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Solder Joint Examination and Characterization by using the 3ω-Method

Ralf E. Bernhardsgrütter[1], Yannick Barb[1], Julia Schläpfer[1], Rainer Schädler[1], Christoph Hepp[1]
[1] Innovative Sensor Technology IST AG, Ebnat-Kappel, Switzerland
ralf.bernhardsgruetter@ist-ag.com

Summary:
Solder joint quality strongly depends on the size and number of voids and cracks in it. The check of the quality of these solder joints (e.g. X-ray or photomicrography) is often complex and time-consuming. This paper presents a new approach to examine the solder joint quality of soldered platinum elements by using the 3ω-method. The results show high reliability and are compared to results of photomicrographs and thermal contact measurements using constant temperature anemometry. The presented method enables an automated 100 % validation to increase the solder joint quality.

Keywords: solder joint examination, 3ω-method, platinum thin film technology, thermal contact, thermal sensor

Motivation and Background

Soldering of sensor elements on the area of interest is a crucial assembly and packaging technology in many fields, e.g., for temperature sensors, thermal flow sensors and others. For such applications the quality of the soldering joint is critical. Today, the screening of soldering joints is often done by optical techniques, e.g., X-ray or photomicrography [1, 2]. Such techniques are time-consuming and depend partially on the subjective validation of the operator.

An automated, purely electrical validation is preferred. The validation criteria of such a method are operator independent. The presented validation is based on the 3ω-method and is applicable for resistive elements having a defined and finite temperature coefficient of resistance (TCR).

Method

The claims of this paper are: (1) The 3ω-method can be used to validate the solder joint of a resistive element having a defined and finite TCR. It is shown for a thermal sensor element based on platinum thin film technology. (2) The method is purely electrical, and no operator validation is needed. (3) The method can be used to compare different joining techniques.

The 3ω-method is a well-known method to measure thermal properties of solids, liquids, and gases [3,4]. It is based on a metallic resistive structure with a defined TCR. The resistor is driven by an AC-current with the frequency ω which heats it up due to Joule heating. The resulting temperature oscillation has an AC-component with the frequency 2ω which acts as a thermal wave. The propagation of this wave depends on the thermal properties of the resistor's surrounding. Due the resistor's TCR, the resistor is also modulated with the frequency 2ω. Therefore, the voltage across the resistor contains an AC-component with the frequency 3ω which is the signal of interest.

Due to different thermal properties of the solder layer including voids or cracks, the quality of the soldering joint can be characterized by the 3ω-method.

Experiment and Results

The solder joint validation using the 3ω-method is investigated by using a thermal sensor (see figure 1). The sensor is based on a platinum thin film element which soldered on a stainless-steel surface. The resistor is designed as a 50 Ω at 0 °C resistance with a temperature-to-resistance coefficient of 3850 ppm/K.

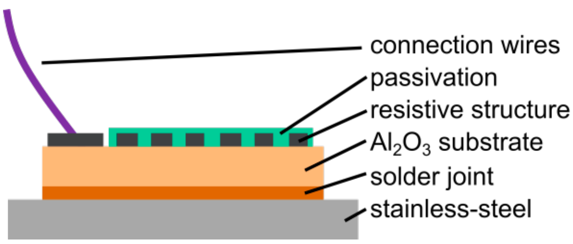

Fig. 1: Sensor cross section: Platinum thin film element on a Al_2O_3 substrate. The resistor has a resistance of 50 Ohm at 0 °C with a temperature-to-resistance coefficient of 3850 ppm/K.

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The setup for the 3ω-method is based on a digital lock-in amplifier. The drive frequency was set to 1 Hz and the current amplitude to 50 mA for the presented results. In addition to the electronical measurements, photomicrography and heat transfer measurements using constant temperature anemometry (CTA) act as reference validation techniques.

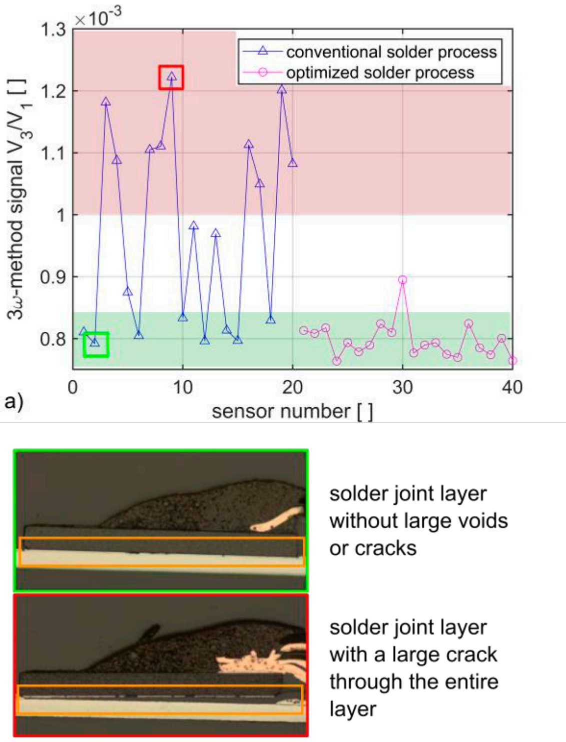

Fig. 2.: Comparison between the signal of the 3ω-method and optical inspection using photomicrography. a) The signal of the 3ω-method of 20 sensors. A signal of around $0.8x10^{-3}$ (green background) indicates solder joints without large voids and cracks. Signals larger than $1.0x10^{-3}$ (red background) indicates solder joints with large voids and cracks. b) Examples of solder joint with no large voids and cracks (green frame) and with large voids and cracks (red frame).

In a first step, the signals of 40 solder joints are investigated by the 3ω-method and by photomicrography. Figure 2 shows its result. One could show that the signal of the 3ω-method can be correlated with findings in the photomicrograph of the corresponding solder joints. The lower the signal of the 3ω-method, the less voids and cracks are observed in the photomicrograph. Theoretical considerations confirm this finding. The better solder joint is, the higher the thermal contact to the area of interest. Therefore, the heat wave of the 3ω-method can better propagate through the solder joint meaning that the heat is less confined, and the corresponding signal is lower. The signals around $0.8x10^{-3}$ correspond to be the lowest signal for this sensor structure and indicates a proper solder joint.

In a second step, the solder joints of 70 sensors are tested by investigating the thermal contact using the 3ω-method and CTA as a reference. Both methods are independent of the operator. Therefore, a purely objective comparison is possible. The CTA is done by using a water flow below the stainless-steel layer with a velocity of 0.26 m/s. Furthermore, the temperature difference between the element and the ambient temperature is set to 8 K. The 3ω-method signal as a function of the signal of CTA is shown in figure 3. The signal of the 3ω-method correlates with the CTA power. This correlation can be approximated by a linear behavior.

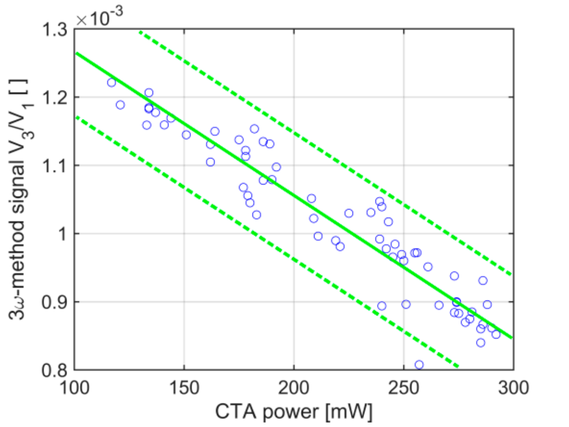

Fig. 3: Comparison between the signal of the 3ω-method and the heat transfer measurement. A linear correlation between the signal of these two methods can be seen.

This experiment verifies that the 3ω-method is an excellent method to characterize the quality of solder joint. Especially for higher volume serial products this method is interesting. Such an electronical test enables an automated 100 % validation. Furthermore, no complex measurement setup or time-consuming sample preparation are needed. In fact, this method can also support the optimization of new solder process because of its simplicity (see figure 2).

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