Feature Extraction for Fillet Profile of Pb-free Solder and Its Application to Inspection†

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Abstract

An image processing technique for characteristic extraction of microsoldering fillet pattern is discussed from the viewpoint of the external feature inspection system. The visual inspection system for the shape of Pb-free solder fillet aims to decrease the influence of surface roughness. When the surface roughness affects the luminance distribution of a solder fillet profile, two methods are proposed; binarization and band summation. In experiments, the two kinds of Pb-free solder are adopted (Sn-Ag-Cu and Sn-Ag-Bi-In systems). Images of solder fillets are observed by CCD digital microscope by changing the incident light angle and image processing is carried out. It is found that binarization and band-summation are useful for the characteristic extraction. The two methods decrease the influence of surface roughness and make the characteristics clear.

KEY WORDS: (Characteristics extraction) (Lead-free solder) (Solder fillet) (Surface roughness) (Image processing)

1. Introduction

External feature inspection equipments for microsoldering have been used since the latter half of the 1980s, because of the mass production of microsoldering on print circuit boards (PCB) [1,2]. Various advanced testing systems have been developed [3-6]. But, various problems increase as the demand increases. Also, because of environmental protection, usage of Pb-free solder makes it more difficult to extract the characteristics of fillet profiles [7-11]. There exists several problems for developing a proper inspection system of solder fillet profiles. For example, the surface roughness of Pb-free solder fillets has a large influence on the luminance distribution from the solder fillets [7-11]. Disinformation is very often observed from the profile images. To avoid this disinformation, it is important to decrease the influence of surface roughness. The purpose of the present paper is to extract the characteristics of solder fillet profile by image processing techniques. The relationship between solder surface profiles and luminance distributions is discussed. Further, two methods to made it easier to recognize the fillet profile of Pb-free solder are investigated.

2. Materials and Observation Method

2.1 Materials

Two kinds of solder paste; Sn-3.5Ag-0.7Cu (mass %) and Sn-3.5Ag-2.5Bi-2.5In were used. The kinds of materials used in the present study are shown in **Table 1**. A PCB of 100 mm square with a thickness of 0.8 mm was used for a substrate, and four Quad Flat Packages (QFPs) were mounted on the PCB. The lead of QFP with 0.5 mm pitch and Au/Pd/Ni plated layer was used. The reflow cooling rate was about -6 °C/s. The SEM images of after reflow

Table 1 Kinds of Pb-free solder used in the present study.

Kinds of solder (mass %)	Melting points (K)	Peak temperatures in reflow process (K)
Sn-3.5Ag-0.7Cu	491	503
Sn-3.5Ag-2.5Bi-2.5In	483	493

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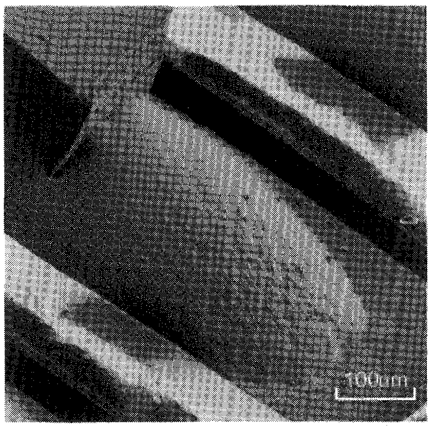
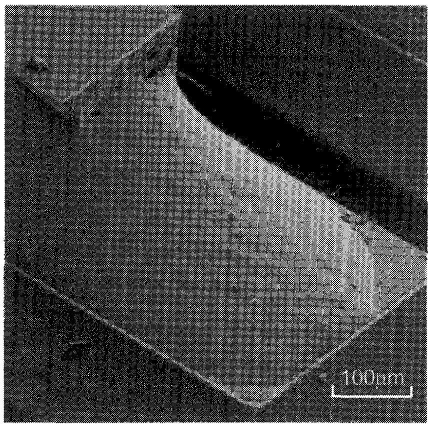


(a)



(b)

Fig. 1 SEM images of the Pb-free solder fillet. (a) Sn-Ag-Cu and (b) Sn-Ag-Bi-In systems. These are connected with Au/Pd/Ni plated lead.

soldering are shown in **Fig. 1**.

2.2 Observation method

Figure 2 shows the relationship between the digital microscope and the solder surface. The camera angle θ is the angle from vertical direction of the substrate. The observing direction is equal to that of incident light. Maximum reflection occurs at $\theta_i = \theta_r$. The deviation angle α is defined as the angle between the observing direction and the maximum reflection direction. The camera angle θ was set so that α could be small , i.e., the highlight area could

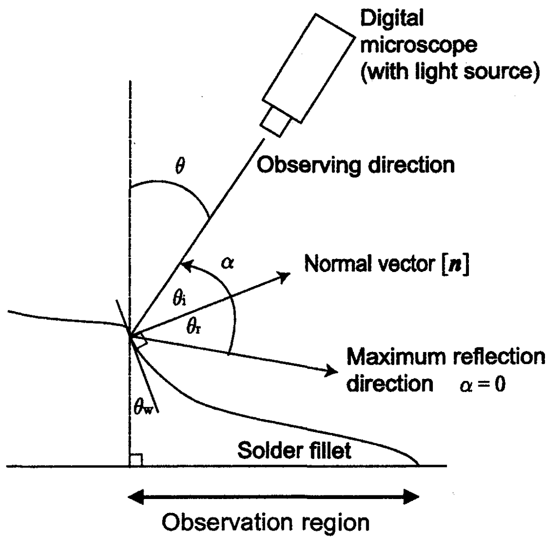


Fig. 2 Schematic illustration of relative position between incident light and reflected light on the fillet surface, where α is the deviation angle from maximum reflection direction to observation angle.

appear in the vicinity of the top-fillet.

3. Feature of Pb-free Solder Surface

The surface roughness has several problems for the characteristics extraction. In Pb-free solder, the surface roughness is easily produced, compared with Sn-Pb eutectic solder [7-9]. To obtain characteristics of solder fillet profiles, the fluctuation of shape has to be investigated.

The digital images taken by a digital microscope were binarized with a certain threshold value. The coordinates of center of gravity of highlight area in the vicinity of the top-fillet were measured. The results are shown in **Table 2**.

4. Procedure of Image Processing

As stated elsewhere [7-9], the luminance distribution from Pb-free solder fillet has a fluctuation due to the surface roughness, which prevents the extraction of the fillet profile characteristics. In the present study, two methods

Table 2 Fluctuating highlight area in the vicinity of the top-fillet.

Kinds of solder (mass%)	Threshold	σ of the center position (μm)	Highlight area width (μm)
Sn3.5Ag0.7Cu	40%	13.6	17.5-62.5
Sn3.5Ag2.5Bi2.5In	50%	8.1	55.0-75.0

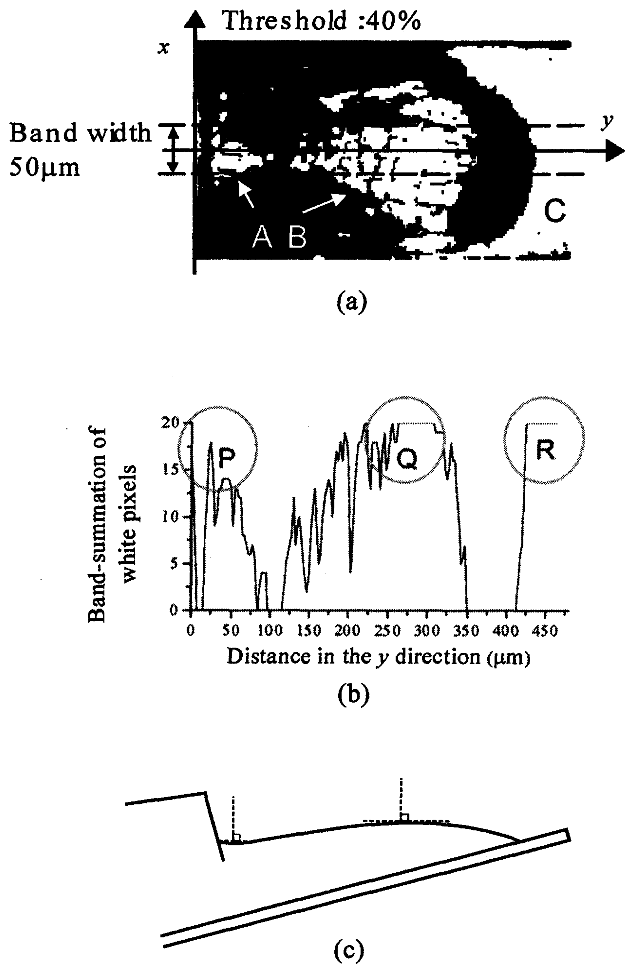


Fig. 3 Results of image processing for solder of Sn-3.5Ag-0.7Cu system ($\theta = 15°$). (a) Feature image of solder fillet after binarization. The threshold level was 40% for total levels. (b) Change in the band summation of white pixels arrayed in the x direction with band width of $x = \pm$ 10 pixels (50 μm). (c) The cross section profile in the y direction of the solder fillet.

were adopted; binarization and band-summation of gray levels in the x and y directions in order to decrease the influence of surface roughness and to clear the whole feature of the fillet.

After color images of solder fillets were taken by CCD digital microscope, the color images were transformed into gray levels of 256. The gray digital images were binarized with a certain threshold value. After that, the binary images were summed along the x (or y) axis in certain regions of the x (or y) coordinate. The distributions of the summed data were drawn in computer display.

5. Results and Discussion

Figure 3 (a) shows the image of the solder fillet

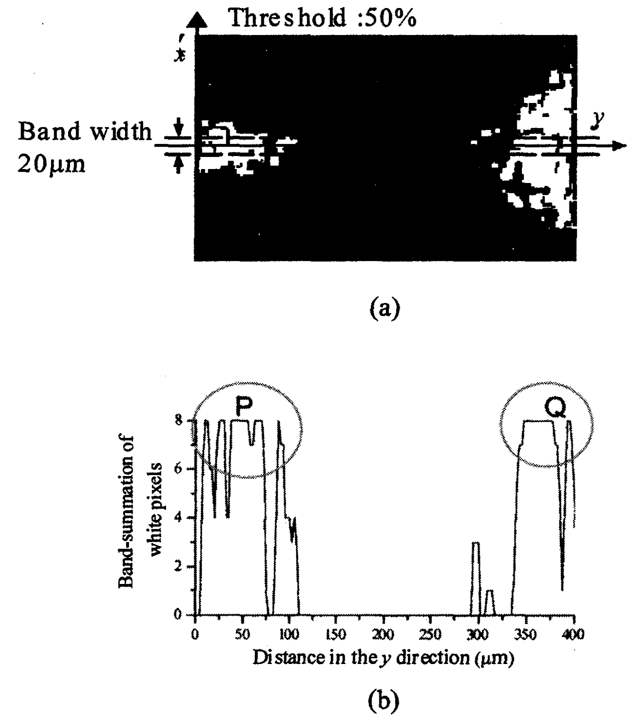


Fig. 4 Results of Sn-3.5Ag-2.5Bi-2.5In system ($\theta = 30°$). (a) Feature image of solder fillet after binarization. The threshold level was 50%. (b) Change in the band summation of white pixels with band width of $x = \pm$ 4 pixels (20 μm).

after binarization. The white area is made of the pixels the level of which are higher than the threshold of 102 (40% of 256 total levels) . Highlight area appears in the vicinity of the top-fillet (area "A") and at the middle position "B" between the top-fillet and the toe-fillet. The image of a land (area "C") is observed in the right hand side, because the wettability of Sn-Ag-Cu system solder to the land is not so good. **Fig. 3** (b) is the distribution of the band-summation along the y direction. In that stage, the band width in the x direction was $x = \pm$ 10 pixels, where the number of white pixels was counted. The characteristics of highlight area become more clear, because the band-summation avoids the fluctuation of the luminance distribution in the y direction. From **Fig. 3** (b), the actual fillet profile cross section can be drawn as shown in **Fig. 3** (c), although the cross section is a rough profile. In **Fig. 3** (b), the peak "P" and the peak "Q" with high value of summation of pixels suggests that the surface regions at the two peaks are normal to the incident light. Also, in the **Fig. 3** (b), the valley region between peaks "P" and "Q" and the region between the peaks "Q" and "R" mean that the surfaces of the regions are declined from the normal plane. The band-summation is helpful for feature extraction of the whole shape of a solder fillet.

Experiments of using Sn-3.5Ag-2.5Bi-2.5In were also carried out. **Fig. 4** (a) shows the image of the solder fillet after binarization. **Fig. 4** (b) shows the distributions of the band-summation. Because the solder with indium has a fine surface roughness, the band width is able to be reduced to ± 4 pixels (20 μm). As seen in **Fig.s 3** and **Fig. 4**, highlight and low intensity (black) regions can be divided by using band-summation method.

In the actual inspection, it is necessary to determine a range because the shape of Pb-free solder fillets often fluctuates. The band width of the band-summation should be set as the range of fluctuation.

6. Conclusion

Two methods adopted in the present study; binarization and band summation processes, are very useful for decreasing the influence of surface roughness. Pb-free solder inspection will be improved if these methods are adopted.

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