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New Generation Semi-Automatic Thermosonic Wire Bonder

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Abstract: The physical and technological aspects of wire ball-wedge bonding in the assembly of integrated circuits are considered. The video camera and the pattern recognition system (PRS) of new bonder helps to provide accurate positioning of the bonding tool on the chip pads of integrated circuits. The formation of the loop wire cycle is ensured by the synchronous movement of the bonding head along the Z axis and the working table along the XY axes based on the servo drive. A feature of the bonder is that it can bond all the wire loops of the electronic device according to the pre-recorded program without needing to align the bonding points.

Keywords: High frequency ultrasonic; Gold wire bonding; Ball formation; Bonding tool; Matching parts of ultrasonic transducer

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1. Introduction

Today's global industry produces more than 60 billion types of electronic devices a year. This variety includes devices that control the systems of personal computers (PC), spacecraft, aircraft, cars, televisions, mobile phones, digital cameras, DVD players, and many more. The market requires more features in smaller, faster, cheaper devices, which are assembled in many frameworks such as chip-scale package (CSP), ball grid array (BGA), wafer-level chip-scale package (WCSP), true chip-size package (TCSP), plastic leaded chip carrier (PLCC), small outline integrated circuit (SOIC), small outline package (SOP), and many more.

Assembly of more than 90% of these frameworks is associated with the technology of interconnections by gold and aluminum wires [1]. Thus, interconnect technology is the critical technology that connects the pads of semiconductor chips to the outside pads of electronic devices. Modern chip bonding in semiconductor technology involves high-temperature Au-Si eutectic spray (377 °C) method and widely used of low-temperature adhesives and solder, which requires wire bonding to be done at temperatures of 120–180 °C, instead of 200–250 °C. The high degree of integration of the IC and the reduction of chip pads leads to the need to use for interconnections of small diameter gold wire (17.5 µm–20 µm). This makes new requirements on the accuracy of the bonded points and necessitates the automation of the alignment of the bonding tool with the small contact pads of electronic device.

2. Ultrasonic bonding systems

It is known that the quality of work of any wire bonder in electronic products using ultrasound is determined by its ultrasonic system, which includes an ultrasonic transducer (UST) and an ultrasonic generator (USG). Increasing the requirements for equipment performance and reducing the size of the contact pads on the crystals requires precise operation of the ultrasonic system. The supplied electrical oscillations from the USG are converted by the UST into mechanical vibrations. In turn, the matching of the bonding tool with the UST is required. The requirements for the bonding tool for ultrasonic bonding can be formulated as follows:

(1) The shape and dimensions of the instrument must provide efficient transmission of ultrasonic vibration energy with a gain of > 1.

(2) The material of the tool should provide the minimum attenuation of US vibrations and should not chemically interact with the output material.

To preserve the spectrum of natural frequencies and the type of oscillations (bending in particular), it is necessary to observe the following condition [2]:

$$\frac{\lambda}{d} > (2.5\text{–}5)$$

where λ is the wavelength of the bends vibrations; d is the cross-sectional diameter of the bonding tool.

Connection of wire of small cross section $\leq$ 20 microns at the lowered temperature of a bonding zone (120–180°C) for industrial application of new semiautomatic bonder has the following characteristics:

(1) A precision bonding head with programmable force of the bonding tool on bonding positions according to a given profile and ultrasonic transducer with high resonance frequency (100 or 135 kHz).

(2) Uses precision wire break-feed mechanism.

(3) Digital ultrasonic generator with phase locked loops (PLL) of high frequency and with high resolution of parameter setting (amplitude, duration of output pulse).

(4) Bonding process control at each connection point, which will improve the quality of the products.

Until the early 1990s, ultrasonic bonding systems used ultrasonic frequency of about 60 kHz. Since 1991, leading manufacturers of assembly equipment have been actively using ultrasonic high-frequency systems in the range from 90 to 140 kHz [3].This was due to the development of "smart-card" technology, when it was necessary to carry out the process of bonding the gold wire using the "ball-wedge" method on the ribbon with chip from Heraeus (Germany) at a temperature not exceeding 140 °C. Previous operation of ultrasonic systems of high frequency in the range of 90–140 kHz has shown that this ensures high quality and reliability of connections at a temperature of 120 ºC and, with lesser bonding time. This is almost 100 °C less than the temperature of thermosonic bonding at a standard frequency of 60 kHz (200–220 °C).

Given the requirements of modern production of electronic products and the experience of using ultrasonic bonder model EM-4320U [4], OJSC Planar-SO has developed a new generation of semi-automatic bonder EM-6705-2 (**Figure 1**).

The EM-6705-2 is a semi-automatic model that performs ball-to-wedge bonding.

Figure 1. Thermosonic wire bonder EM-6705-2

The unit is equipped with ball bonding head, USG, negative electronic flame-off (NEFO) which provide connection of terminals with a gold/copper wire diameter of 17.5 μm –75 μm. The software allows you to quickly select the appropriate bonding parameters in the program menu on display. To solve the problem of high-quality connection, the bonding system contains the following mechanisms and sub-systems:

(1) Wire feed with stepper motor mechanism using standard 2-inch wire coils from manufacturers such as SPM (Malaysia) and Heraeus (Germany).
(2) Precision servo drivers in Z and X-Y coordinates with a resolution of 1 μm and a high-speed touch sensor to determine the moment of contact of the bonding tool with the bonding pad, ensuring minimal deformation of the wire before bonding.
(3) Bonding head with programmable loading device, providing minimum force when touching the bonding point from 10 G to 15 G and the required bonding force profile (constant, trapezoidal, stepped) with a discrete load setting of not more than 0.2 G in the range from 10 G to 150 G
(4) Ultrasonic generator (USG) with a frequency range of 60–140 kHz and an output power of up to 4 W (or up to 10 W) with a set resolution of 0.01 W. To reduce the welding temperature to 120–180 °C, a model range of ultrasonic transducers with an increased resonance frequency in the range of 98 kHz ± 2 kHz (or up to 136 kHz) and a low impedance (10–25 Ω) was developed.
(5) Output current of NEFO regulated in the range 5–50 mA.

The bonder contains two control units: on the right is a control unit with a built-in small computer and a 19-inch PC display; on the left is the control unit for the drive and peripherals. The control system performs programmable movements of the bonding head in the Z coordinate (vertically) and the work table in the X-Y coordinates.

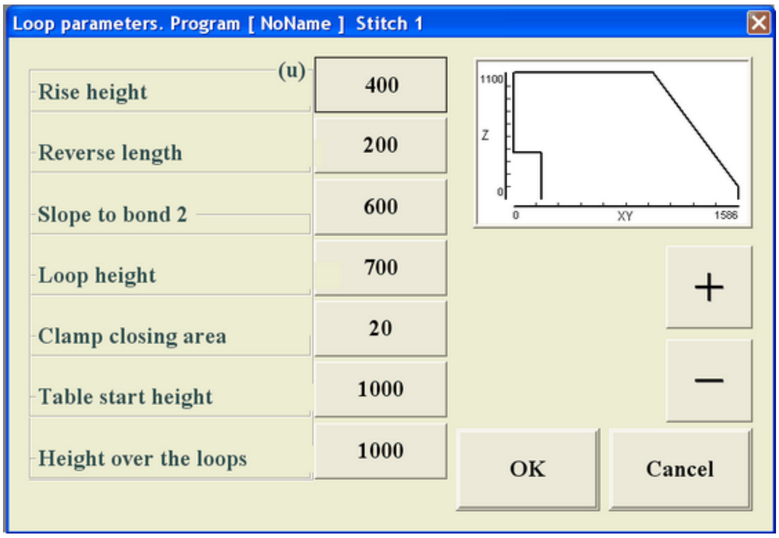
All welding parameters are programmed via the display and stored in the system memory. Each stitch bonding point and the stitch (loop) shape itself can be individually programmed and stored in the system memory. Thus, it is possible to name the program of bonding of the specific device and save it in the system memory.

To pre-align the tool with the bonding point, a video captured by a charge-coupled device (CCD) camera and cross-hair is displayed. After moving the bonding head to the alignment position, you can slowly move the bonding head closer to the bonding position by rotating the mouse wheel to accurately align the tool end with the bonding position. This software option is useful when assembling devices with welding points of different heights and with small contact pads (40–50 microns). However, the main bonding mode is automatically carried out according to the recorded program using the embedded pattern recognition system and CCD video camera.

The peripheral system control interface contains a discrete I / O based on a PCI-1750 board and RS-232/USB channels. The bonding head can be easily removed after loosening the locking screw and disconnecting the flat cable connector. The main control buttons of the operator is a standard PC keyboard. On the panel of the right control unit there are power buttons of the systems (on/off), and an emergency stop button for the drives.

When setting the tearing speed, it is also necessary to take into account the breaking force of the wire and its relative elongation. Precision actuators in X and Y coordinates and their software interpolation allow the formation of stable loops at length of 150–200 microns. The flexibility of loop formation is provided by a set of programmable parameters shown in **Figure 2**.

The output power of USG can be controlled via RS-232 or an 8-bit parallel port. The wide range of operating frequencies allows to use this USG with high frequency UST for upgradation of the operating bonders with the system of 60 kHz.



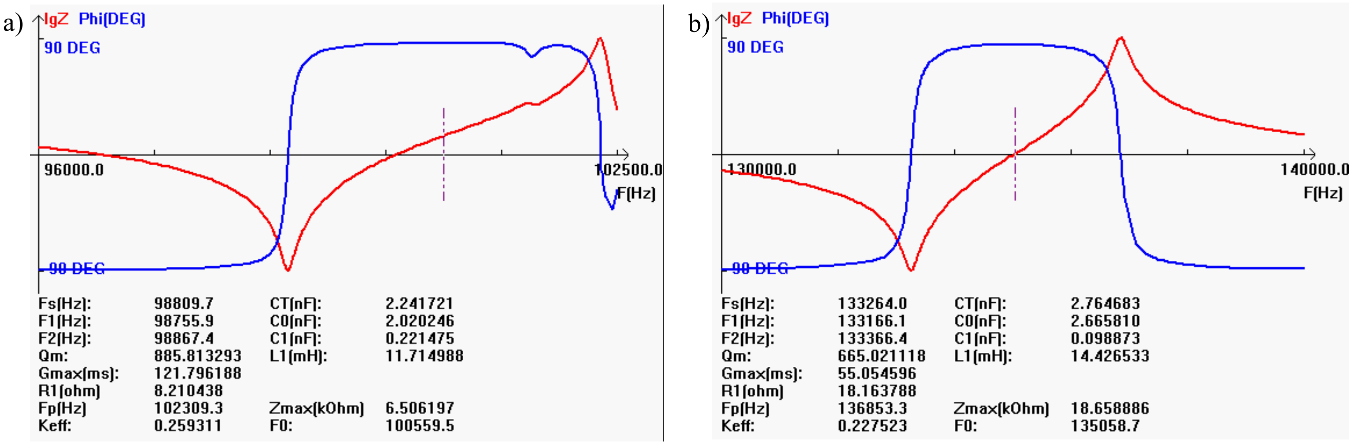
Loop parameters. Program [NoName] Stitch 1

(u)

Rise height 400
Reverse length 200
Slope to bond 2 600
Loop height 700
Clamp closing area 20
Table start height 1000
Height over the loops 1000

Figure 2. Loop programming section

The ultrasound setup results (resonance frequency in Hz and impedance in Ω) are displayed on the connection setup display. The built-in phase locked loops (PLL) system supports the operation of ultrasound at the resonant frequency of the ultrasonic transducer (UST). Typical phase and impedance diagrams obtained using the impedance analyzer are shown in **Figure 3**. The latest models of generators produces diagrams for quick diagnostics of the ultrasound system and view the result of matching bonding tool with UST.



```
Fs[Hz]:       98809.7      CT[nF]:      2.241721
F1[Hz]:       98755.9      C0[nF]:      2.020246
F2[Hz]:       98867.4      C1[nF]:      0.221475
Qm:           885.813293   L1[mH]:      11.714988
Gmax[ms]:     121.796188
R1[ohm]       8.210438
Fp[Hz]        102309.3     Zmax[kOhm]   6.506197
Keff:         0.259311     F0:          100559.5
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Fs[Hz]:       133264.0     CT[nF]:      2.764683
F1[Hz]:       133166.1     C0[nF]:      2.665810
F2[Hz]:       133366.4     C1[nF]:      0.098873
Qm:           665.021118   L1[mH]:      14.426533
Gmax[ms]:     55.054596
R1[ohm]       18.163788
Fp[Hz]        136853.3     Zmax[kOhm]   18.658886
Keff:         0.227523     F0:          135058.7
```

Figure 3. Impedance (blue) and phase (red) diagrams of transducers for ball wire bonding: a) UST with resonance frequency 988 kHz and impedance 8,2 Ohm(left); b) UST with resonance frequency 1333 kHz and impedance 182 Ω (right)

3. Physical and technological aspects of wire formation

The process of thermosonic bonding generally consists of four stages [5], as shown in **Figure 4**. In the first stage (preliminary deformation), the wire is deformed by 10–15% in the vertical direction under the action of the applied load to the bonding tool. The amount of pre-deformation plays a decisive role in the subsequent bonding process. If the deformation is too strong, the crystal structure of the metal of the contact surface and the wire itself changes significantly, which in turn causes the quality of the bonded joint to deteriorate.

In the second stage (cleaning), under the action of external load and ultrasonic oscillations, shear stresses occur in the wire, leading to the rupture of the surface oxide film, as well as the oscillating movement of the wire relative to the contact pad. These movements help to remove the oxide film and other contaminants from the contact surfaces. The vibration energy is used to clean surfaces from oxides and other contaminants. Only a small fraction of the energy deforms the wire. The tool oscillates together with the wire along the contact surface.

In the third stage (deformation), the plastic deformation of the wire predominates due to the heating of the wire by ultrasonic vibrations. As a result, setting points are formed and conditions are created for diffusion in the joint volume. During this phase, the temperature of the wire increases. The oscillations level the friction surfaces, causing the temperature at the point of contact to rise. The metals are ground to each other until the distance between the crystal lattices is interatomic. The high temperature of the contact spot stimulates the mutual diffusion of atoms in the lattice dislocation, and the metals are thermally released in the bonding zone. From this point on, the tool oscillates separately from the fixed wire, causing a further rise in temperature.

In the last stage (diffusion), which is the final formation of the micro bonded joint, intermetallic phases are formed due to the diffusion process. There is no significant increase in temperature or deformation. The heat given off by the friction of the capillary against the surface of the bonded wire is used to heat the bonding spot. This causes further release of metal at the bonding site. The tempering process stabilizes the bonding zone, and due to the gradual curing of metals in the diffusion zone, the joint is not brittle.

The magnitude of the mechanical energy of the ultrasonic vibrations introduced into the zone of formation of the micro-bonded joint is determined mainly by their amplitude A and frequency w, as shown in the equation below:

$$E = 1/2\, \rho V\, (\mathrm{Aw})^2$$

where ρ is the density of the material, and V is the volume of the joint zone.

Increasing the frequency of ultrasonic oscillations for bonding micro-wires should be considered as an opportunity to reduce the magnitude of the oscillation amplitude without changing the acoustic power. Reducing the amplitude of oscillations in turn reduces the alternating stresses in the bonded materials and the risk of fatigue failure, the probability of which is especially high when bonding thin wires.

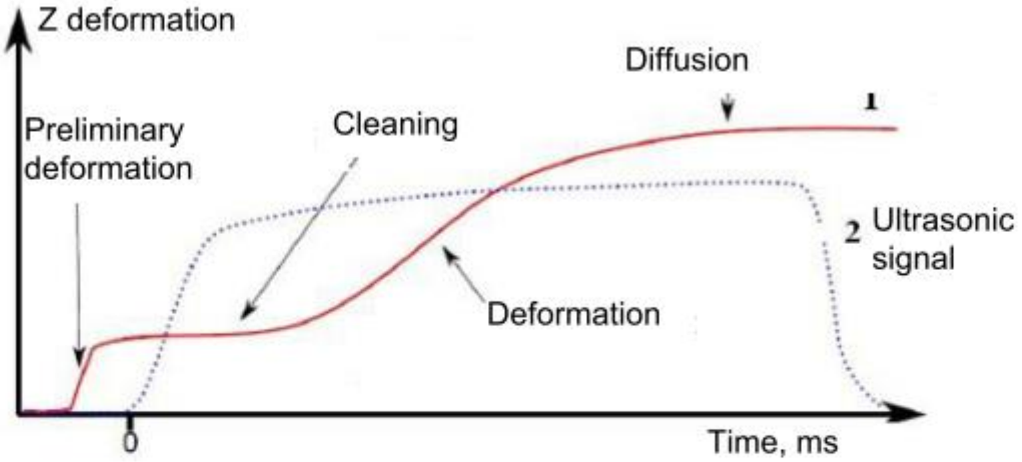

Figure 4. Stages of formation of the connection by the thermosonic "ball-wedge" wire bonding method

As is known, bonding of gold wire by the "ball-wedge" method begins with the process of forming a ball at the end of the gold wire. The EM-6705-2 uses the technology of applying high-voltage negative polarity to the sparking wand, which allows balls of stable diameter to be obtained [6]. The appearance of the gold ball at the end of the gold wire is shown in **Figure 5**. **Figure 5** shows the ideal transition of the ball into the wire, the so-called "neck," which is a critical place in the formation of the ball due to the annealing of the wire during its melting. The size of the annealed wire, the so-called heat-affected zone, depends not only on the strength of the formed bridge, but also on its formation [7]. The appearance of the first ball bonding is shown in **Figure 6**, and the second butt bonding in **Figure 7**.

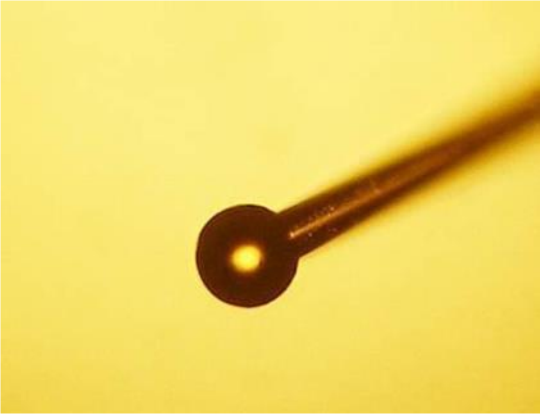

Figure 5. A typical outer ball obtained on a gold wire with a diameter of 20 microns on the EM-6705-2 model

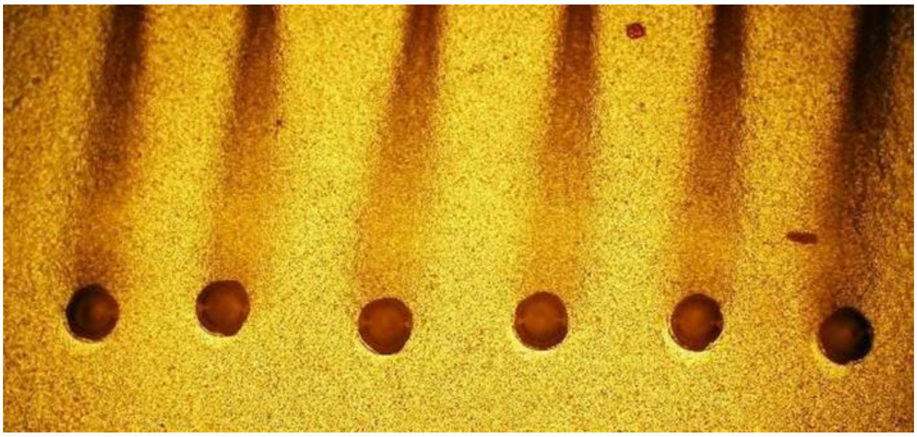

Figure 6. First ball bonding received on a gold wire with a diameter of 20 microns on the EM-6705-2 system

Figure 7. Appearance of the second bonding (wedge) obtained on a gold wire with a diameter of 20 microns on the EM-6705-2 system

4. Conclusion

A new generation of semi-automatic system for gold wire bonding, the EM-6705-2 bonder, which can be used in small-scale production of electronic products, is presented. The main bonding mode is automatically carried out according to the recorded program using the embedded pattern recognition system and CCD video camera. This system can be useful in educational institutions for micro-bonding for research and training.

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Disclosure statement

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References

[1] Prasad SK, 2004, Advanced Wirebond Interconnection Technology, Kluwer Academic Publishers, New York.

[2] Kundas SP, Lanin VL, Tjiavlovsky MD, et al., 2003, Ultrasonic Processes in the Manufacture of Electronic Products, Volume 2, Bestprint, Minsk.

[3] Ramsey TH, Alfaro C, 1991, The Effect of Ultrasonic Frequency on Intermetallic Reactivity of Au-Al Bonds. Solid State Technology 1991(12): 37–38.

[4] Petuhov I, Lanin V, 2016, Technology and the Equipment for the Wire Bonding of Electronic Modules. Electronics: Science, Technology, Business, 2016(1): 178–185.

[5] Farassat F, Valev S, 2004, Control of the Process of Ultrasonic Welding: Solving Problems of Instantaneous Quality Assessment, Documentation, and Statistical Analysis. Electronic Components, 2004(11): 1–5.

[6] Lanin VL, Tsinman AF, Petuhov IB, 2011, The Choice of the Polarity of the Electric Discharge During the Formation of the Ball in the Installations of the Connection of Wire Terminals. Vestnik PSU, 2011(3): 110–116.

[7] Harmann GG, 2010, Wire Bonding in Microelectronics, McGraw Hill, New York.