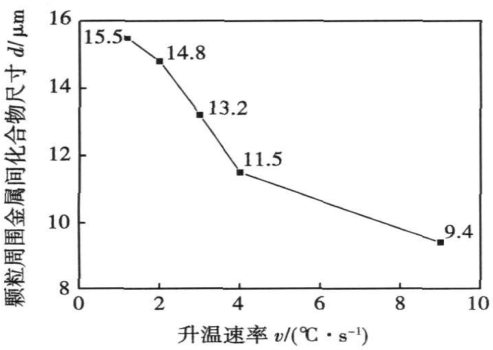

图 5　升温速率对增强颗粒周围的化合物尺寸的影响

Fig. 5　Effect of heating rate on IMCs sizes around reinforced particle

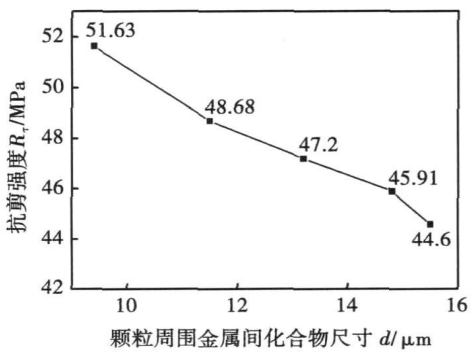

图 6　增强相颗粒周围金属间化合物尺寸对抗剪强度的影响

Fig. 6　Effect of IMCs sizes around reinforced particle on shear strength of soldered joints

2.2　升温速率对复合钎料接头力学性能的影响

图 6 显示的是在不同升温速率下得到的复合钎料中增强颗粒周围的金属间化合物尺寸与接头抗剪强度之间的关系, 通过对比可以发现升温速率越大, 得到的颗粒周围的化合物尺寸越小, 其接头的抗剪强度也就越大。虽然焊接后, 复合钎料中铜增强颗粒周围形成的金属间化合物尺寸相对较大, 但这种复合钎料从理论上也达到了固溶强化或弥散强化的要求, 从而提高了钎焊接头的强度。

通常情况下, 颗粒增强复合钎料的力学性能会随着铜增强颗粒周围形成的金属间化合物尺寸的增大而下降。随着复合钎料中铜颗粒周围的化合物尺寸的增大, 单个铜颗粒与基体的接触面积较大, 与基体的热膨胀差异也相应增加, 导致铜颗粒承受的载荷增大。另一方面, 在铜颗粒表面形成缺陷的可能性也增大。在同等应力水平条件下, 表面存在缺陷的铜颗粒更易发生开裂。从试验结果中可以看出, 随着铜颗粒周围化合物尺寸的减少, 其接头的抗剪强度会增加, 因而升温速率越大, 所形成的铜颗粒周围化合物尺寸越小, 其接头的力学可靠性也就越好。

含有较大增强相颗粒的复合钎料在进行力学性能测试时，断裂过程会由基体断裂控制转变为颗粒断裂控制，使得钎焊接头的强度降低。产生这种情况的原因有以下几点：(1) 颗粒周围出现较大尺寸的金属间化合物本身就容易存在更多的缺陷，一旦从颗粒发生断裂，复合钎料钎焊接头的整体承载能力会下降，引起复合材料的迅速失稳，从而造成材料的强度下降。(2) 复合钎料中增强颗粒周围金属间化合物尺寸较大，会更易发生应力集中。在断裂之前，增强颗粒周围金属间化合物尺寸较小的复合钎料钎焊接头内部颗粒及金属间化合物间的基体材料会发生强烈的塑性变形，宏观表现为基体间的延性断裂，而基体在断裂之前几乎没有明显的塑性变形。由此可见，复合钎料中铜颗粒周围金属间化合物的尺寸对复合钎料接头的力学性能及断裂机制均会有较大的影响。

3 结 论

(1) 不同升温速率下，复合钎料中铜增强颗粒周围存在着厚度不均的金属间化合物层。不同的升温速率对这层金属间化合物的形貌基本没有影响，只会对其厚度尺寸有影响。

(2) 在恒定的冷却速率条件下，升温速率越大，复合钎料内部铜颗粒周围金属间化合物尺寸越小，其抗剪强度越高。

(3) 铜颗粒周围金属间化合物尺寸较大的复合钎料接头的断裂过程由基体断裂探制转变为颗粒断裂控制，从而使钎焊接头的抗剪强度降低。

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Abstract: On the basis of designing a longitudinal magnetic field generator with powerful engineering practicability and miniaturized structure, the longitudinal magnetic field is applied to streaming transfer MAG with the shielded gas of 98% Ar and 2% O_2. Magnetically induced rotating MAG welding process is put forward. At the meantime, the influence on arc shape and moving behavior, wire melting character, drop transfer mechanics, and weld formation of exciting current is studied. The shortage of deflecting weld for this new welding process is pointed out. The result shows that under the effect of the outer longitudinal magnetic field, all of arc and molten cone and liquid metal jet deflect from the wire axis and rotate with high speed. The larger of the exciting current, the faster of arc rotating angular velocity, the shorter of arc length, the faster of drop transfer frequency, the lower of welding current and the larger of wire melting coefficient.

Key words: longitudinal magnetic field; arc shape; drop transfer; weld formation

Microstructure and properties of electron beam welded joints of AZ31B magnesium alloy TAN Bing, WANG Youqi, CHEN Donggao, WANG Ying (Ningbo Branch of China Academy of Ordance Science, Ningbo 315103, Zhejiang, China). p75—78

Abstract: 10 mm thick AZ31B magnesium alloy was welded by the electron beam welding. The appearance, the macrophotograph, the microstructure, the alloy elements profile, the patterns and etc of welded joint were analyzed by means of OM, SEM, X-ray diffraction and etc. The results show that the appearance in the face of weld is perfect and the appearance in the back of weld has many tiny cupped hole. The ratio of the depth of fusion to the weld width is 8∶1. The proportion of Al and Mn element has increased, and Mg, Zn has decreased in the welding zone. There are Mg, Al and a little $Mg_{17}Al_{12}$ in the welding zone where there are columnar grains of 8-18 μm. Hardness of the welding joint is almost uniformity. The strenghth of welding joint is 223 MPa.

Key words: electron beam welding; AZ31B magnesium alloy; mechanical property; microstructure

Effect of heating rate on microstructure and mechanical properties of composite solder joints TAI Feng, GUO Fu, SHEN Hao, Han Mengting (College of Materials Science and Engineering, Beijing University of Technology, Beijing 100124, China). p79—82

Abstract: The different soldering processes condition has been found to play a significant role in determining the intermetallic compound (IMC) morphology and dimension in some metallic particulate (such as Ni, Ag, and Cu metallic particles) reinforced composite solders, and the morphology and dimension of IMCs around the reinforced particulate have an influence on mechanical propertirs of composite solder joints. The current study was to research the morphology of the IMC formed around the metallic Cu reinforced particulates incorporated in the Sn-3.5Ag solder by mechanically, and the mechanical property of composite solder joints. Experimental results indicated that the different heating rate have no influence on the morphology of the IMCs formed around Cu reinforced particulate, but just have effect on the thickness of the IMCs and mechanical property of composite solder joints. The relationship between dimension of IMCs and mechanical property in different processing condition was established.

Key words: heating rate; composite solder; intermetallic compound; mechanical property

In-situ synthesis of chromium carbide coating by VEB LU Binfeng, LU Fenggui, TANG Xinhua, YAO Shun (Shanghai Key Laboratory of Materials Laser Processing and Modification, Shanghai Jiaotong University, Shanghai 200240, China). p83—86

Abstract: A novel electron beam irradiation method and a novel powder mixture method were employed to modify the surface of a carbon steel substrate. By optimizing the electron beam parameters, chromium carbide is in-situ synthesized in the surface composite layer. The surface composite layer was analyzed with optical microscope, SEM, EDAX and XRD analysis. There are two main phases in the surface composite layer, one is chromium carbide [M_7C_3(M=Fe, Cr) and Cr_7C_3], the other is austenite. The primary chromium carbide shows a typical hexagonal shape, while the eutectic chromium carbide finely diffuses in the austenite structure. The microhardness of the composite layers was 2.7 times higher than that of the steel substrate, which provides a notable improvement on the wear resistant property of the surface layer.

Key words: surface composite layer; vacuum electron beam irradiation; in-situ synthesis; chromium carbide

Analysis of temperature measurement based on the model of arc radiation in welding thermal process FAN Fanglei, LI Liangyu, ZHOU Xin, JIANG Haizhen (Electrical and Technical College, Tianjin Polytechnic University, Tianjin 300160, China). p87—90

Abstract: Base on Saha equation, the arc plasma particles' density is obtained, and then according to the theory of Kramers-Unsöld, the radiation intensity of arc is obtained. In order to get the model of arc radiation, the location of temperature measurement has been built. The ratio of signal to noise is used to analyze the effect of arc on radiation thermometry which the three factors of the angle of temperature detector, wavelength and the arc effective temperature are considered. Theoretically, the method of temperature measurement is feasible when the arc current is decreased to a smaller value in welding process. Experiment has been done; temperature data of three times which are peak value of arc current, least value of arc current and time of cutting arc current instantaneous have been collected. The experiment results show that the method of temperature measurement is feasible.

Key words: arc radiation; arc model; ratio of signal to noise; thermometry

Analysis of microstructure characteristic of 9% Cr-1% Mo heat resistant steel weld metal WANG Honghong[1], ZHANG Hanqian[2], SUN Xian[3] (1. Shanghai Jiaotong Univrersity, Shanghai 200240, China; 2. Baosteel Research Institute, Shanghai 201900, China; 3. Taiyuan University of Technology, Taiyuan 030024, China). p91—95

Abstract: The concept of "weld bead heat affected zone" (WBHAZ) was proposed. The microstructure characteristic of multi-