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MODELING AND CONTROL OF THE PARAMETERS OF ULTRASONIC TRANSDUCERS FOR CONNECTING WIRE OUTPUTS

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Abstract. *The methods of modelling and control parameters of the ultrasonic piezoelectric transducers used for wire bonding in the electronic devices are investigated. It is established, that resonance frequencies of ultrasonic transducer may be with different mechanical oscillation modes. It was found that the matching of the piezoelectric driver and the horn in the mode of longitudinal mechanical vibrations at the resonance frequency helps to achieve the maximum quality of the wire bonding. Technological tests carried out confirm this statement.*

Key words: *Piezoelectric driver, horn, ultrasonic transducer, wire bonding.*

Currently, installations for mounting wire and tape leads in electronic products use ultrasonic or thermosonic microwelding with the resonant frequency of an ultrasonic transducer (UST) in a wide frequency range - mainly from 60 to 140 kHz [1,2]. The use of ultrasonic pulsers with a resonant frequency of ≥ 100 kHz expands the technological capabilities of the lead-wire equipment, providing flexible modes of micro-welding on the contact pads of the crystals and the external leads of the package.

A modern UST for microwelding installations is a classic design consisting of a piezoelectric emitter connected to each other and a waveguide with a hole at the end for clamping a working tool (Fig. 1). The main function of the waveguide is to supply the working tool with longitudinal mechanical vibrations enhanced in amplitude from a piezoelectric emitter (piezodriver), which converts the input electrical signal into mechanical vibrations due to the inverse piezoelectric effect. On the back side of the UST there is a piezoelectric emitter based on an even number (4,6,8) of piezoelectric rings, compressed by two metal plates by means of a pin or bolt. This design converts the supplied electrical voltage of ultrasonic frequency at a certain resonant frequency (depending on the design of the UST) into mechanical vibrations of a piezoelectric emitter. Mechanical vibrations propagate along the waveguide to the attachment point of the working tool, which transmits these vibrations to the connection zone.

The parameters of a piezoelectric radiator or an UST assembly (a piezoelectric radiator with a screwed waveguide by means of a threaded stud) are usually measured by an impedance analyzer or a vector analyzer with the calculation of the values of the elements of the known equivalent circuit of the UST [3,4], its resonant frequency *Fs*, quality factor *Q* and impedance R_1 (Fig. 2).

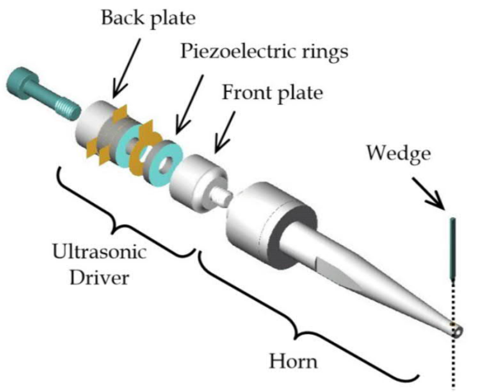
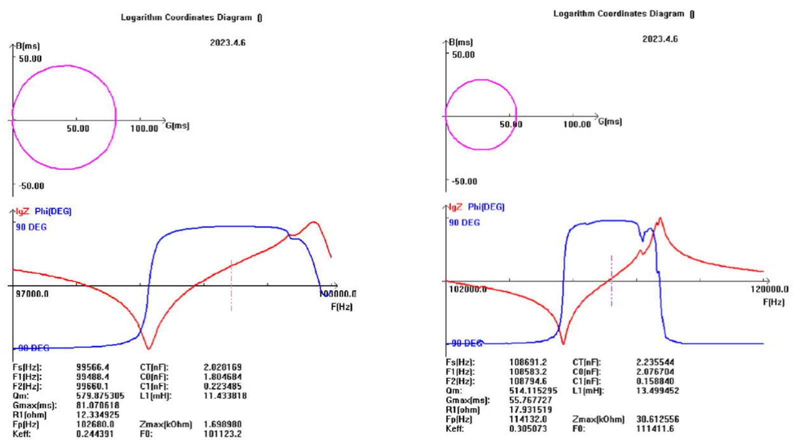


Figure 1. *Design of an ultrasonic transducer for terminal connections*

In this case, not only numerical parameters are available, but also graphical information on the behavior of the impedance, the phase shift between the applied alternating voltage to the SPD and the current flowing through it near resonance, as well as a circular diagram of admittance (similar to the Wolpert-Smith diagram). It can be seen from Fig. 2 that both USTs have almost ideal circular dependences of the total conductivity in the resonance region, which means that there are no side resonances. The graphs below the pie charts show impedance (red line) versus frequency and the phase shift between UST voltage and current (blue line). At the resonance frequency, the phase curve has a stepped character, which is widely used for phase locked loop systems. Despite the different resonant frequencies (99.6 kHz and 108.7 kHz) of the ultrasonic transducers shown in Fig. 2, they are comparable in terms of the quality factor Q_m = 579.9 for the UST in

Fig. 2a and Q_m = 514.1 in Fig. 2a. 2b and impedance 12.3 ohms (for 99.6 kHz) and 17.9 ohms (for 108.7 kHz).

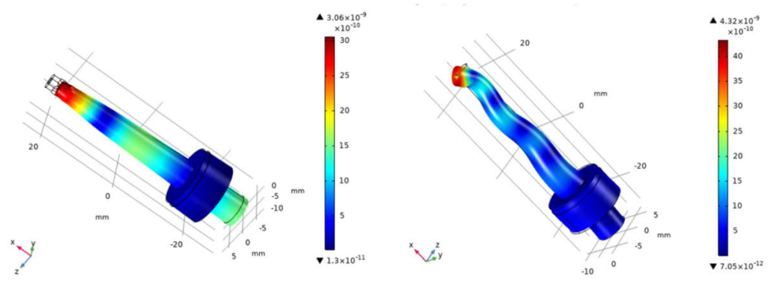
It is obvious that the resonant frequency of the piezoelectric radiator must match or be as close as possible to the natural resonant frequency of the waveguide, while the resonant frequency of the SPD assembly measured by the impedance analyzer will be close to the frequency of the piezoelectric radiator. It has been experimentally established that the deviation of the resonance frequency of the assembled UST by more than 1.4 kHz from the resonance of the piezoelectric emitter leads to a deterioration in the quality of the connection.



a) *б)*

Figure 2. *Electrical parameters of 2 SPDs obtained using a vector network analyzer at resonance frequencies: 99.6 kHz (a) and 108.7 kHz (b)*

To find out the reason, the modeling of waveguides designed for ultrasonic radiant resonance frequencies in the UST environment was carried out by the finite element method in the ANSYS, FEATool Multiphysics and Comsol Multiphysics packages. The simulation results show that the waveguide can have several natural resonant frequencies with different oscillation modes in the area of the working tool clamp (Fig. 3). The mode shape of the waveguide also depends on the geometry of the waveguide itself. Therefore, it is advisable in the process of designing a waveguide to carry out simulations in the above UST systems to analyze the spectrum of natural vibrations of the waveguide. Figure 3 shows a significant change in the distribution of nodes (dark blue) and antinodes (red, light green) along the waveguide axis from the point of docking with the piezoelectric emitter to the clamping point of the working tool at the end of the waveguide.



а) *б)*

Figure 3. *Longitudinal vibrations in waveguides at a calculated resonance frequency of 98 kHz (a) and bending-torsional vibrations at a frequency of 106 kHz (b)*

These negative phenomena are usually reflected in the diagram in Fig. 2 as small peaks on the impedance curve, which may signal the need for more thorough diagnostics and tuning of the assembled UST. Technological tests were carried out in the mode of assembly of semiconductor devices with aluminum wire with a diameter of 50 microns. The current strength of the leads was 21-23 g. The appearance of the wire connections is shown in Fig.4.

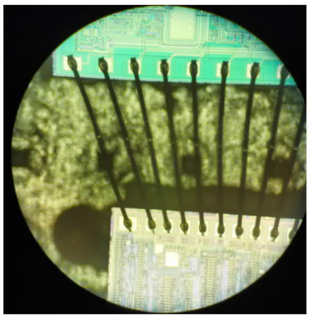


Figure 4. *Appearance of wire interconnects Al wire with a diameter of 50 microns*

In this case, a waveguide with various piezo emitters with resonant frequencies of 99.8 kHz and 104.8 kHz was used. The best results (in terms of product yield) were achieved with 99.8 kHz piezoelectric radiators.

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