INTERMETALLICS BEHAVIOUR IN ULTRASONIC ACTIVATION OF THE Sn-Ag-Cu SOLDER DURING EUTECTIC SOLDERING PROCESS

S.V. SAVU[1], I.D. SAVU[2]

The paper presents results of research on the influence of the ultrasonic irradiation, which is component of the Eutectic-Ultrasonic soldering process, on the bond structure. It was used 45-50-55kHz frequencies and process cycle consisting of ultrasonic cleaning, hybrid heating and post-heating ultrasonic vibration of the formed intermetallics. Differential Scanning Calorimetry (DSC) analysis was used to evaluate the heat flow and that revealed the influence of the irradiation on the diffusion process (2°C decreased melting temperature). Scanning Electron Microscopy (SEM) and X-Ray Diffraction (XRD) analysis were used to reveal Cu_3Sn, Cu_6Sn_5, Ag_3Sn intermetallics. Stokes-Einstein relation was used to calculate the pre-factor and diffusion coefficient; simulation of the mathematical model was developed. Increasing of the coefficient from $7.23x10^{-8}cm^2/s$ to $2.91x10^{-7}cm^2/s$ for 600K due to the ultrasonic irradiation. Arrhenius plot shows faster formation of the Cu_3Sn comparing to Cu_6Sn_5 due to an accelerated diffusion at the interface. Ultrasonic irradiation reduces the growing of the intermetallics and it brakes them in 2-4 pieces.

Keywords: intermetallics compounds; nucleation and growth; bonding; ultrasonic processing; microstructure

1. Introduction

Soldering is the technology used for the fabrication of the electrical contacts, being essential technology in the construction of electronic equipment. Oldest technology used in the development of the electrical circuits, soldering gained different versions in time: a) for macro and micro joints, b) using resistive/hot air/hot wave/IR/laser/microwave, or else, c) using different mechanisms of bonding as eutectic/non-eutectic, anodic, reflow and else, d) manual, mechanized, automatic or robot soldering. Eutectic bonding use the eutectic reaction to decrease to a minimum the soldering temperature and, since the Directive 2002/95/EC of the European Parliament regarding the elimination from the electrical materials of the

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dangerous substances as Lead and Cadmium, it is in full development due to large number of new introduced lead-free solders. During the eutectic bonding it can be revealed several basic phenomena [1,2,3,4]: wetting of the surface, formation of specific intermetallic compounds at the interface between the base metal and the solder, formation of specific intermetallic compounds inside the solder (both due to the diffusion processes), fusion bonding at the interface between the base metal and the solder, metallic reactions at the interface and Kirkendall voids formation due to the diffusion coefficients of the base metal and of the solder which are different. These are specific to the soldering using classic power sources as resistive or IR or hot-air or solder wave. The second mentioned phenomenon, the formation of intermetallic compounds (IMC), has significant importance for the bonding process stability and for the quality of the bond [2,5,6]. IMC are generated by the interaction between the solid and liquid phases, during bonding process, or later by solid-state diffusion [2,5,7]. They are high strength and hard materials, with low dislocation mobility, high creep resistance, high resistance to fatigue and low diffusion coefficient [8-14]. Harris [7] showed that the formation of IMCs Ag_3Sn Sn-Ag alloys and of Cu_6Sn_5 in Sn-Cu alloys, improve the hardness and the resistance to fatigue of the alloys and Cabarat [9] used a resonant beam technique on bulk material to obtain for Cu_6Sn_5 the Young's moduli of 102.38 GPa. The value of 102GPa was obtained by Ostrovskaya [10] even since 1985 from the change in resonant frequency of the beam due to the deposited layer. The effects of the intermetallic compounds turned out to be negative, meaning an increasing of the susceptibility to cracking, due to the high hardness of the IMC and that was shown by Lotfian who experimentally demonstrated that the Cu_6Sn_5 and Cu_3Sn intermetallics display a brittle-to-ductile transition at 90°C [11]. Wang [6] showed that the thickness of the IMCs has important effect on the cracking risks. Liu [15] analyzed the 3D morphology of IMC and concluded that the addition of Ce promotes grain refinement and it blocks the development of the IMC layer. He reported also that the grains' microstructure became thick and coarse with the increase of thermal aging time. Positive effects can be mentioned, because Chen and Zhang reported that the formation and the growth of IMC will increase the wettability and the shape of the bumps [16, 17]. Better behavior of the bonds is met when the number and dimensions of the IMCs is low [18]. The reported method to decrease the volumes of IMCs consists in the doping of the solder with specific elements which are able to block the formation of the IMCs or the growth of the IMCs. Tsao [19] reported refining of the Ag_3Sn phase and of the β-Sn by doping the solder with TiO_2 nanopowders. Same effect was reported by Rizvi [20] who added 1 wt%Bi into the Sn-2.8Ag-0.5Cu solder alloy and he obtained a refining of the Ag_3Sn and Cu_3Sn.

The paper proposes new method to decrease the dimension of the IMCs, consisting in the application of ultrasonic irradiation during and after the eutectic reaction. The ultrasonic irradiation will act as second power source, creating with the classic applied power source a hybrid system of heating and, subsequently, will act as mechanical ultrasonic waves which are used as tools to inhibit the formation of IMCs and to brake in multiple pieces the already formed IMCs. Working in conjunction, the two power sources create a resistive—ultrasonic hybrid heating system which is expected to give synergic effect to the heating process.

The actual application of the ultrasounds in soldering is related to three other processes and these are the promotion of de-oxidation process, the cleaning of oxides and the preheating to improve the wettability. Byron [21] and later Walker [22] and Schwartz [18] described in their works the effects of the ultrasounds on the surface oxide layers during the soldering process and all concluded that the soldering of copper and aluminum and titanium is possible flux-free by using ultrasonic irradiation of the surface which is able to brake and remove the oxide layers but without protection against the future oxidation processes. Facundo [23] evaluated the influence of the ultrasonic frequency and of the ultrasounds irradiation application modes on the cleaning efficiency. They reported that the using of ultrasounds in cleaning process was effective and this effectiveness increased at lower frequencies. Although no significant differences they observed between the different ultrasounds applications modes. In the same time Galleguillos-Silva [24,26] shown that the apparent wettability of a surface is linearly dependent on the peak vibration velocity and independent of the vibration frequency. Higher vibration speed lowers the contact angle and therefore causes greater surface wettability. The new approach reported in this paper consists of the using of an ultrasonic beam to irradiate the molten solder and to energetic activate the interface between the liquid phase of the solder and the solid phase of the base metal. The irradiation of the molten pool will conclude in better wetting of the base metal surface and the energetic activation of the interface will increase the mass transfer between the base metal and the solder by diffusion which is required for the eutectic reaction. The application of the ultrasonic vibration to the molten pool of the solder, during the eutectic bonding, creates a cavitation phenomenon inside of solder [25]. That consists of the formation of small cavities in spheroidal form, due to pressure differences which is produced by the ultrasonic field in the molten solder. The cavities are vibrating (changing their volumes) in phase with the ultrasonic mechanical waves. They are increasing tens of times and when reach a specific volume they are violently collapsing due to the compression cycle of ultrasonic wave [25]. Due to the bubble collapsing it is expected to record a decreasing of the chances of IMCs' to be formed due to dispersion by vibration. More, it is expected that the IMCs to be broken in pieces by mechanical vibration.

2. Energetic activation of the liquid/solid interface by ultrasound irradiation

The activation of the interface is complex process, because the power source is hybrid one and due to the simultaneously working of the power sources a synergic effect was observed: the effect in heating was more than the sum of the heat transfer from the sources to the target, if take separately. For optimal equilibration of the hybrid system, the frequency of ultrasounds is necessary to be optimized. The evaluation of the required frequency for the ultrasonic power source can be done by analyzing the energy between the molten solder and the solid base metal. Following the expertise of Hagan and Popov [27] who simulated the acoustic pressure wave propagation by solving the Helmholtz equation, we also propose the analysis based on the evaluation of the Helmholtz free energy for the interaction between the hybrid power source and the interface between the solder and the base metal. The internal energy of the solder which receives heat to reach the melting point is [13]:

$$dU = \delta Q_{res} + \delta Q_{US} + \delta L \tag{1}$$

where: dU is the internal energy, $\delta Q_{res} = T_1 \cdot dS_1$ is the heat transferred from the resistive power source which produces the entropy dS_1 due to the increasing of the temperature with T_1, $\delta Q_{US} = T_2 \cdot dS_2$ is the heat transferred from the ultrasonic power source which produces the entropy dS_2 due to the increasing of the temperature with T_2 and $\delta L = -p \cdot dV$ is the work to melt the solder (the melting temperature of the solder was determined to be 224.44^{o}C).

$$dU = T_1 \cdot dS_1 + T_2 \cdot dS_2 - p \cdot dV \tag{2}$$

and that helps to calculate the Helmholtz free energy of the system [28,29] in transformation which consists of the solder receiving energy from the hybrid source:

$$dF = -S_1 \cdot dT_1 - S_2 \cdot dT_2 - p \cdot dV \tag{3}$$

Considering a factor to relate the increasing of the temperature, factor which is practically obtained by adjusting the functional parameters of the power sources

$$k_T = \frac{dT_1}{dT_2} \tag{4}$$

results: $dF = -dT_2 \cdot (S_1 \cdot k_T + S_2) - p \cdot dV$ (5)

The term $(S_1 \cdot k_T + S_2)$ can be accepted as the entropy of fusion for the solder which is transforming from the solid phase into the liquid phase.

$$dF = -S_{fus} - p \cdot dV \tag{6}$$

Since no relevant changes in pressure and volume during the transformation from solid to liquid is recorded [28-30], the term that represents the status of the solder can be considered as constant for very short time $p \cdot dV = k_{stat}$. The fusion entropy becomes

$$S_{fus} = -dF - k_{stat} \tag{7}$$

When the solder is turning from solid to liquid, the atoms of Sn and Ag and Cu increase their vibration in frequency and in amplitude as well [28,31]. When increase the amplitude of vibration, the fusion entropy receives a component which is created by the displacement of the atom during vibration, S_{vib} and the rest is specific to the movement of the atom in the new status of liquid atom, S_{mov}. Both the fusion entropy and the movement entropy of the liquid atom are measures of the energy accumulated by the interface between the liquid and the solid phases, E_{int}, and of the energy consumed by the atoms to change their position. Important is the energy accumulated by the interface between the liquid and the solid phases, because that energy participates to the activation of the diffusion processes from the solid to liquid and vice versa. The diffusion is the main process used by the eutectic bonding to obtain in the solder the chemical composition of the eutectic, in order to have the minimum possible melting temperature. Jian and his collaborators [28] gave in previous reporting values for the fusion entropy and atom movement entropy for copper ($S_{vib} = 9.59\ Jmol^{-1}K^{-1}$ and $S_{mov} = 1.03\ Jmol^{-1}K^{-1}$). Using those values and considering a participation of 25% of the ultrasonic energy to the melting of the solder (so, $k_T = dT_1/dT_2 = 4$, and taking account that an efficient melting is obtained for a heating to 250^{o}C, then $dT_1 = 200^o C$ and $dT_2 = 50^o C$) is possible to experimentally obtain the required frequency of the ultrasonic power source, for specific resonator. The optimum frequency was evaluated to be in the range 44.5–55.150Hz. Starting from this, the sonotrode was designed in figure 1.

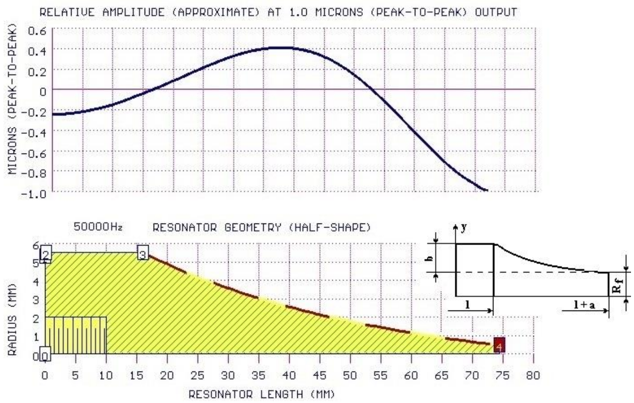


Fig. 1 Designed resonator for 50 kHz frequency and 1 mm radius active surface

3. Experimental program

The tasks of the experimental program were: a. revealing and evaluation of the influence of the energetic activation on the melting temperature of the solver enriched in copper by the diffusion process (that was expected to give appropriate information on the chemical composition changing of the solder material and the expected eutectic compounds.); revealing the IMCs able to form for the used pair solder-base metal; revealing and evaluation of the influence of the acoustic field on the formation and dimension of the IMCs. The main coordinates of the experimental were: thermosonic bonding equipment having range of ultra-acoustic frequency: 20-150 kHz; base metal: copper foils, 160µm thickness; solder: Sn-3.9%Ag-0.7%Cu; environment: nitrogen jet, 15 l/min flow rate. Ultrasonic energetic activation of the molten solder and of the solid base metal has been performed (Figure 2) during eutectic soldering, using 45kHz, 50kHz and 55kHz frequency of the ultrasonic field. In parallel, classic eutectic soldering (without energetic activation) was done and the results were compared. The heating cycle (Figure 3) for the energetic activation consisted of previous irradiation of the compound (base metals and solder layer) to improve the wettability, followed by the application of the resistive power source in parallel with the ultrasonic field. The pre-activation produced an increasing of the wetting comparing to classic eutectic bonding from 34.6mm^2 to 39.8mm^2 (13.065%). Figure 4 shows example of soldered joint.

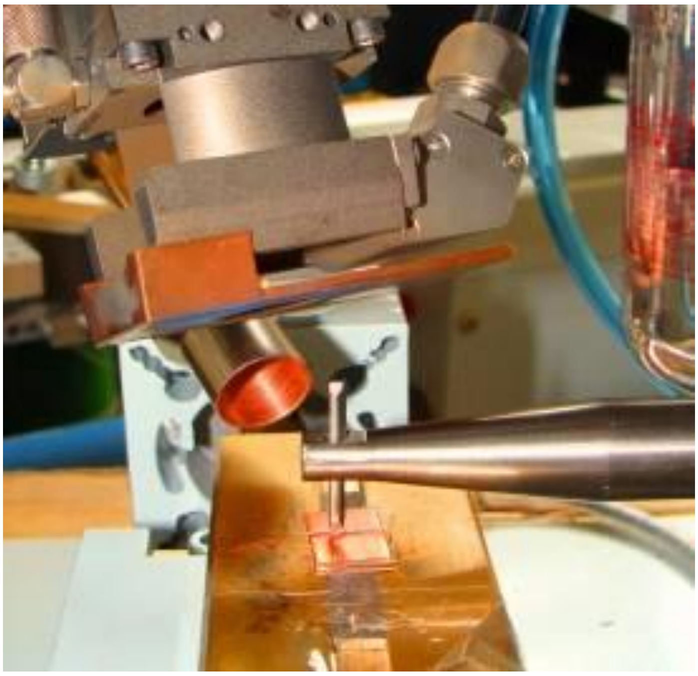


Fig. 2 Experimental setup

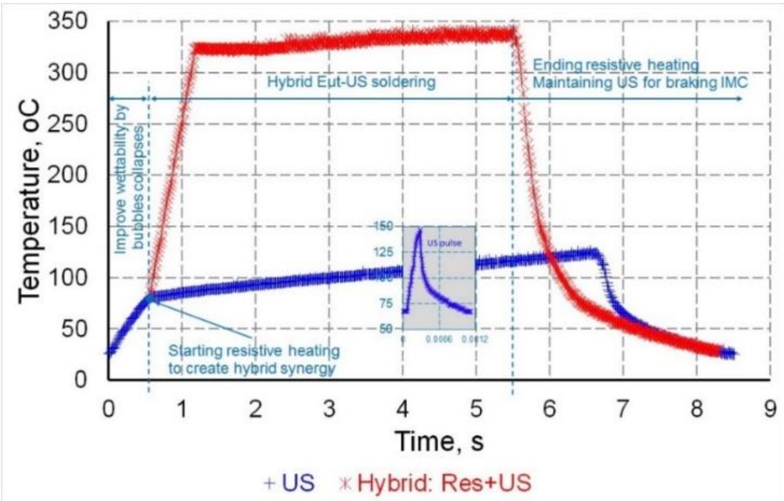


Fig. 3 Hybrid heating cycle

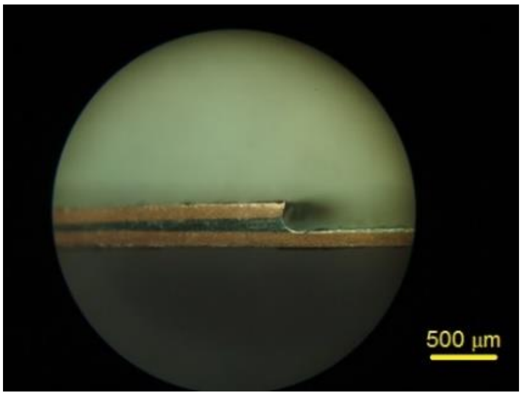


Fig. 4 Soldered joint

4. Results and discussions

The modification of the solder chemical was revealed by DSC thermal analysis of the heat flow associated with material transitions as a function of time and temperature (Figure 5). Each sample was heated at a rate of 5°C/min. from 30°C to 300°C in nitrogen gas flowing at a rate of 25 l/min. It was recorded a difference between the endothermic peaks: 217.57^{o}C for the eutectic chemical composition and 224.44^{o}C for the solder. A displacement of the endothermic peak from solder to eutectic was recorded for the both situations, with and without energetic activation and this is due to the resistive heating which create conditions for the diffusion of copper from the base metal to the solder. The difference between the two situations was related to the amplitude of the displacement. Increasing the frequency of the ultrasonic irradiation the amplitude of the displacement increased. The maximum amplitude was for f = 55 kHz and the endothermic temperature for that probe was 222.23^{o}C. No significant differences were recorded for the hysteresis of the DSC curves, which had almost the same shape.

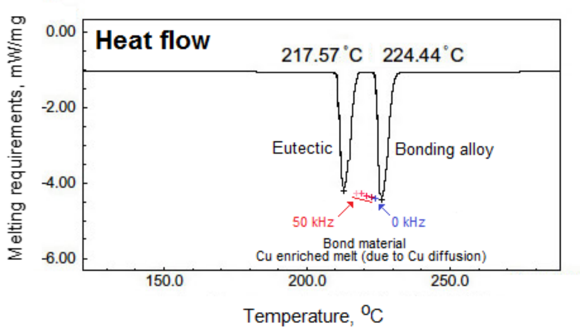


Fig. 5 DSC curve for the eutectic chemical probe and for the solder probe

By using XRD analysis it was identified the formed phases and it was concluded that three types of IMCs are forming when solder copper using Sn-Ag-Cu solder. To the interface between the base metal and the solder precipitates as a layer Cu_3Sn IMC. Going to the core of the solder new IMC is formed: Cu_6Sn_5. This IMC type is hexagonal one. In the core of the solder, where the content of copper is the solder one (0.7%) the main formed IMC is Ag_3Sn. Figure 6 is example of the recorded Thomson scattering against the diffraction Bragg angle 2θ in area located to 50±5μm from the base metal-solder interface to the solder core.

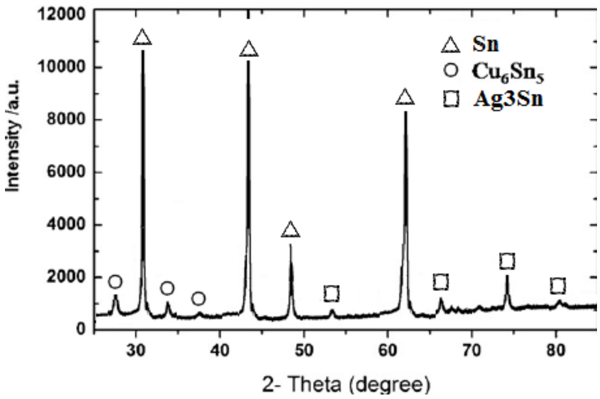
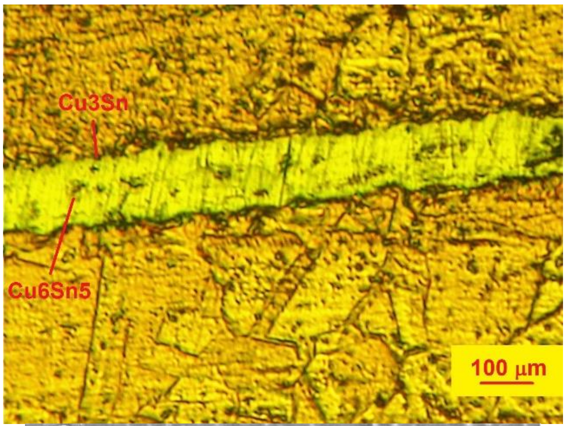
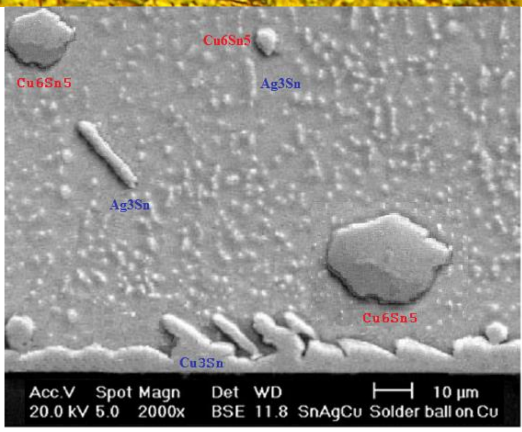


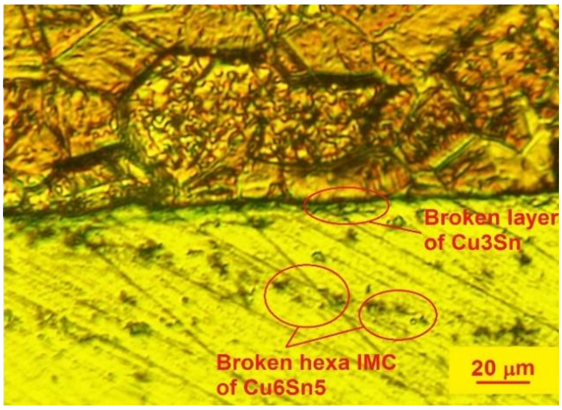
Fig. 6 XRD scattering of the bond material at 50±5μm from the interface base metal-solder (Cu_6Sn_5-(224)-(402), Ag_3Sn-(110),Sn-(301)-(321))

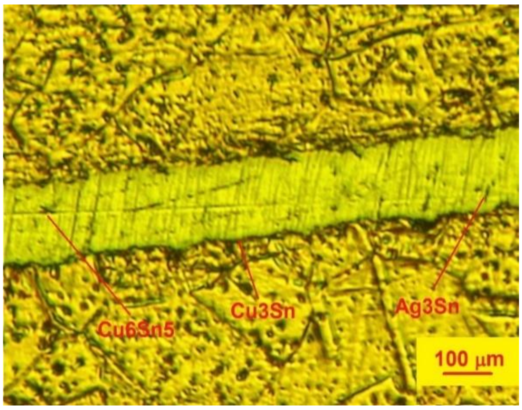
Figures 7a,b,c,d and e show the existence of the IMC formed in the bond material (solder core) and at the base metal-solder interface. The bonds were done at 320°C for 10s, with and without acoustic activation. Figure 7a and b present details of a bond done without acoustic activation. It can be observed the Cu_3Sn layer which is ~5μm thick at the both base metal-solder interfaces. The IMC layer is almost continuous and its thickness is not constant. In the core of the solder it can be observed the quasi-hexagonal formations of Cu_6Sn_5. All IMC formations are visible in Figure 7b which is SEM image of the solder. Using the same parameters new bond was done and acoustic activation (f = 45 kHz for example in Figures 7c,d) was applied (Figure 7b). It can be observed that the Cu_3Sn layer became very thin and in some places on the interface disappeared remaining small artifacts, only (Figure 7d). In Figure 7d it can be observed that the Cu_6Sn_5 formations suffered breakage due to mechanical vibration. The breakage of the IMCs formations is presented in the SEM image of Figure 7e.


Cu3Sn
Cu6Sn5
100 μm

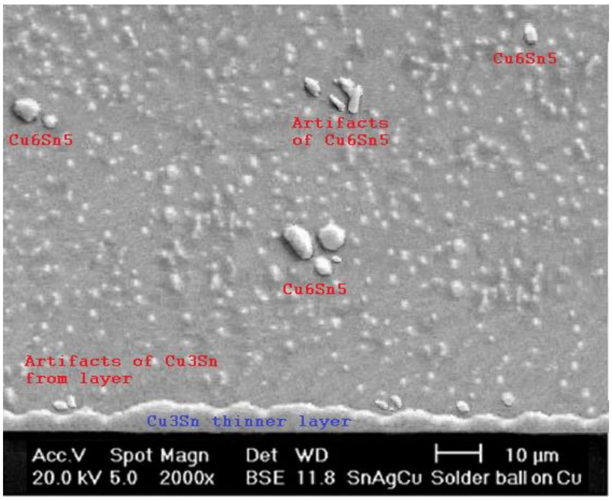

Cu6Sn5
Cu6Sn5
Ag3Sn
Ag3Sn
Cu6Sn5
Cu3Sn
Acc.V Spot Magn Det WD 10 μm
20.0 kV 5.0 2000x BSE 11.8 SnAgCu Solder ball on Cu

a. b.


Broken layer of Cu3Sn
Broken hexa IMC of Cu6Sn5
20 μm



c. d.



e.

Fig. 7 IMCs formations in the solder

A qualitative difference between the classic eutectic soldering and the ultrasonic activated eutectic process is presented in Figure 8. It can be observed the effect of the mechanical vibrations to the IMCs formations which suffer breakages and they are reducing their volumes.

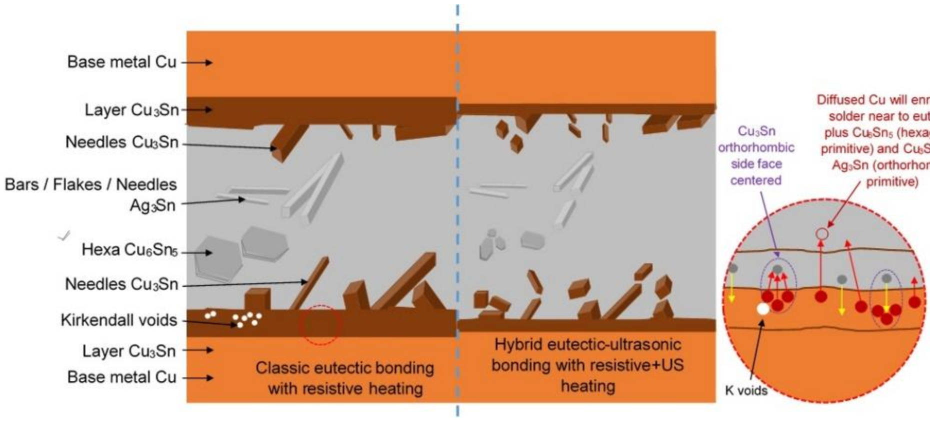


Fig. 8 Sketch of the effect of the ultrasonic activation of the solder during the eutectic bonding process

The effects are: 1.the thickness of the Cu_3Sn layer decreases with the frequency of the applied ultrasonic field; 2.the IMCs formation are divided in 2-4 pieces due to the mechanical vibration. The diffusion of the copper atoms from the base metal to the solder is the phenomenon which is the base of the Cu_3Sn layer and of part of the Cu_3Sn_5 formation. Diffusion is developing in eutectic soldering with or without ultrasonic activation. Theoretical and experimental research of the influence of the ultrasonic activation on the diffusion process were considered and the main point to followed to be revealed was the melting point which shows that, near the interface, the diffusion of the copper modified the solder chemical bringing it closer to the eutectic chemical. Applying the Stokes-Einstein relation for the diffusion coefficient, D, of the copper atoms in the solder, which has η viscosity, it can be predicted the evolution of the diffusion during the heating between 300K and 600K.

$$D = \frac{k_B\cdot T}{h}\cdot\frac{n\cdot d^2}{2\cdot\alpha}\cdot e^{\frac{-\Delta F}{k_B\cdot T}} = D_o\cdot e^{\frac{-\Delta F}{k_B\cdot T}} \qquad (8)$$

where α is dimensionality of the motion ($\alpha = 1$), ΔF is difference in the Helmholtz free energy between the 300-600K and d is distance the atom is jumping ($d = 2.556$). Constant n shows the shape of the new status growth curve. For copper, it is considered that the growth is controlled by bulk diffusion, declining with time, the growth rate is parabolic and n=0.5. Using equation (11) and the factors considered above it were calculated the values of the pre-factor D_o and the values of the diffusion coefficient D for 300K/600K temperatures. The pre-factor D_o for the classic eutectic bonding process resulted to be of $5.52x10^{-4}cm^2/s$ at 300K and $5.89x10^{-4}cm^2/s$ at 600K. When ultrasonic activation is applied the values are slightly decreasing: $4.04x10^{-4}cm^2/s$ at 300K and $4.38x10\text{-}4cm^2/s$ at 600K for $f = 45kHz$ frequency of the ultrasonic irradiation; $3.02x10^{-4}cm^2/s$ at 300K and $3.21x10^{-}$

^{4}cm^{2}/s at 600K for $f = 55kHz$ frequency (Figure 9).
The diffusion coefficient D is 2.58x10^{-14}cm^{2}/s for 300K and 7.23x10^{-8}cm^{2}/s for 600K for the classic $f = 0Hz$ process. The application of the ultrasonic activation increases the values of the diffusion coefficient to: 5.26x10^{-14}cm^{2}/s at 300K and 2.68x10^{-7}cm^{2}/s at 600K for $f = 45kHz$ frequency; 5.78x10^{-14}cm^{2}/s at 300K and 2.91x10^{-7}cm^{2}/s at 600K for $f = 55kHz$ frequency (Figure 10). That increasing means an acceleration of the diffusion and increasing of the mass transfer (number of atoms) and that will conclude in the increasing of the area which is enriched in copper atoms. In that area the chemical of the solder is changing, going closer to the eutectic chemical.

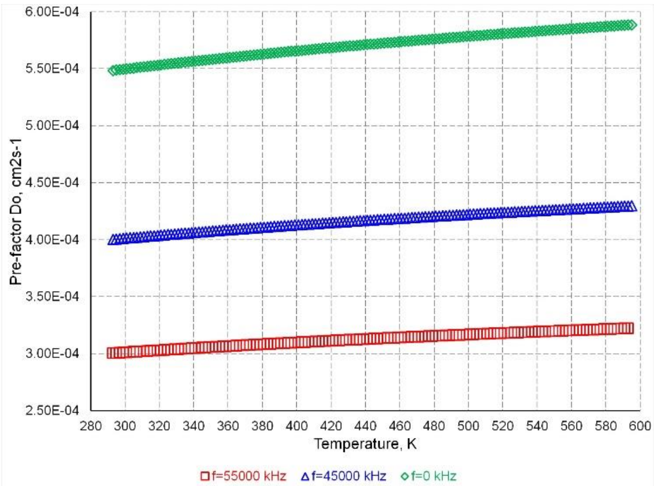


Fig. 9 Calculated values for the pre-factor, D_o

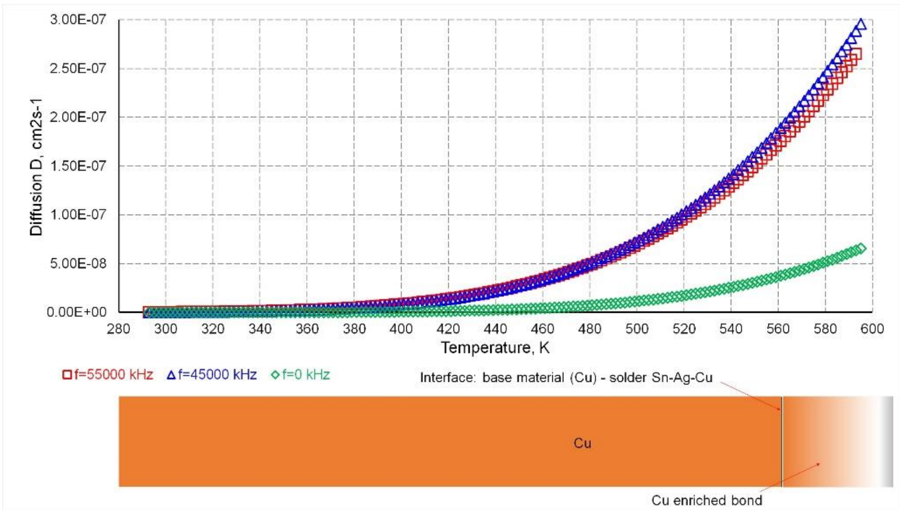


Fig. 10 Calculated values for the diffusion coefficient, D

Figure 11 shows Arrhenius plot of the reaction rate. It can be observed that the slope of the Cu_3Sn IMC is higher than the slope of Cu_6Sn_5 which shows a faster formation of the Cu_3Sn due to an accelerated diffusion at the interface. The formation of Cu_3Sn is also faster due to the low number of atoms to participate to the reaction (3 of copper and 1 of tin) comparing to the Cu_6Sn_5 formation reaction which requires 11 atoms. The same motivation is met in the case of Ag_3Sn which has almost the same slope of the log D as Cu_3Sn.
To better understand the modification of the chemical composition due to the diffusion process it have been measured the melting points in areas located at 20μm from the interface for different frequencies of ultrasonic activation: $f = 0/45/55 kHz$. Being an area that suffered chemical modifications, the melting temperature is decreasing from the 224.44°C (solder) to about 222°C. The decreasing was revealed by the measured values (Figures 12, 13). Decreasing of the temperature is more pregnant with the increasing of the ultrasounds frequency. The formation of the 3 types of IMC due to the diffusion the atoms of copper and silver are being consumed in the reaction faster than the atoms of tin and that creates condition for the Kirkendall voids to appear. That means new risk introduced by the formation of the 3 IMCs. The voids introduce critical reliability risk when the bond is used for specific PCB boards [1].

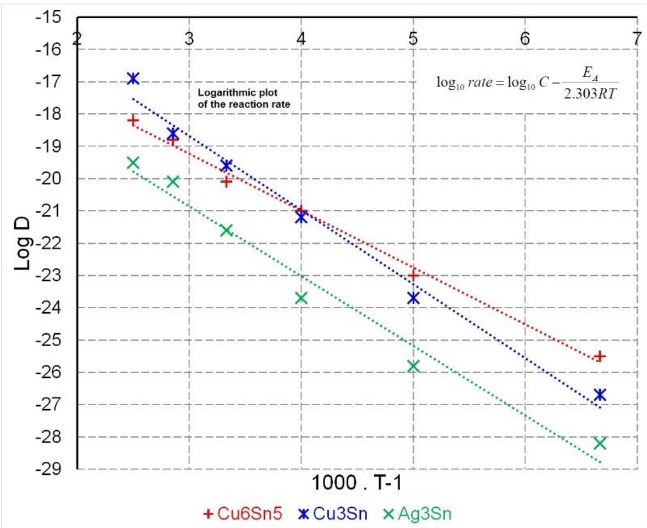


Fig. 11 Typical Arrhenius plot of the reaction rate for the 3 types of IMC revealed

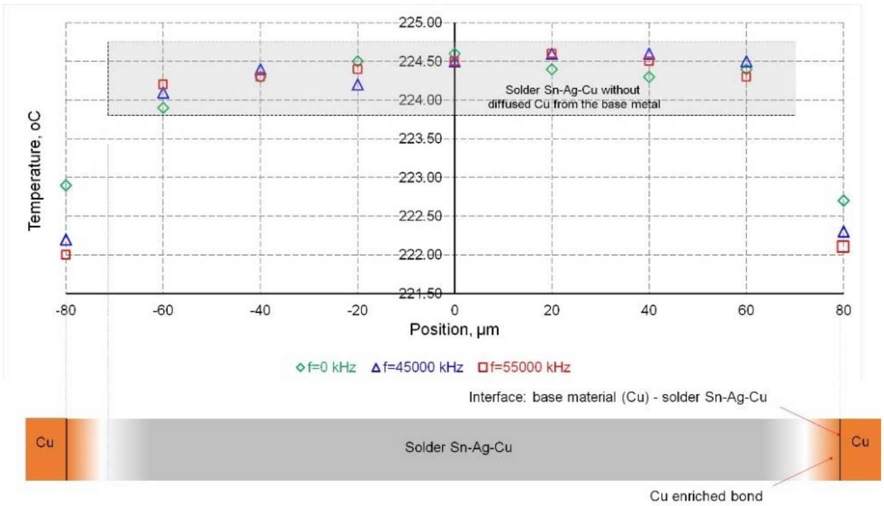
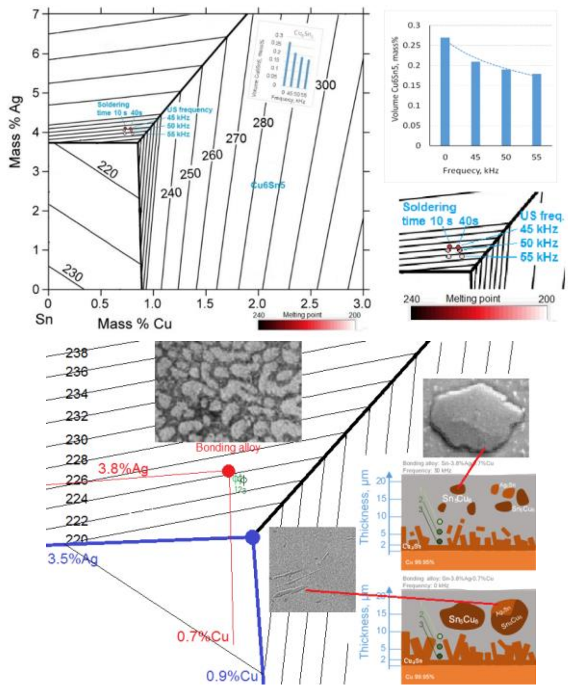


Fig. 12 Measured values of the melting temperatures



a. b.

Fig. 13 Position of the melting points for different frequencies and soldering times

After the formation of the IMCs they are increasing in volume if the thermal cycle permits such process, taking account that according to Arrhenius the growth of the phases are influenced by temperature. Plotting of the growth is possible by using the following form of the Arrhenius relation:

$$\ln\left(\frac{k_1}{k_2}\right) = \frac{-E_a}{R}\cdot\left(\frac{1}{T_2}-\frac{1}{T_1}\right) \quad (9)$$

and the results plotted against the time (26 h after the soldering process) for Cu_6Sn_5 are presented in Figure 14.

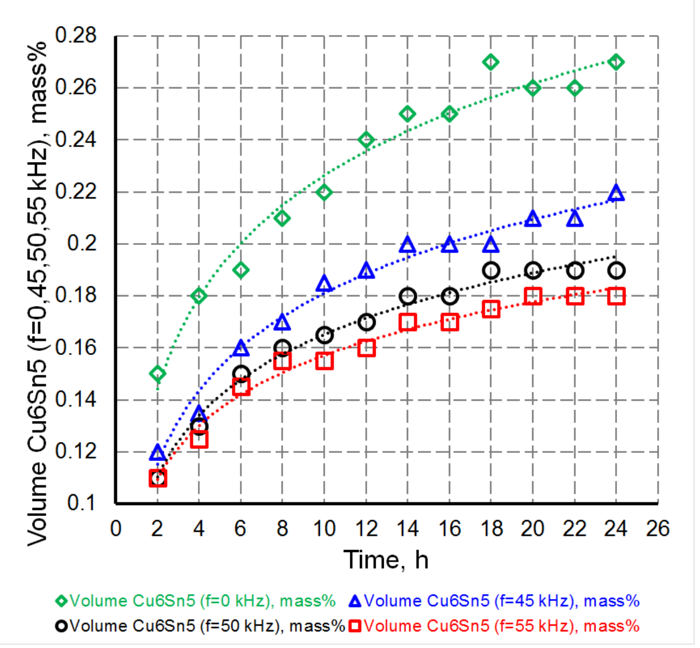
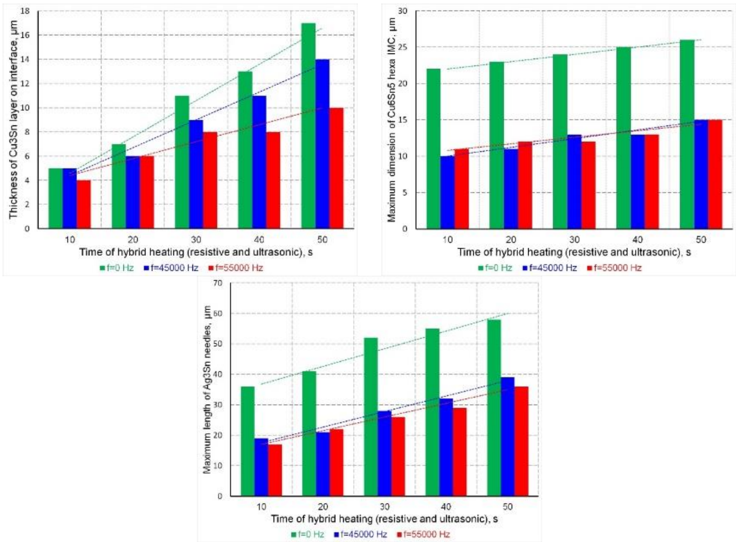


Fig. 14 The evolution of the Cu_6Sn_5 IMC volume

Ultrasonic irradiation was revealed to have influence on the dimension of the IMCs formed at the interface between the solder and the base metal and in the solver. It has been observed that the increasing of the ultrasounds frequency decreases the thickness of the Cu_3Sn layer which is usually forming at the interface between the solder and the base metal. Applying ultrasonic field up to 55kHz frequency the quantity of formed Cu_3Sn is decreasing and the developed layer is about 60-65% (from maximum value of 18µm thickness at 320°C soldering temperature and 50s time of the process to 14µm for f=45kHz and 10µm for f=55kHz) from the thickness which is recorded for classic eutectic bonding (Figure 15a). That means an important decreasing of the susceptibility to cracking due to the high hardness and brittleness of the Cu_3Sn IMC [6]. Almost similar effect was recorded for the Cu_6Sn_5 hexagonal IMC. The application of the ultrasonic field reduced the biggest dimension of the hexagonally shape of the IMC from maximum value of 25µm for classic eutectic bonding to maximum value of 15µm for both 45kHz and 55kHz frequencies of the ultrasonic irradiation. It can be observed in Figure 15b that no difference between the Cu_6Sn_5 dimensions for the both high frequencies was measured. That means that the ultrasonic field creates a decreasing of the formed IMC dimension, but the frequency brings no influence. Similar effect was revealed (Figure 15c) for the Ag_3Sn needles formed in the solder due to the high content of silver (3.9%Ag for an improvement of the electrical properties). The length of the needles decreased from maximum value of 58µm for f=0Hz to maximum value of 38 µm for both 45 kHz and 55 kHz.



a. b. c.

Fig. 15 Maximum dimensions of the formed IMCs measured in SEM images

The decreasing of the IMCs dimensions shows that the application of the ultrasonic irradiation, at the specific temperatures of IMCs generation and growing, creates a blocking of the reaction of IMCs forming. After the formation of the IMCs the ultrasonic irradiation is able to brake the formed IMCs and that was proved by the artifacts revealed in SEM analysis of the bonds (figure 7e). It can be observed in the SEM images several artifacts of Cu_3Sn resulted from the front of the Cu_3Sn layer which was broken by vibration. Artifacts resulting from the breakage of the hexagonal Cu_6Sn_5 and from the breakage of the Ag_3Sn needles were met, as effect of the mechanical vibration of the IMCs. No significant difference between the number and the dimensions of the artifacts for the two used frequencies was recorded. The main dimensions of the artifacts resulted from the hexagonal Cu_6Sn_5 was around the 25-30% of the dimensions measured for the classic eutectic bonding.

5. Conclusions

Even if the ultrasonic irradiation is usually used to clean and de-oxidize the surface of the base material in flux-free soldering, new approach is proposed: 1. to use the ultrasonic activation of the solder and of the base material in order to improve the diffusion of the copper atoms from the base metal to the solder; 2. To reduce the formation and the growth of the IMCs: 3. To break the formed IMC.

The increasing of the copper diffusion produces an enriching with copper of the solder chemical to be closer to the eutectic chemical and that reduces the soldering temperature from 224.44^{o}C with ~2^{o}C.

Due to the copper diffusion and to the solder chemical, three types of IMCs were revealed in the bond material and in the interface between the solder and the base metal: Cu_3Sn as layer at the interface and several islands in the solder, hexagonal Cu_6Sn_5 formations in the solder and Ag_3Sn needles in the solder.

Even if the diffusion is accelerated by the ultrasonic activation the volume of the formed IMCs is lower comparing to the classic eutectic soldering, due to the vibration which makes the atoms more mobile and that is preventing the reactions between the copper, silver and tin atoms. Decreasing of the volume of the formed IMCs is up to 30% from the volume which is specific to the classic soldering.

By maintaining of the ultrasonic vibration few seconds after the ending of the hybrid soldering process, allows to the ultrasonic field to produces fragmentation of a part of the formed IMCs in 2-4 pieces. That decreases the susceptibility to cracking due to the brittleness of the IMCs.

R E F E R E N C E S

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