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基于改进光照模型由SFS方法重构SMT焊点三维形状技术

赵辉煌[1]， 周德俭[2,3]， 黄春跃[3]
(1. 西安电子科技大学 机电工程学院, 西安 710071; 2. 广西工学院 机械工程系, 广西 柳州 545006;
3. 桂林电子科技大学 机电工程学院, 广西 桂林 541004)

赵辉煌

摘 要: 在采用SFS方法重构SMT焊点三维形状技术中, 由于焊点表面镜面反射而在图像中产生的亮点会影响重构形状, 从而降低SMT焊点三维重构精度, 为此提出一种改进光照模型, 该模型不仅对物体表面漫反射分量进行了改进, 同时考虑了物体表面镜面反射分量对表面重构所产生的影响, 把漫反射分量和镜面反射分量线性叠加, 在采用图像处理技术对焊点图像进行适当处理后, 利用改进模型对SMT焊点进行三维重构. 结果表明, 采用改进光照模型与传统光照模型相比, 改进光照模型能较好地减少镜面反射对重构结果的影响.

关键词: 表面组装技术; 三维重构; 灰度重构形状方法; 光照模型; 图像处理
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0 序 言

由表面组装技术(surface mount technology, SMT)形成的电路模块产品, 其SMT焊点具有既要保障电气性能畅通、又要保障机械连接可靠的特征, 它的组装质量与可靠性是SMT产品的生命. 对SMT焊点2D图像进行3D重构分析研究, 并提取能反映SMT焊点质量信息的参数, 有利于指导改善SMT焊点质量及其焊接工艺, 提高SMT焊点质量自动检测能力, 同时推动智能鉴别技术的发展[1].

图像灰度重构形状(shaping from shade, SFS)方法, 即根据一个确定的反射模型建立物体表面形状与图像亮度之间的约束关系, 并根据对物体表面形状的先验知识建立物体表面形状参数的约束关系, 然后对这些约束关系联立求解可得到物体表面三维形状, 其特点是只需要单幅图像就可重构物体的三维形状. 近年来, 国内外的很多学者将该方法应用到工业检测与测量, 模式识别、逆向工程及自然景物模拟等领域[2,3]. 但采用SFS方法对SMT焊点重构仍存在重构精度较低的问题[4], 其中包括图像中由于焊点镜面反射而产生的亮点, 从而降低SMT焊点三维重构精度. 光照模型用来客观地描述光照反射现象, 是SFS重构技术的基础, 其精度直接影响着单幅图像表面三维重构的精度. 文中从改进光照模型入手, 以Oren-Nayar光照模型为基础, 提出一种改进光照模型. 对改进光照模型求解后, 采用图像处理技术, 对SMT焊点图像进行处理, 应用改进光照模型对SMT焊点进行三维重构. 结果表明, 文中提出的方法对减少镜面反射, 提高SMT焊点表面重构精度有较好的效果.

1 SMT焊点表面三维重构技术基本原理

基于改进光照模型的SMT焊点表面三维重构具体方法是通过CCD采集元器件SMT焊点2D图像, 得到彩色的焊点图像, 图像采集过程中, 由于元器件不平整或者焊点表面有很多的污点、光源上面有瑕疵等一系列问题, 都会使采集到的图像产生噪点. 必需采用合适的图像处理技术, 对SMT焊点图像进行处理. 然后采用一种比较理想的光照模型, 利用SFS三维重构方法, 对单幅SMT焊点图像进行重构, 得到SMT焊点的三维形状. 基本原理如图1所示(实线框部分). 对SMT焊点图像进行三维重构, 提取出能反映SMT焊点质量信息的参数, 从而为以后对SMT焊点进行进一步的比较和分析创造基本条件.

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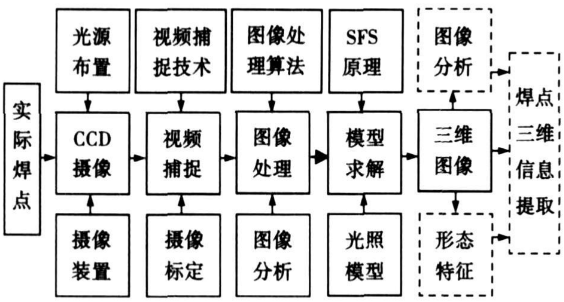


图 1 SMT 焊点三维重构基本原理

Fig. 1 Principle of 3D reconstruction for SMT solder joint

2 改进光照模型及 SMT 焊点图像三维重构算法流程

2.1 光照模型

光照模型即根据光学物理有关定律, 计算物体表面上任意一点投向观察者眼中的光亮度大小和色彩组成的数学公式, 用来描述光照射到物体表面发生的反射、折射和吸收等物理现象[5]. 光照模型根据其推导原理分为几何光照模型和物理光照模型. 其中 Lambert 模型是典型的几何光照模型. 典型的物理光照模型有 Oren-Nayar 模型和 HE 模型[6].

Lambert 模型是理想情况下的漫反射光照模型, 假设光在物体表面只存在漫反射. 但由于该模型没有考虑观察方向对反射结果的影响, 所以只能对反射现象做出近似描述, 在精度上还有较大误差. 针对 Lambert 模型存在的缺点, Oren 和 Nayar[7] 提出了一种新的描述粗糙表面反射现象的光照模型, 其模型公式为

$$L_d(\theta_r, \theta_i, \phi_r - \phi_i, \sigma) = \rho L_i \cos\theta_i \{A + B[0, \cos(\phi_r - \phi_i)]\sin\alpha\tan\beta\}/\pi \qquad (1)$$

式中: $A = 1 - 0.5\sigma^2/(\sigma^2 + 0.33)$; $B = 1 - 0.45\sigma^2/(\sigma^2 + 0.99)$; σ 为高斯分布的标准方差, 由物体表面粗糙度确定; ρ 为表面反射率; L_i 为入射光强度; $\alpha = \max[\theta_r, \theta_i]$; $\beta = \min[\theta_r, \theta_i]$; θ_i, θ_r, ϕ_r 和 ϕ_i 的关系如图 2 所示.

对于一些 SMT 焊点图像中特别亮的"高光区", 它是由于光源在物体表面上产生镜面反射的结果. 传统的光照镜面反射模型数学表达式复杂, 参数过多, 难以直接用于方程组的逆向计算. Torrance-Sparrow 假设物体表面平面斜率分布函数符合高斯分布, 提出一种简单的镜面反射光照模型[8], 其模型公式为

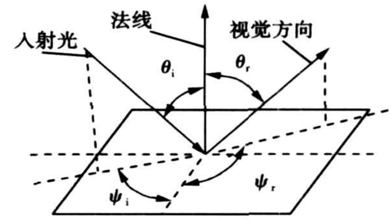


图 2 反射角度关系

Fig. 2 Angles of light reflection

$$L_s = G_s L_i \rho e^{-(\varphi/\sigma)^2}/\pi \qquad (2)$$

式中: φ 为表面微平面的法线方向 $\boldsymbol{N}$ 与表面平均法向 $\boldsymbol{H}$ 的夹角, 即 $\varphi = \arccos(\boldsymbol{N} \cdot \boldsymbol{H})$; 单位向量 $\boldsymbol{H}$ 可近似表达为 $\boldsymbol{H} = 0.5(\boldsymbol{L} + \boldsymbol{V})$; $\boldsymbol{V}$ 为视觉方向; $\boldsymbol{L}$ 为光源方向; G_s 为几何衰减因子, 取值范围为[0.8, 1]; L_s 为镜面反射光照强度. 镜面反射模型的推导原理决定了该模型不能很好地表示光的漫反射.

2.2 改进光照模型

由图 2 所示, 在 SMT 焊点图像拍摄过程中, 很多情况下, 光源方向与拍摄方向相同, 则 $\alpha = \beta = \theta_i = \theta$, 可对 Oren-Nayar 模型进行改进, 得到公式为

$$L_d(\theta, \sigma) = \rho L_i(A\cos\theta + B\sin^2\theta)/\pi \qquad (3)$$

即得到改进的漫反射模型为

$$L_d = \rho L_i(A\cos\theta + B\sin^2\theta)/\pi \qquad (4)$$

实际物体表面一般为非理想漫反射表面, 在光照反射现象中, 当光照射到物体表面时, 反射光中除了漫反射分量, 还包含镜面反射分量. 当物体表面粗糙度较大时, 镜面反射分量对图像表面三维重构的影响比较小, 在描述光照现象时可以忽略; 相反, 当物体表面粗糙度较小时, 镜面反射分量较大, 不能忽略. 上述推导的改进漫反射模型和镜面反射模型都是独立的光照模型, 都可以应用 SFS 方法得到相应的表面三维形状, 为了吸取各自的优点和弥补它们的不足, 同时提高物体表面三维重构的精度, 分别对式(2) 和式(4) 进行线性叠加, 提出完整的改进光照模型, 即

$$I = L_s + L_d = L_i K_s \rho G_s e^{-(\varphi/\sigma)^2}/\pi + L_i K_d \rho(A\cos\theta + B\sin^2\theta)/\pi \qquad (5)$$

式中: K_d 为漫反射系数; K_s 为镜面反射系数, 可以根据实际物体表面的粗糙度和表面反射率确定, 需要满足条件 $K_d + K_s = 1$, 可以根据实际情况调整漫反射系数和镜面反射系数.

2.3 基于改进光照模型求解

在利用改进光照模型对 SMT 焊点图像进行三维重构之前, 还必需对光照模型进行求解, 可采用线性化方法对改进光照模型求解, 以表面梯度(p, q)

为变量[9]. 为了提高线性化函数中高度 Z 值的精度, 使用有限差分法离散 p, q, 再采用 Jacobi 迭代法求解, 得到任意点(i,j)的高度迭代约束公式为

$$Z^{n}(i,j)=Z^{n-1}(i,j)+\frac{-f(Z^{n-1}(i,j))}{\dfrac{\mathrm{d}}{\mathrm{d}Z(i,j)}f(Z^{n-1}(i,j))} \tag{6}$$

式中: $Z^{n-1}(i,j)$, $Z^{n}(i,j)$ 分别为第 $n-1$ 次和第 n 次迭代法结果; f 为改进光照模型式(5) 所对应的函数表达式.

2.4　SMT 焊点图像三维重构算法流程

根据上述 SMT 焊点三维重构基本原理和方法, 以及利用 SFS 方法对改进光照模型的求解结果, 设计出 SMT 焊点表面三维重构流程如图 3 所示.

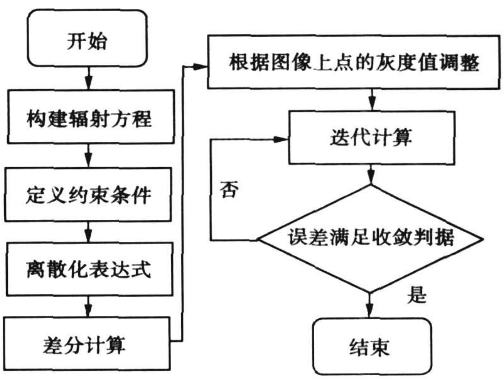


图 3　基于改进光照模型的 SMT 焊点图像三维重构算法流程

Fig. 3　Flow chart for SMT solder joint 3D reconstruction arithmetic based on improved illumination model

图 3 中离散化表达式为利用 SFS 方法对改进光照模型的求解结果表达式, 同时可根据图像上点的灰度值不同来调整改进光照模型中的参数. 由改进光照模型的推导原理可得出, 焊点图像中的点的灰度值越大, 则表示所对应的镜面反射越强, 那么式(6) 中镜面反射系数 K_s 增大、漫反射系数 K_d 减小, 有利于提高重构精度; 焊点图像中的点对应的灰度值越大, 焊点表面粗糙度越小, 减小高斯分布标准方差 σ 有利于提高重构精度; 同时根据经验, σ 的取值范围为[0.1, 0.6].

3　焊点图像处理过程及结果

在由 SFS 方法重构 SMT 焊点三维形状技术中, 图像处理算法的好坏, 对重构结果的精度有直接的影响. 由于彩色图像不能达到特定三维重构算法的要求, 所以必须先将彩色图像转化为灰度图像, 灰度化以后的图像并不能消除 SMT 焊点图像上的噪点. 一般来说, 图像的能量主要集中在低频部分, 噪声所在的频段主要在高频段, 同时所要提取的图像信息也主要集中在低频部分, 使用低通滤波算法去掉高频干扰又同时保持低频信息. 经过第一次低通滤波去噪, 图像已经平滑, 但是由于图像可能存在比较大的噪点, 这些噪点经过单次或者多次低通滤波叠加也无法去掉, 这时可以通过中值滤波完成[10]. 彩色焊点图像经过图 4 所示步骤来进行处理, 得到比较满意的焊点图像.

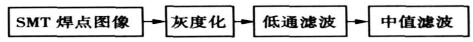


图 4　SMT 焊点图像处理过程

Fig. 4　Process of SMT solder joint image processing

文中选取的重构对象为 0805 片式电阻, 通过图像采集设备, 采集到相应的 SMT 焊点及电阻图像如图 5 所示, 其中左边焊点上的光亮部分为镜面反射结果. 分割出焊点, 如图 6 所示. 对 SMT 焊点采用文中描述的图像处理算法进行相应处理, 图像处理结果如图 7 所示.

图 5　原始图像

Fig. 5　Original image

图 6　分割后的 SMT 焊点图像

Fig. 6　Solder joint image

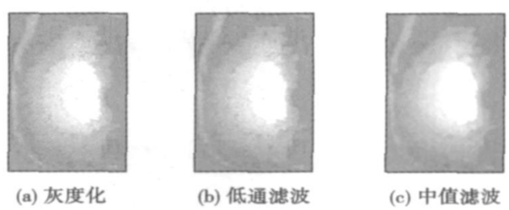
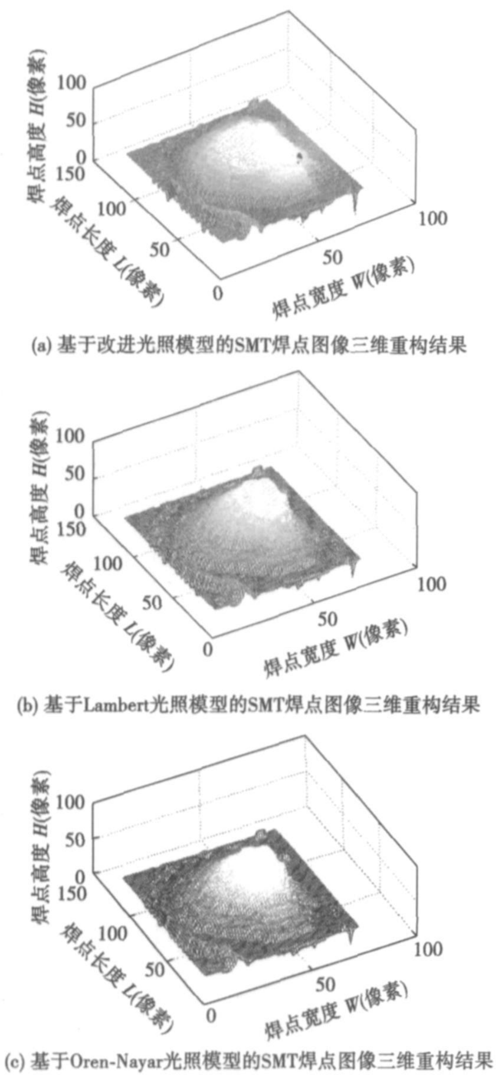


图 7　SMT 焊点图像处理

Fig. 7　Solder joint image processing

4 基于改进光照模型下的 SMT 焊点三维重构结果及比较

如图 7c 所示的 SMT 焊点图像为例, 根据 SMT 焊点图像三维重构原理, 按照图 3 所示的基于改进光照模型的SMT 焊点图像三维重构方法流程, 编写相应的程序, 得到能反映 SMT 焊点质量信息的各点高度值. 采用不同的光照模型重构出对应的 SMT 焊点的三维图像, 结果如图 8 所示.



(a) 基于改进光照模型的SMT焊点图像三维重构结果

(b) 基于Lambert光照模型的SMT焊点图像三维重构结果

(c) 基于Oren-Nayar光照模型的SMT焊点图像三维重构结果

图 8 SMT 焊点三维重构结果

Fig. 8 Reconstructed result of SMT solder joint

分别采用 Lambert 光照模型和 Oren-Nayar 光照模型对图 7c 进行三维重构, 其结果如图 8b, c 所示. 由于都未对镜面反射进行相应处理, 在镜面反射产生"高光区", 两重构结果图中焊点表面高度变化过大; 相比图 8a, 采用改进光照模型能较好地消除镜面反射对重构结果的影响, 表面高度变化更加平缓, 重构形状更为理想.

5 结 论

(1) 结合相关图像处理技术对SMT 焊点图像进行预处理, 有利于改善 SMT 焊点三维形状重构结果.

(2) 根据实际情况考虑漫反射分量和镜面反射分量有利于提高光照模型的精度.

(3) 采用改进光照模型能有效地减少由于焊点镜面反射而产生的亮点对 SMT 焊点表面三维重构的影响, 重构形状更为理想.

参考文献:

[1] 周德俭, 黄春跃, 吴兆华, 等. SMT 焊点虚拟成形和 SMT 产品虚拟组装技术研究[J]. 计算机集成制造系统, 2006, 12(8): 1267-1272.
Zhou Dejian, Huang Chunyue, Wu Zhaohua, *et al*. SMT solder joints quality assurance based on solder joints virtual evolving technology[J]. Computer Integrated Manufacturing Systems, 2006, 12(8): 1267-1272.

[2] Gao Yuefang, Luo Fei, Gao Jianzhong. A shape from shading algorithm and its application[C] // IEEE International Conference on Control and Automation, New York, 2007: 2133-2135.

[3] Li Zhang. Restoring warped document images using shape-from-shading and surface interpolation[C] // 18th International Conference on Pattern Recognition, New York, 2006: 20-24.

[4] Prados E, Faugeras O. Shape form shading: a well posed problem? [C] // International Conference on Computer Vision and Pattern Recognition, New York, 2005: 870-877.

[5] Torrance K E, Sparow E M. Theory for off-specularre flection from roughened surfaces[J]. Jounral of Optical Society of America, 1967, 57(9): 1105-1114.

[6] He X D, Torrance K E, Sillion F X, *et al*. A comprehensive physical model for light reflection[J]. Computer Graphics, 1991, 25(4): 175-186.

[7] Oren M, Nayar S K. Generalization of Lambert's reflectance model [C] // Proceedings of the 21st Annual Conference on Computer Graphics and Interactive Techniques, New York, 1994: 239-246.

[8] Cook R L, Torrance K E. A reflectance model for computer graphics [J]. Computer Graphics, 1981, 15(3): 307-316.

[9] Zhang Ruo, Tsai Ping-Sing, James Edwin Cryer, *et al*. Shape from shading: a survey[J]. IEEE Transactions on Pattern Analysis and Machine Intelligence, 1999, 21(8): 119-131.

[10] Kong Fanhui, Wang Yongxin. Reconstruction of solder joint surface based on shape from shading[C] // IEEE Third International Conference on Natural Computation, New York, 2007: 58-62.

作者简介: 赵辉煌, 男, 1982 年出生, 博士研究生. 主要研究方向为制造自动化、模式识别和图像处理. 发表论文 3 篇.
Email: zhaohuihuang278@163.com

Materials Science and Engineering, Shenyang University of Technology, Shenyang 110178, China). p 73– 76

Abstract: The nickel-base alloy was deposited on the low carbon steel by plasma arc surfacing with transverse magnetic field. The influence of transverse alternative pulsed magnetic field frequency on microstructure and properties of plasma arc surfacing layer was researched. The hardness, wear resistance and microstructure of surfacing layer at different pulsed magnetic field currents were systematically analyzed by optical electronic microscope, wear test and microscopic hardness test. The results indicated that the transverse alternative pulsed magnetic field can effectively improve the crystal shape in plasma arc surfacing layer and refine crystal grain. With the proper pulsed magnetic field frequency, the optimum effect of electromagnetic stirring can be obtained, the amount of hardening phase in overlay deposit is increased, the growth direction of hardening phase can be controlled and the hardness and wear resistance of the surfacing overlay are improved.

Key words: plasma arc; transverse magnetic field; microstructure; wear resistance

3D reconstruction technology of SMT solder joint by shape from shading based on improved illumination model

ZHAO Huihuang[1], ZHOU Dejian[2,3], HUANG Chunyue[3] (1. School of Mechanical and Electronical Engineering, Xidian University, Xi'an 710071, China; 2. Department of Mechanical Engineering, Guangxi University of Technology, Liuzhou 545006, Guangxi, China; 3. School of Mechanical and Electronical Engineering, Guilin University of Electronic Technology, Guilin 541004, Guangxi, China). p 77– 80

Abstract: Three-dimensional shape and its accuracy are dissatisfactory because of the highlight caused by specular reflection when the shape from shading is used to reconstruct the three-dimensional soldered joint. An improved illumination model is proposed, which can modify the diffuse reflectance component based on the features of image shooting, make a linear superposition for both specular reflection component and diffuse reflectance component. Then the improved illumination model is used to reconstruct the three-dimensional soldered joint after dealing with the soldered joint image by the proper image processing arithmetic. The experimental results show that the 3D shape by SFS based on the improved illumination model is more satisfactory in decreasing specular reflection influence than that of the traditional methods.

Key words: surface mount technology; three-dimensional reconstruction; shape from shading; illumination model; image processing

Reliability analysis of PBGA soldered joints based on Taguchi method

DAI Wei, XUE Songbai, ZHANG Liang, JI Feng (College of Materials Science and Technology, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China). p 81– 84

Abstract: In order to evaluate the reliability of PBGA soldered joints, an optimized method was proposed based on Taguchi design and numerical simulation, in which the Anand equation was used to describe the viscoplastic behavior of Sn3.0Ag0.5Cu solder, and the distribution of equivalent stress and strain in soldered joints under temperature cycle were studied respectively. Results indicate that the thermal fatigue life of soldered joints can be substantially improved by filling up the underfill between the PCB and substrate. The linear expansion coefficients of substrate, epoxy mold compound, underfill and PCB were considered as the controlling factors, and the linear expansion coefficient of the substrate and that of epoxy mold compound were deemed to the main influencing factors by Taguchi method. The optimized controlling factor combination can be decided as A3B3C3D3, and the verification test shows the maximum equivalent strain of the optimization scheme was decreased by 41.4%, and the ratio of signal to noise was increased by 4.61 dB.

Key words: plastic ball grid array; underfill; Taguchi method; linear expansion coefficient

Contact reactive brazing between Al alloy/Cu/stainless steel and analysis on grain boundary penetration behaviors

WU Mingfang[1,2], SI Naichao[1], PU Juan[2] (1. Jiangsu University, Zhenjiang 212013, Jiangsu, China; 2. Jiangsu University of Science and Technology, Zhenjiang 212003, Jiangsu, China). p 85– 88

Abstract: Grain boundary penetration behavior occurs easily in the Al/Cu contact reactive brazing. In this paper, the mechanisms of formation and evolution of grain boundary penetration were investigated when contact reactive brazing between 6063 Al Alloy and 1Cr18Ni9Ti stainless steel was conducted using Cu as interlayer. The results show that the grain boundary penetration phenomenon is prominent. Grain boundary penetration depth was up to 200 μm when the brazing temperature was 570 ℃ and holding time was 60 min. The diffusion of atom into grain boundary was not sufficient but necessary for forming of grain boundary penetration. The key factor to induce grain boundary penetration was non-equilibrium diffusion of atom between the grain boundary and base metal, which led to crystal lattice expanding, and promoted the vacancy transferring into grain boundary, and resulted in a thin groove. And then, microcracks were formed in the grain boundaries, the eutectic liquid was sucked into the groove by capillary force, and finally grain boundary penetration was created. The interface reactive layer consisted of Fe-Al intermetallics (IMCs) in the side of 1Cr18Ni9Ti, the adjacent zone was Cu-Al IMCs, welded seam zone was composed of Al-Cu eutectic structure and large blocked Al solid solution.

Key words: Al Alloy; stainless steel; contact reactive brazing; grain boundary penetration; structure

Reaction mechanism and microstructure of interface in soldered joint of zinc-based alloy

LIU Xiuzhong[1,2], YANG Min[1,2], LIU Xinghong[3] (1. Key Laboratory of Liquid Structure and Heredity of Materials (Ministry of Education), Shandong University, Jinan 250061, China; 2. School of Materials Science and Engineering, Shandong University, Jinan 250061, China; 3. Xiangshan Tongjia Foundry-die Plant, Xiangshan 315700, Zhejiang, China). p 89– 92

Abstract: The micro-region compositisions, fine microstructure and phases of interface region in joint soldered with new solder and flux self-developed were studied by means of XRD, EPMA, TEM and SEM. The results show that the interface region mainly consists of diffusion zone and dissolution zone. There was more Cd based solid solution (1.44% Zn) in diffusion zone, while more Zn based solid solution in dissolution zone. The interface region mainly consists of Cd, Sn, Zn, Al solid solution, and oxides such as SnO, SnO_2, CdO and metallic compounds such as MgZn, Mg_2Sn, Al_4Cu_9 and $Mg_2Cu_6Al_5$. No continuous intermetallic compounds layer which