应力对Ag颗粒增强SnCu基复合钎料蠕变性能的影响 *

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摘 要 使用搭接面积为 1 mm^2 的单搭接钎焊接头, 研究了恒定温度下应力对 Ag 颗粒增强 SnCu 基复合钎料钎焊接头蠕变寿命的影响, 结果表明: Ag 颗粒增强 SnCu 基复合钎料的蠕变抗力优于 99.3Sn0.7Cu 基体钎料; 随着应力的增大, 复合钎料及其基体钎料钎焊接头的蠕变寿命均呈下降趋势, 且应力对复合钎料钎焊接头蠕变寿命的影响比基体钎料明显.

关键词 材料科学基础学科, 蠕变寿命, 复合钎料, 应力

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The influence of stress on creep behavior of Ag particle enhancement SnCu based composite solder

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ABSTRACT Single shear lap creep specimens were developed using Ag particle-enhancement SnCu based composite solder to examine the influence of stress on creep behavior of the composite solder in this paper. Results show that the creep resistance of solder joints of particle enhancement 99.3Sn0.7Cu based composite solder is superior to that of 99.3Sn0.7Cu solder joints. At the same time, the creep rupture lifetime of the solder joints of the composite solders was decreased with the increasing of stresses and felt down faster than those of 99.3Sn0.7Cu solder joints.

KEY WORDS foundational discipline in materials science, creep rupture lifetime, composite solder, stress

铅具有毒性, 材料 (包括钎料) 无铅化已成为必然的趋势 [1−5]. SnCu 共晶或近共晶钎料的成本低, 是 SnPb 钎料的最佳替代材料之一 [5−9]. SnCu 共晶钎料的抗拉强度和剪切强度比 SnAg 和 SnPb 共晶钎料的低 [10−13]. 与其他无铅钎料相比, SnCu 钎料的蠕变性能较差. Ag(5%, 体积分数) 颗粒增强 SnCu 基复合钎料钎焊接头的力学性能明显改善 [14], 蠕变寿命比基体钎料提高 13 倍 (在 13.13 MPa 和 50 ℃)[15]. 温度和应力是影响钎焊接头蠕变性能的主要因素, 本文研究在恒定温度下应力对 Ag 颗粒增强 SnCu 基复合钎料钎焊接头蠕变寿命的影响.

1 实验方法

复合钎料的基体是 SnCu 共晶钎料, 颗粒直径为 43 μm; 增强直径为 1 μm 的 Ag 颗粒, 体积分数为 5%[16]. 复合钎料与免清洗中性助焊剂的质量比为 7 : 1. 按上述比例将增强体、基体及助焊剂均匀混合, 制成 Ag 颗粒增强 SnCu 基复合钎料膏.

为了模拟实际印刷电路板钎焊接头的尺寸与冷

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却条件，采用微型单搭接钎焊接头，搭接面积为 1 mm^2，钎缝厚度为 0.15 mm. 基材为 0.1 mm 厚的紫铜箔. 蠕变参数的测试温度为 283–398 K; 应力范围约为 4–20 MPa.

在恒载拉剪条件下进行蠕变试验，实验温度为 50 ℃，75 ℃，100 ℃和 125 ℃. 在一定温度下，拉剪应力分别选取 11.27 MPa、13.23 MPa、16.17 MPa 和 18.13 MPa. Ag 颗粒增强 SnCu 基复合钎料和 99.3Sn0.7Cu 的钎焊接头在相同的条件下获得. 取 12 个钎料试样的平均值为其在该试验条件下的蠕变寿命.

2 结果与讨论

温度和应力是影响钎焊接头蠕变寿命的关键因素. 一般, 应力增大, 钎焊接头蠕变快, 蠕变寿命变短; 同样, 温度升高, 钎焊接头的力学性能快速下降, 从而导致钎焊接头蠕变寿命降低. 图 1 给出了 Ag 增强复合钎料和基体钎料钎焊接头蠕变寿命与应力的关系. 可以看出: 与基体钎料 99.3Sn0.3Cu 相比, Ag 增强复合钎料钎焊接头蠕变寿命均比较长. 在相同温度条件下, 钎焊接头蠕变寿命均随应力的增大而降低, 且应力对复合钎料钎焊接头蠕变寿命的影响显著, 即随应力增大, 复合钎料钎焊接头蠕变寿命下降快; 对比图 1 各图可以看出: 在相同应力条件下, 钎焊接头蠕变寿命均随温度提高明显下降, 且温度对复合钎料钎焊接头蠕变寿命的影响较基体钎料明显. 这主要与 Ag 增强颗粒在复合钎料作用密切相关.

图 2 表明: Ag 颗粒部分分布在晶界上, 部分分布在晶内. 弥散分布的 Ag 颗粒在晶内能有效地阻碍晶内位错滑移. 弥散分布的 Ag 颗粒与基体中 Sn 可以发生冶金结合, 形成 Ag–Sn 金属间化合物 (图 2c), 使增强颗粒与基体紧密结合, 颗粒强化作用增强, 复合钎料钎焊接头的蠕变寿命提高. 因此, 在相同温度和应力下, 复合钎料钎焊接头蠕变寿命均较基体钎焊接头蠕变寿命长.

从图 1 还可以看出: 在相同的温度下, 与基体钎料相比, 复合钎料钎焊接头蠕变寿命随着应力的增加下降较快. 温度为 75 ℃, 当应力由 11.27 MPa 增到 18.13 MPa, 复合钎料钎焊接头蠕变寿命下降速率为 2391 min/MPa, 是基体钎料 99.3Sn0.7Cu 钎焊接头的 8.6 倍, 可见应力对复合钎料钎焊接头蠕变寿命的影响较基体钎料显著. 其原因是, 增强颗粒的加入使钎焊金属的晶粒细化. 根据 YB/T5148-93 测定 Ag 颗粒增强复合钎料晶粒尺寸为 16.4 μm, 而 99.3Sn0.7Cu 钎料合金的晶粒为 36.8 μm. 晶粒细化增大了晶界的面积, 增大了晶界能, 对蠕变不利 [17]. 因此在颗粒增

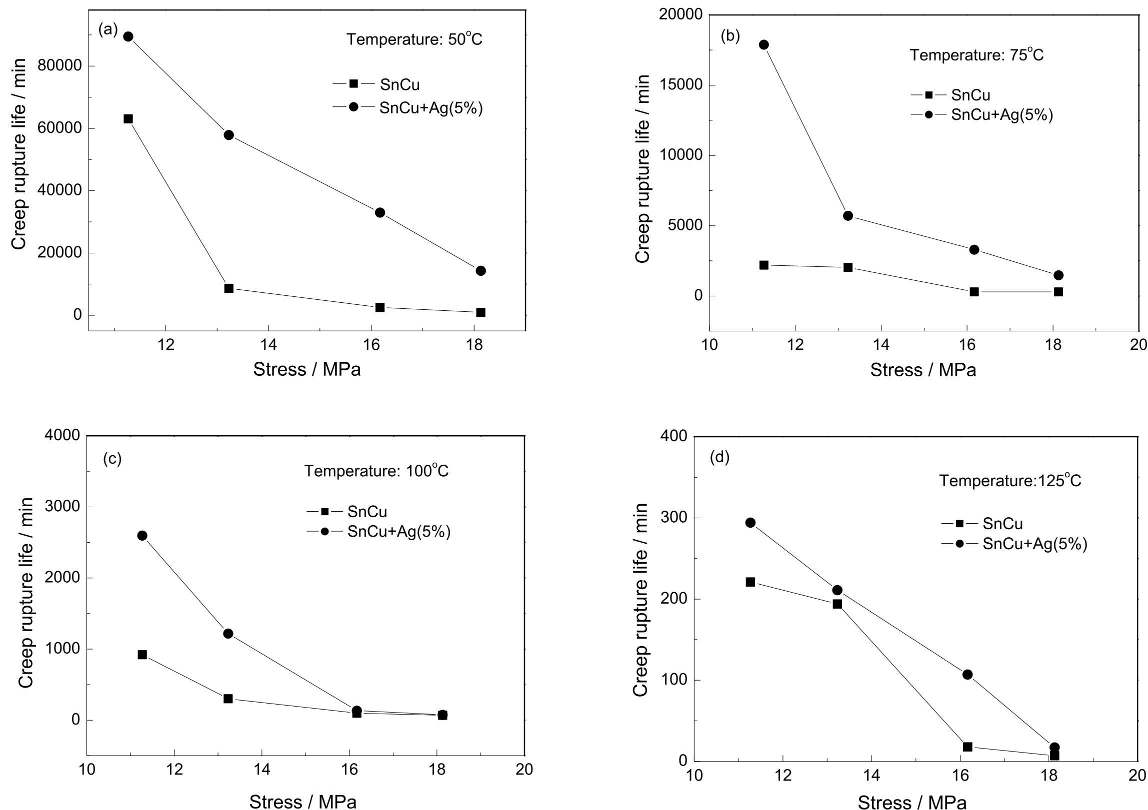

图 1 应力对 Ag 增强 SnCu 基复合钎料及 99.3Sn0.7Cu 钎焊接头蠕变寿命的影响

Fig.1 Effect of stress on creep rupture life of Ag particle-enhancement composite solder joints and 99.3Sn0.7Cu solder joints (a) 50 ℃, (b) 75 ℃, (c) 100 ℃, (d) 125 ℃

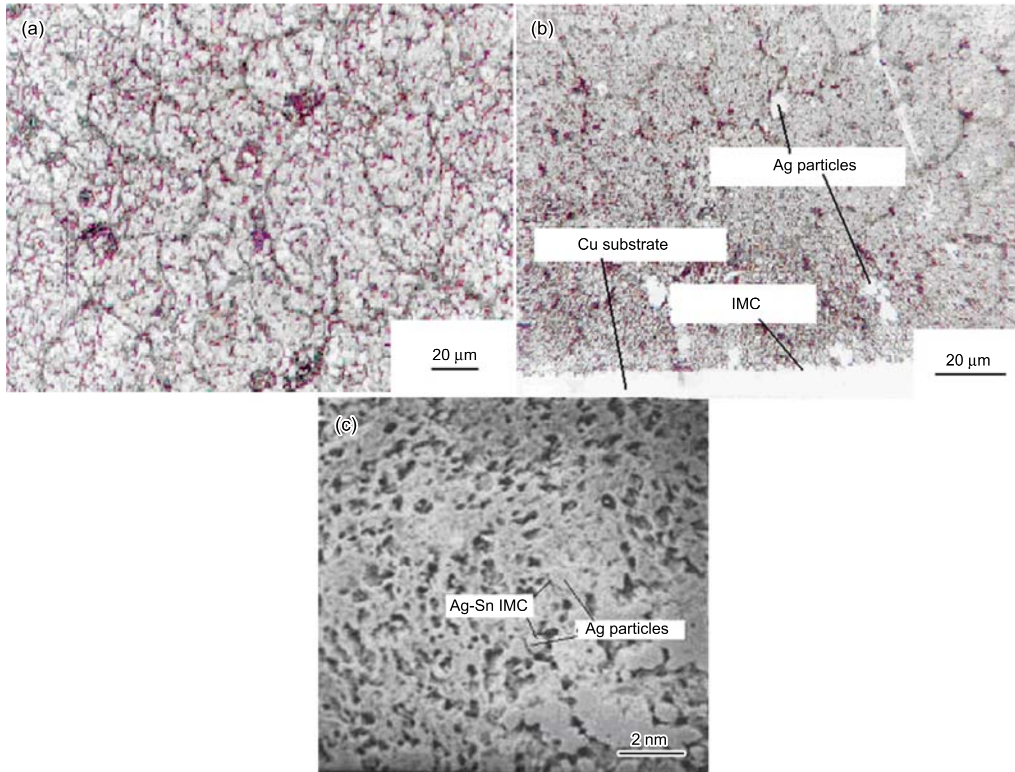

图 2　钎料合金的金相图

Fig.2 Microstructure of solder alloys. (a) 99.3Sn0.7Cu, (b) composite solder, (c) SEM micrograph of the composite solder

表 1　Ag 颗粒增强复合钎料及其基体钎料应力指数 [20]

Table 1 Stress exponents of the composite and matrix solder

Solder alloy	High temperature and low stress	Low temperature and high stress
99.3Sn0.7Cu	6.48	8.73
99.3SSn0.3Cu+Ag0.5%	8.2	10.84

强复合钎料中, Ag 颗粒具有颗粒强化和晶粒细化双重作用, 使复合钎料钎焊接头蠕变寿命提高, 且随应力变化明显. 另外, 温度相同时钎焊接头稳态蠕变速率与应力的关系 [18,19] 为 $\dot{\varepsilon} \propto l^n$, 其中 $\dot{\varepsilon}$ 为稳态蠕变率, τ 为应力, n 为应力指数. 即在相同温度下, 钎焊接头的稳态蠕变速率 $\dot{\varepsilon}$ 与应力 τ 呈幂指关系. 因此应力增大, 蠕变速率加快, 钎焊接头蠕变寿命缩短. 从表 1 可以看出: 在相同的实验条件下, 复合钎料应力指数均较基体钎料 SnCu 大, 因此钎焊接头的蠕变寿命随应力呈下降趋势, 且 Ag 颗粒增强复合钎料钎焊接头稳态蠕变速率随应力增大得快.

3　结　论

1. Ag 颗粒对基体钎料具有颗粒强化作用, 使 Ag 颗粒增强的 SnCu 基复合钎料的蠕变抗力优于基体钎料, 尤其在低温低应力下. 在 75 ℃和 11.27 MPa, 复合钎料的蠕变寿命较基体钎料提高了 7 倍以上.

2. 钎焊接头的蠕变寿命随应力的增大呈下降趋势, 且 Ag 颗粒增强复合钎料钎焊接头稳态蠕变速率随应力增大得快.

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