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Analysis of Wire Bonding Pull-off/Shear Force for Various Wire Materials and Contact Pads

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Abstract

In this paper we study wire contacts made of varied materials (Ag, Au, Cu) and microwelding methods at contact pads with different coatings — immersion gold, galvanic gold, galvanic silver. We present the results of bonding pull-off/shear force testing and compare results of various wire contacts technological operation.

Keywords: Microwelding; Immersion gold; Galvanic gold; Wire contact

1. INTRODUCTION

Each stage of wire bonding technological process determines quality of optoelectronic devices and their storage life. The key points of the technological processes are type and thickness of contact chip coatings as well as methods and materials of wire bonding process.

Ref. [1] describes the possibilities of implementing wire bonding with various materials, but there is no data about quality of the joints. In electronics industry, as a rule, materials are used with following requirements:

- high electrical and thermal conductivity;
- corrosion resistance;
- low hardness of the material to reduce the pressing force;
- high enough hardness to reduce mechanical wear during frequent on and off switching;
- small erosion;
- high arc resistance (melting point);
- high current and voltage required for arcing;
- ease of processing and low cost.

It is almost impossible to find a material that would satisfy all these contradictory requirements. The following materials can satisfy the conditions [2]: copper, silver, aluminum, platinum, gold, molybdenum, tungsten and tungsten alloys.

Microwelding technology is aimed at studying characteristics of intermetallic compounds. It is mainly a comparison of gold and copper contacts. The articles [3,4,5] describe the feasibility of bonding copper compounds on gold contact pads and the characteristics of intermetallic bonding. These articles describe testing of pull-off force bonding of wire copper galvanic gold coating made with "wedge" type connection. Using silver and copper contacts while achieving high-quality bonding characteristics can reduce the cost of the assembly process [6,7].

Although wafer-level packaging [8], tape automated bonding and flip chip technologies are also widely used, wire bonding is the most common IC (integrated circuit) packaging technology in the industry [8,9]. Because of its flexibility and low cost wire bonding dominates over 90% of the IC packaging market. [10–14].

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2. TECHNOLOGY OF WIRE BONDING AND PULL-OFF/SHEAR FORCE TESTING METHODS

To study the strength characteristics, the technology of ultrasonic ball-wedge microwelding and Bond Stitch On Ball (BSOB) were used. Ultrasonic microwelding is a type of deformation microwelding where a wire is softened under the influence of ultrasonic energy and pressing force and is deformed at a contact pad. The BSOB technology is the formation of a bump (ball) on a contact pad surface and using wedge-wedge microwelding for contact fixation. The formation of wire bonding was carried out on a semi-automatic microwelding unit TPT HB-16. In the study we used gold, silver, aluminum and copper wires as well as silver and gold contact pads made by immersion and galvanic deposition methods.

To analyze the pull-off/shear force we used DAGE 4000 Plus in accordance with the MIL-STD 883 2019.9, MIL-STD 883 2011.9 standard [15].

During the pull-off test the hook is delivered to wiring connection parallel to the bond plane, and then it is lifted in a vertical upward direction at a controlled speed. The pull-off force is controlled by strain gage transducer which signal is processed by the controller and displayed on a monitor in digitized and graphic form.

3. RESULTS AND DISCUSSION

The study of the qualitative characteristics of materials connection was accomplished with three materials of wire connections — Ag, Au and Cu — bonding with the equal parameters on contact pads with different coatings: immersion gold, galvanic gold, galvanic silver. Table 1 shows the values of impacts for the materials used in accordance with the standard [15]. Table 2 shows the parameters of the wires with the minimum test indicators.

Table 1. Threshold value of impacts during mechanical testing for wire breakage near the ball and wedge and testing for shear of the ball.

Wire material	Pull-off/shear force, g	
	Pull-off test	Shear test
Gold	3 ± 0.15	9 ± 0.2
Copper	3 ± 0.2	9 ± 0.2
Silver	3.5 ± 0.2	10.5 ± 0.25

During the study a standard loop of the "ball-wedge" type was formed. Testing of the results of the microwelding technological process was executed by two methods of mechanical testing, in accordance with the MIL-STD-883H standard [15], "Shear test" and "Pull-off test". The results of mechanical testing are presented in Table 3.

Table 3 and Table 4 present the average numerical values generated from the test scores of a series of wire connections for each type of material.

The results analysis of silver contacts mechanical tests has shown satisfactory outcomes for the wire pull-off test alongside the first microwelding spot and for the first and second bumps shear; however, there were also unsatisfactory results for the pull-off test alongside the second microwelding spot on every circuit board caused by contact pad material defects. Analyzing the second microwelding spot the sulfites were found due to the silver specific properties; therefore, it is required to encapsulate products with such wire material as soon as possible.

According to the results of wire connections mechanical tests and the implementing the technological process of forming a wire connection, several conclusions can be drawn:

- There is no adhesion between gold wire contact and galvanic silver. The implementation of this connection type in the microassembly process is impossible. According to the results of mechanical testing, it was possible

Table 2. Characteristics of wire materials.

Wire material	Wire diameter, μm	Wire composition,%	The minimum value of the force on separation, g		Manufacturer
			Pull-off testing	Shear testing	
Gold	25	99.9 Au, 0.1 Si	3.5	10.5	Tanaka
Copper	18	99 Cu, 1 Pd	3	9	Tatsuta
Silver	20	97 Ag, 3 Pd	3	9	Nippon

Table 3. Numerical indicators of microwelded joints mechanical testing.

Wire material	Detachment near the ball, im. gold, g	Gap near the ball, gal. gold, g	Detachment near the wedge, im. gold, g	Separation near the wedge, gal. gold, g	Ball shift, im. gold, g	Ball shear, gal. gold, g	Ball shift, gal. silver, g	Separation near the wedge, gal. silver, g
Gold	7.5914	6.761	6.224	6.843	39.819	54.218	no contact	no contact
Silver	8.891	6.453	7.214	3.517	18.985	19.661	10.320	2.754
Copper	17.12	5.342	6.513	no contact	17.12	16.405	18.208	1.305

Table 4. The numeric results of mechanical testing of silver contacts welded on boards with immersion gold, galvanic gold and silver coatings.

Type of testing	Contact pad coating type and microwelding method			
	immersion gold, BSOB, g	galvanic gold, BSOB, g	galvanic gold, ball – wedge, g	galvanic silver, BSOB, g
Pull-off test near the ball	8.891	6.453	9.028	7.214
Pull-off test near the wedge	3.659	3.517	5.677	2.754
Ball shear test	18.985	19.661	25.518	no contact
Bump shift test	23.276	28.579	37.252	no contact

to obtain high adhesion properties during microwelding on galvanic gold.

- Copper wire contacts do not form a strong connection at the second point of the wire connection with galvanic gold. However, they have high microwelding strength on galvanic silver and immersion gold (17.12 g at the first connection point of copper and 6.513 g at the second connection point of copper with immersion gold; 18.208 g at the first connection point and 1.302 g at the second connection point with galvanic silver). When forming copper contacts, it was not possible to obtain stable microwelding process, which significantly increases the consumption of resources for the implementation of technological operation.
- Silver contacts possess weak adhesion at the second point of microwelding on galvanic coatings (3.715 g and 2.754 g). However, during microwelding on immersion coatings, the stable process was observed throughout the formation of a series of wire connections.

4. CONCLUSION

Depending on the method of applying contact pads, several parameters can be distinguished that affect the quality of the device design strength characteristics: the thickness of the contact pads layer, the presence of impurity elements. The material of wire connection and the presence of impurities also affect the adhesive properties of connections.

The obtained results can be used to modernize the technological processes of optoelectronic devices assembly operations, depending on the used materials properties.

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Анализ усилия отрыва/сдвига при соединении проводов для различных материалов проводов и контактных площадок

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Аннотация. В статье исследуются проволочные контакты из различных материалов (Ag, Au, Cu) и способы сварки контактных площадок с различными покрытиями - иммерсионным золотом, гальваническим золотом, гальваническим серебром. Мы представляем результаты испытаний соединения на отрыв/сдвиг и сравниваем результаты различных технологических операций проволочных контактов.

Ключевые слова: микросварка; гальваническое покрытие; иммерсионное покрытие; проволочный контакт