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COMPARISON BETWEEN THERMAL PERFORMANCE OF SILVER CONDUCTIVE ADHESIVE AND Sn-Ag-Cu SOLDER JOINTS IN A MEDICAL ULTRASOUND ARRAY TRANSDUCER

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Abstract – The RoHS and WEEE European Directive, recently introduced, [1,2], represent focal points for the environmental regulation in the field of electronics industry. While removal of some material of concern has been relatively straightforward, the reduction or quite elimination of Lead (Pb) has caused significant disruption to the electronics manufacturing supply chain [3]. This materials and technological conversion will increase the risk for premature product failures and degraded performances. As known, the Sn-Pb solder joint has over 50 years of manufacturing, field experience and knowledge [4,5,6]; the Pb-free solution, instead, needs accurate studies voted both the characterization of performances and electronic properties of material. To this aim the paper presents preliminary results about new materials for soldering process and, in particular, a comparison between silver conductive adhesive and Sn-Ag-Cu (SAC). As an application, a medical ultrasound array transducer with new soldering materials, between a platelet of piezoelectric and fingers, brass micro-connections between the substrate of piezoelectric material and the printed circuit, is also presented in the paper. Factors, which influence the soldering process, like the thickness of soldering and the polymerization or reflow temperature, the duration of the process, are taken into consideration in order to realise samples for the experimental tests. In order to verify the samples behaviour under thermal stresses, measurements of electrical resistance, parameter chosen like failure pointer, were carried out.

Keywords: silver conductive adhesive; SAC solder joint; piezoelectric array transducer, thermal performance.

1. INTRODUCTION

The European Union banned the use of Pb in electronics and electrical equipment commercialised in the EU as of July 1, 2006. For the worldwide electronics industry this means that Pb-Sn eutectic solder can no longer be used to assembly components together into functional circuit boards in many fields of application. All products commercialised at such time must be assembled by using Pb-free solder. A new international standard Pb-free solder alloy has been chosen based on the Sn-Ag-Cu system and many of the basic manufacturing and reliability issues associated with Sn-Ag-Cu have to be solved [3]. However, many application-specific issues require research to solve, particularly for high reliability applications such as medical device, military, aerospace and automotive electronics. Four current areas of Pb-free solder research are:

- the interaction between circuit boards materials, components and Pb-free solders during high temperature circuit board assembly;
- manufacturing and reliability issues as Pb-free and Sn-Pb technologies are mixed during the transition to Pb-free assemblies;
- the role of grain growth and stress relaxation on Sn-whisker formation in Pb-free thin films, a possible source of failure and short circuiting in Pb-free electronic assemblies,
- the relationship between performance in accelerated thermal cycling tests and reliability for specific applications.

These four areas are of significant interest in microelectronics industry.

In this paper we present experimental study for the performance characterization of solder realized by new conductive adhesive technology, where the silver is the filler [7]. The results are compared with the Sn-Ag-Cu solder alloy, after thermal cycling tests.

In particular, the research focuses the attention on the planning and the implementation of a soldering process with Lead free alloy and conductive epoxy resin on a medical ultrasound array transducers and the relative characterization. Solderings between a substrate of piezoelectric material and the fingers connections are realised to this aim. Considering that the break of also a single electrical interconnection can compromise the functionality of all the array transducer, made up by 128 microelements, it will be necessary to guarantee extremely resistant and reliable joints, being able to sustain the unavoidable electrical, mechanics and environmental stress, that take place during the operating life.

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2. PROPOSED APPROACH

A) SAMPLES REALIZATION

The first phase of the experimentation concerns in the planning and implementation of a soldering process with conductive adhesive or SAC alloys between a substrate of piezoelectric material, gold film covered, and the fingers connections. In order to realize a medical ultrasound transducer, the conductive adhesive or SAC alloys soldering phase is followed by the gluing of the PZT platelet on the backing substrate and the cutting in 128 piezoelectric elements to build the array [8].

The realized samples are characterised by a piezoelectric material (PZT) platelet of 23 mm of width x 14 mm of length x 0,5 mm of height. The platelet is covered by a film of 1,25 µm of gold on which fingers (0,24 mm of width x 6,7 of length, of which only 2 mm soldered) were soldered with silver conductive adhesive or SAC alloy. Figure 1 shows a particular of the array transducer where two of 128 microelements (one on the right and one on the left of the platelet) are represented.

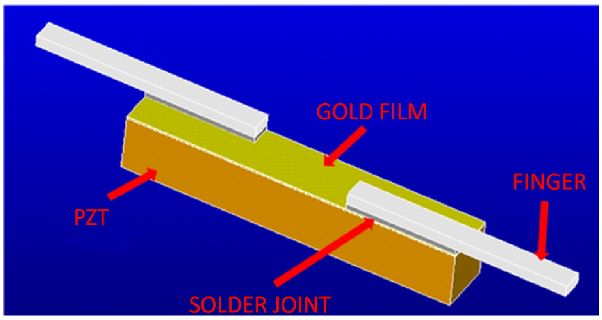

Figure 1: Two of 128 microelements that made up the array transducer

The soldering process with conductive adhesive, specially planned, is characterised by the following steps:

1. Drawing up of the conductive adhesive on the lateral edges of the piezoelectric platelet;
2. “Spin coating” phase to obtain a uniform and homogenous adhesive film;
3. Overlapping of the fingers comb on the PZT ceramics;
4. Putting into an oven for the phase of polymerization.

In the experimentation, two types of conductive adhesive (denoted as A and B) with different silver percentage are considered and two levels of polymerization temperature (80°C and 120°C) are selected [7].

To realize the samples with SAC solder joint, we considered different types of alloy denoted as: Sn95,5Ag3,8Cu0,7 (SAC387); Sn96,5Ag3Cu0,5 (SAC305); Sn99Ag0,3Cu0,7 (SAC307). These alloys are characterised by a fusion temperature of about 217°C, higher than the fusion temperature of the traditional SnPb solder alloy.

The soldering process with SAC, indirect soldering that is the parts are joined by added fused metal, can be summarised as:

1. Alloy deposition on ceramics sides and fingers comb;
2. Positioning fingers comb on ceramics; this phase has been realized through dedicated automatic techniques;
3. Reflow process with parameters optimization;
4. Cleaning, inspection and solder joint thickness measurement.

We chose to deposite the alloy both on the ceramics platelet and on the fingers comb to increase the cohesion in the reflow phase.

The reflow process is carried out by Uniflow® Pulsed Thermode Control (Unitek Miyachi Corporation) following the reflow profile shown in figure 2. We can see that the reflow profile is characterised by a preheat of 5 seconds at 120°C, 2 seconds rise phase, the effective reflow of 8 seconds at about 270°C and the cooling phase with a rate equal to 10°C/sec. As we can observe, the temperature reached in SAC soldering process is higher than in Sn-Pb soldering process (240°C) and in the conductive adhesive one (80°C-120°C); this allows a different opportunity of use according to the application field and the relative material to solder.

Moreover the thickness obteind in the alloy solder joint is about 37,73±21,90 µm, that is higher than the conductive adhesive thickness equal to 7±3 µm, with the consequent consideration about the preferable use of second technology for the dimensions reduction considering the important trend to miniaturization in the electronic field.

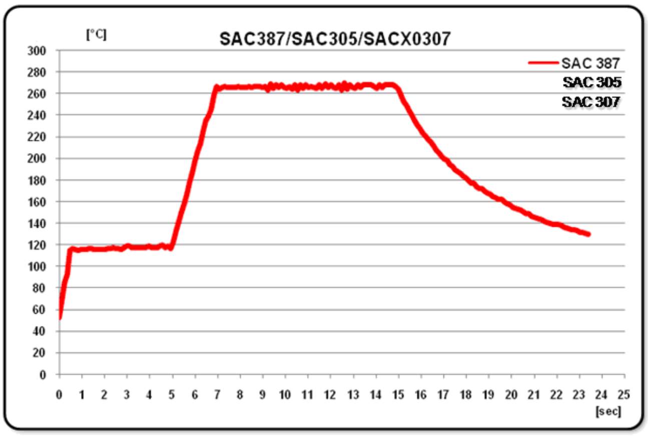

Figure 2: SAC reflow profile

B) TERMAL TESTS AND SAMPLES CHARACTERISATION

In order to plan the thermal tests, the standards IPC-9701A [9] and JEDEC 22-A 104-B [10] are taken into account: the first to choose the test profile and the second one to select the thermal severity. We considered as parameters the maximum temperature of stress Tmax, the minimum one Tmin, the Upper and Lower Dwell Time, the Cycle Time and the cyclic range Δt for the implementation of the thermal cycle.

In particular we assume Tmin = -25°C, Tmax = +100°C, Dwell Time = 10 minutes and thermal gradient inferior to 5°C/minutes (figure 2); so the full duration of one cycle is 70 minutes.

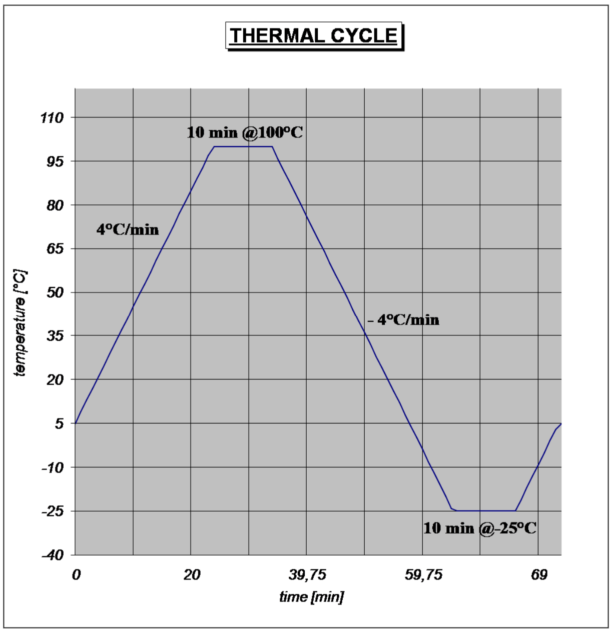

Figure 3: Thermal test profile

In this phase of the research we chose to stress the solderings samples only thermally, maintaining the relative humidity equal to 20% from 20°C to 100°C, in order not to introduce different failure mechanisms.

The electric resistance, measured between two fingers, was assumed as parameter of comparison in order to estimate the goodness of the soldering process.

The measurement system used for characterizing the samples before (preliminary measures) and after the thermal cycles is made up by a precision LCR meter “Agilent 4284A”, connected via IEEE 488 to PC; a program in LabView® allows to check the Device Under Test derive from the pressure of contact of two micro-needles, placed through an optical microscope (10x) and a webcam "Q-tec" (300K) that recorded the measures.

The regulators for the precision placing are fixed through magnets to the bench of measure and the base on which the sample stays has three degrees of freedom: axis X, Y and inclination angle with reference to axis X. Moreover the sample is fixed to the base through holes with the aid of a suction pump.

In order to eliminate the influence of micro-needles pressure on the finger in electrical resistance measure, we adopted the same level in the screw regulation of needle height, executing the contact with the screw at the end of run.

In Figure 4 is shown the LabView® control panel used for automatic measures acquisition; the up and down plots represents the variation of resistance and capacity vs frequency (1 kHz ÷ 100 kHz), respectively.

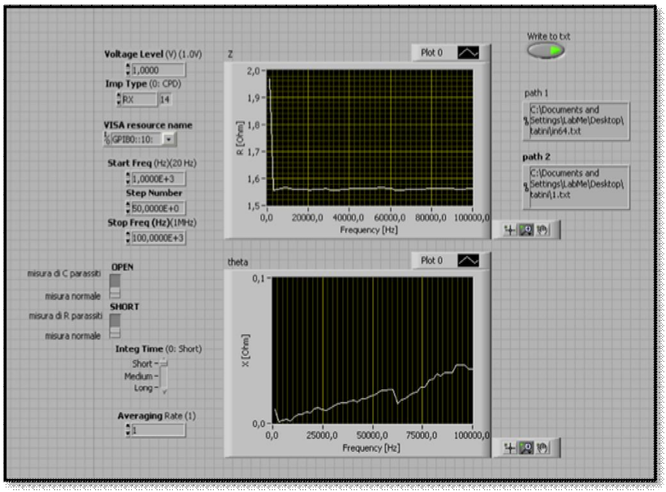
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Figure 4: Labview control panel

After the preliminary measures, we explain the measures after 200 thermal cycles. The values of electric resistance of conductive adhesive and SAC samples obtained before and after the thermal stresses for each samples at 1 kHz are shown in Table I, measurement uncertainty is evaluated equal to 3%.

Each carried out measure is the total resistance obtained from the series of five contributions:

$$R = R_{f1} + R_{s1} + R_{Au} + R_{s2} + R_{f2} \qquad (1)$$

- brass fingers resistance, R_{f1}, R_{f2};
- finger and electrode solder joint resistance, R_{s1}, R_{s2};
- golden layer resistance, that is the electrode, R_{Au};
- contact resistances between the different materials that made up the sample are considered negligible.

Detected that the gold layer and the fingers resistances kept constant, every variation is considered due to the solder joint material.

From the results so obtained it is interesting to observe that for all samples the electric resistance values decrease after the first 200 cycles. This occurrence can be explained considering the thermal stress as a further phase of curing (till the attainment of the stabilization) due to 100°C as the maximum temperature of the thermal cycle: of course this phenomenon is marked for those samples with 80°C as temperature of polymerization. In fact, after 200 cycles, the electrical conductivity turns out better with respect to the samples polymerized at 120°C.

Table 1. Values of electric resistance of conductive adhesive and alloys samples.

SAMPLES	R before test [Ω]	R after 200 cycles [Ω]
Glue Type A; 120°C	4,69	3,54
Glue Type A; 80°C	5,04	3,23
Glue Type B; 120°C	4,80	3,48
Glue Type B; 80°C	5,25	3,31
Sn95,5Ag3,8Cu0,7	1,71	1,67
Sn96,5Ag3Cu0,5	1,69	1,60
Sn99Ag0,3Cu0,7	2,18	1,81

From the data after thermal tests we can observe an optimum behaviour in terms of electrical conductivity both of alloys and conductive adhesive; every sample shows decreased values of resistance; however the values indicate that thermal stress didn't modify the structure of the solder joint. The Lead-free solderings show therefore a thermal behaviour comparable to the Sn-Pb alloy, whose samples present an electrical resistance equal to 2,68 ± 0,21 Ω and 2,42 ± 0,3 Ω after 200 thermal cycles.

4. CONCLUSIONS

Conversion to Pb-free alloy systems, typically SAC alloys, raised many question about the long term reliability of new materials as compared to the standard Sn-Pb technology. Many companies taken the Pb exemption till now, but will be driven to comply with the Pb restriction at some point in time, either by supply chain considerations or elimination of exemption. The broad component mix, board thermal properties, and resulting thermal gradients across complex assemblies pose many thermal challenges and push current capabilities to very edge of allowable limits. New soldering materials, maximum work temperature and type of soldering process and equipment are all sources of concern when trying to guarantee reliability of new Pb-free requirements [11, 12, 13].

The preliminary experimental test implemented and results presented in this paper and, in particular, the comparative evaluation of the performances of different silver conductive adhesive and SAC alloys emphasize the possibility of the real use of these new epoxy resins or alloys for a repeatable and reliable procedure of the soldering in the electrical connections in electronic field.

In the samples under stress, the improvement of the electrical conductivity was observed and the maintenance of a good thermal behaviour of the soldering is emerged without obtain to the degradation. We verified that the resistance of the gold covered ceramics and of the fingers didn't change after thermal tests, so the decrease of the values shown are due to the connection between alloy/conductive adhesive and finger pad.

In order to continue our research activity, further thermal cycles and mechanical stress as random vibration test are planned and will be carried out in order to induce possible failures and to study the chemico-physical degradation model.

In conclusion, the results till now obtained demonstrate that the use of the new material can be considered as a concrete alternative to the traditional Sn-Pb solder joint. It appears possible a good behaviour in terms of electrical conductivity, underlining in particular the conductive adhesive the great advantage of low temperatures of soldering, for instance 80°C, and the small solder thickness, about 10µm. The evaluation of a good thermal behaviour of solder joint with silver adhesive conductive and SAC alloys for an ultrasound transducer showed a general value of the implemented soldering process so we decided to implement the new specially planned soldering process on other materials or technology (for example SMT or BGA) and to evaluate the electrical performance of new different solder lead-free materials under thermo-mechanical stresses.

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