**Practical experience of F&S Bondtec equipment application in the precision electronic devises production**

Morion, Inc. is a leading Russian Company and one of the world leaders in the development and serial production of piezoelectronic devices for frequency stabilization and selection, i.e. crystal oscillators, filters and resonators meant for telecommunication, control, navigation aids and systems, instrumentation, digital TV of both general and space purpose.

Today's Morion Inc. is fitted with modern high-performance and high precision equipment by the leading world manufacturers, and uses the advanced world level technologies.

**Introduction**

A few years ago the Company set the goal to master and launch a serial production of a principally new type of products – a surface mounted miniature precision crystal oven-controlled oscillator.

It was agreed that the product would be manufactured to a combined technology: control microchip's crystal mashing on the base plate followed with sealing thereof and installation of surface mounted items.

The Requirements Specification of the designed oscillator was worded as follows:

1. Serials overall dimensions: 7x5 mm or 5x3 mm;
2. Substrate contact pads coating – 3-5 μm immersion gold;
3. Crystal contact pads 80x80 μm;
4. Pitch of bond ~150 μm;
5. Loop height 100-150 μm;
6. Wire bond maximum length 300 μm;
7. Oscillator bodies are located on a replicated blank of 70x80 mm;
8. Serials output - 6000 pcs a month.

In developing the product, it became evident that crystal mashing on the substrate's contact pads is one of the main critical operations responsible for the product's correct functioning. Morion employees have never used this technology before. Another objective was to produce several main types of serials, as well as to simultaneously develop and manufacture laboratory and preproduction prototypes. The said tasks require a semi-automatic bonding system capable of both producing serials and flexibly correcting the pre-production prototypes process parameters.

Based on the set objectives, it was decided to study the ball-wedge thermosonic bonding with golden wires used by more than 90% of production facilities when making wire bonds for microelectronic products. The said technology combines the ultrasonic and temperature-compensated bonding and includes all advantages of both technologies. Use of golden wire and immersion gold coated contact surfaces provides for most reliable bonding; these bonds are not subject to corrosion, they don't form an inter-metal layer or other conditions for degradation.

Table 1 gives the ball-wedge type technology's advantages and disadvantages. [1]

Table 1. Pluses and minuses of the ball-wedge thermosonic bonding technology

| Pluses | Minuses |
|---|---|
| Process average temperature (~150°C) | Sensitive to contact surface contamination |
| Low US-energy | Possible cavities during bonding |
| It is possible to form a loop in any direction (direct and reverse) | Monitoring of only 4 main parameters of the bonder |
| Full cycle of loop formation takes no more than 20 ms | Large contact pads (~50 μm) and a long pitch of bond (~100 μm) |
| Highly reliable Au-Au bonds | Relatively high consumption of bonding wire |

**Equipment selection**

After thoroughly examining the technology, significant work had been done to search for process equipment that meets all needs of the average-scale and pilot production at the same time. On the one hand, stable operation to the smooth process was required for the serials, on the other hand, the task was to flexibly change the bonding parameters and assess quality of the obtained bonds. To that end, the marketed bonders and bond testers of different manufacturers were studied. In most cases these were two separate units of equipment of almost the same price. However, modern hi-tech equipment should meet the "micro-factory" or "table-factory" concept, permitting to combine several functional capacities in one and the same device.

Our foreign partner's advice was to take note of F&S Bondtec equipment, which bonders are fitted with quick-release bondheads and allow microwire bonding, checking fastening of a crystal for shifting, and evaluating bonds strength. Once the manufacturer's approvals and advices were obtained, it was decided to form our "micro-factory" based on series 56xx platform. Removable bondhead 5610, enabling bonding with golden wire 17-50 μm in diameter (0.7- 2 mil) to the standard ball-wedge method, was chosen as the base system. This bondhead also enabling such bonding modes as *bump* or *bumping, wire with safebump, and snitch on bump*. At the same time, if there is a need to use other bonding methods like wedge-wedge, deep access, heavy-wire or heavy-ribbon, just one of separately supplied bondheads will be required without a need to change the whole bonder.

To test the obtained bonds and crystal fastening quality, an automatic bond tester easily mounted to the main bondhead's seat was purchased. It allows using one of the removable test cartridges, enabling three main (destructive or non-destructive) tests– pull-test, shear-test and tweezer-test.

So, the final base system was as follows (Table 2)

Table 2. Selected equipment

| Unit description | Main parameters |
|---|---|
| Semi-automatic base platform of 56xx series | Working zone and accuracy of movement along X, Y, and Z axes: 100 × 100 × 60 mm; pitch 0.25 μm every 2 μm.<br>Axes velocity: configurable from 0.2 to 16 mm/s<br>Bonding speed: up to 30 loops/min. |
| Substrate heater | Configurable temperature range up to +300° C |
| Bondhead 5610 | Wire type: 17-50 μm (0.7-2 mil), Au<br>Tool: standard capillary 16 mm<br>Bonding strength: 0-300 cN with 1 cN pitch<br>Bonding modes: wedge-ball standard bonding, Bump (Bumping), Wire with Safebump or Stitch on Bump |
| Test head 5600C | Destructive and non-destructive test of bond mechanical strength |
| Pull-head cartridge PH100 for test head 5600C | Test strength range: up to 100 cN, 0.006 cN pitch |
| Sear-head cartridge SH500 for test head 5600C | Test strength range: up to 500 cN, 0.01 cN pitch |

Figure 1. Automatic bonder 5610 based on base platform of 56xx series with fast-release bondtester 5600C

**Pre-bonding operations**

To ensure bonds compliance with the set parameters, extensive studies are required. In fact, three interrelated lines can be specified:

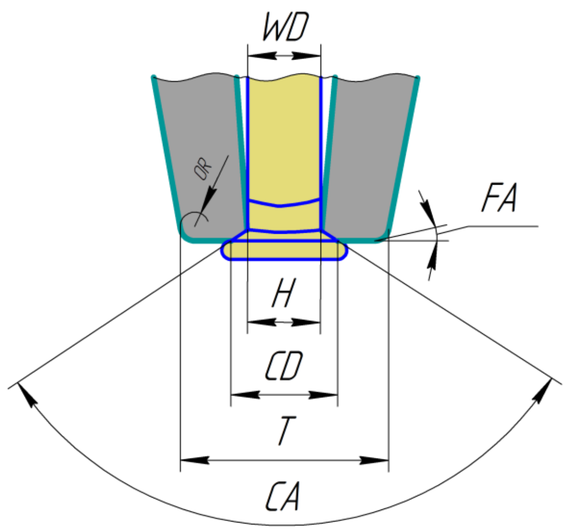
1. Analysis of equipment application field (technical parameters of device, bonding wire, and tools);
2. Analysis of equipment parameters (movement velocity, wire clamp activation, movement distance, loop shape);

3. Analysis of process parameters (clamping strength, bonding process length, ultrasonic energy).

Bondhead 5610 uses a standard 16 mm ceramic capillary, permitting choosing tools for almost any task.

With the standard ball-wedge bonding, there are only two bonding points: «ball bond» (or ball) and «stitch bond» (or wedge). Let's consider each point regarding the tool, starting from forming a ball type bond:

1. Hole Size *H* is chosen based on used wire diameter *WD*. As a rule, *H* equals to 1.2x – 1.5x of *WD*. [2]




| **Wire diameter (*WD*), µm** | **Hole diameter (*H*), µm** |
|---|---|
| 15 | 18 - 21 |
| 18 | 21 - 25 |
| 20 | 25 - 28 |
| 23 | 28 - 30 |
| 25 | 33 - 38 |
| 28 | 35 - 38 |
| 30 | 38 - 41 |
| 33 | 43 - 46 |
| 38 | 51 - 56 |

Figure 2.
Standard wire diameter-to-hole diameter dependence

2. *Chamfer angle CA* provides for a bonding area when forming *a mashed ball diameter (MBD*) on the contact pad. *CA* value also affects *Free Air Ball (FAB) size* , obtained at *Electric Flame-Off (EFO)* – first stage of the ball-wedge bond formation. Standard CA makes 90°. Practice has shown

that CA increased to 120° enables a 1.5 time increased mashed ball diameter (MBD) and, accordingly, the bond strength, if permitted so by the contact pad size [3].

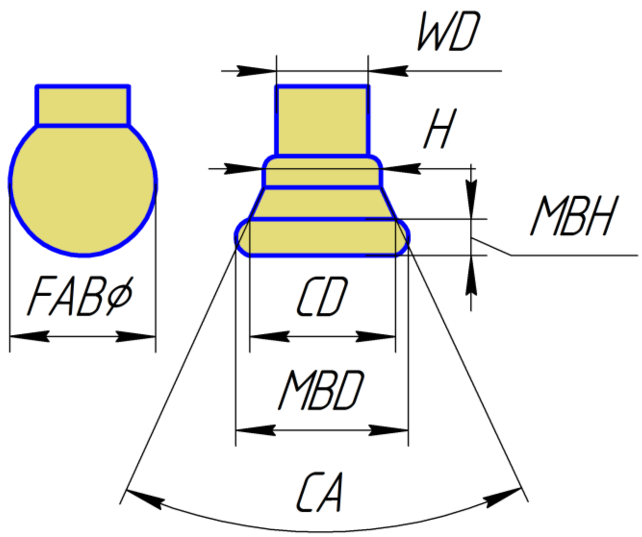



Figure 3. Mashed ball main parameters

It is important to monitor formation of symmetric free ball FAB and mashed ball MBD as the bonding repeatability and reliability depend on it. Any deformed balls shall result in a "tail" elongation to form a free ball, decreased clearance between the sparking device's electrode *(EFO)* and the formed "tail", exclusion of the bonder or capillary movement in the course of bond making [8].

Hence, the properly chosen tool (capillary) is an optimum combination of a capillary internal diameter, wire diameter, chamfer angle, and required mashed ball diameter and height.

Many people think that the bond's second point, i.e. "wedge", is the ball-wedge bonding method main disadvantage [1; 3; 4]. However, the wedge formation process main parameters exist, which records will successfully compensate for the said disadvantage:

1. Work tool's t*ip diameter T* determines a "stitch" length SL. A stitch size for non-protected crystals within a contact pad shall exceed ¾ of this contact pad area and at the same time occupy more than ¾ of the tool footprint area [5].

2. Tool face angle *FA* provides for a required bond thickness, while the interrelated outer radius OR will permit finding a required bond smoothness. The higher is FA, the lower is OR and otherwise. As a rule, FA makes 8° for small pitches and 11° for very small pitches [2].

3. Tool inner chamfer *IC* after a bond has been formed will ensure a tail of a required length to form the next free ball (*FAB*). Stable parameters of the tail formation are important for the bonding process quality and repeatability [7].

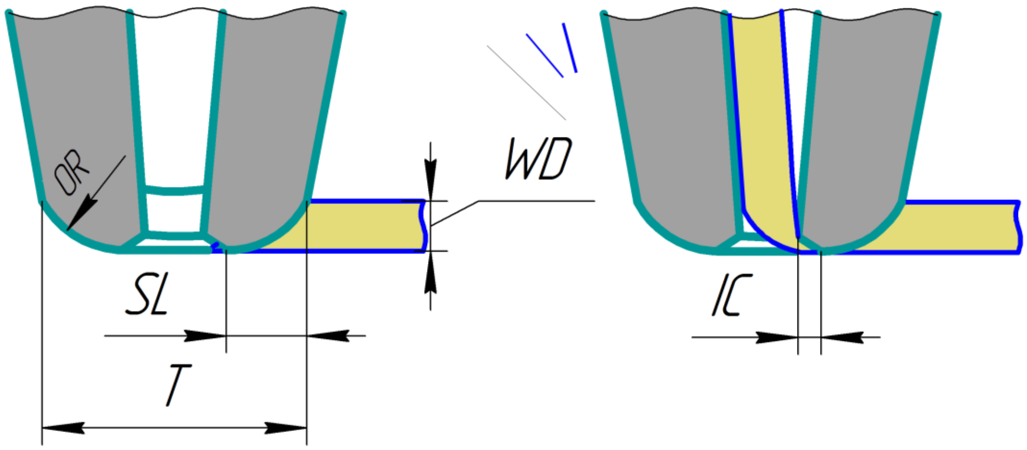


Figure 4. Wedge formation parameters

In this case, a properly selected tool (capillary) means the correctly combined outer radius of the hole and total diameter thereof at a set face angle of the tool.

Pre-start operations on the bonder include writing of the work software followed with further process optimization. There are four parameters directly influencing on quality and strength of the ball-wedge bond: ultrasonic energy power, ultrasound application time, clamping force at ultrasonic energy supply, and substrate temperature.

The bonder under consideration allows using four configurable bonding modes:

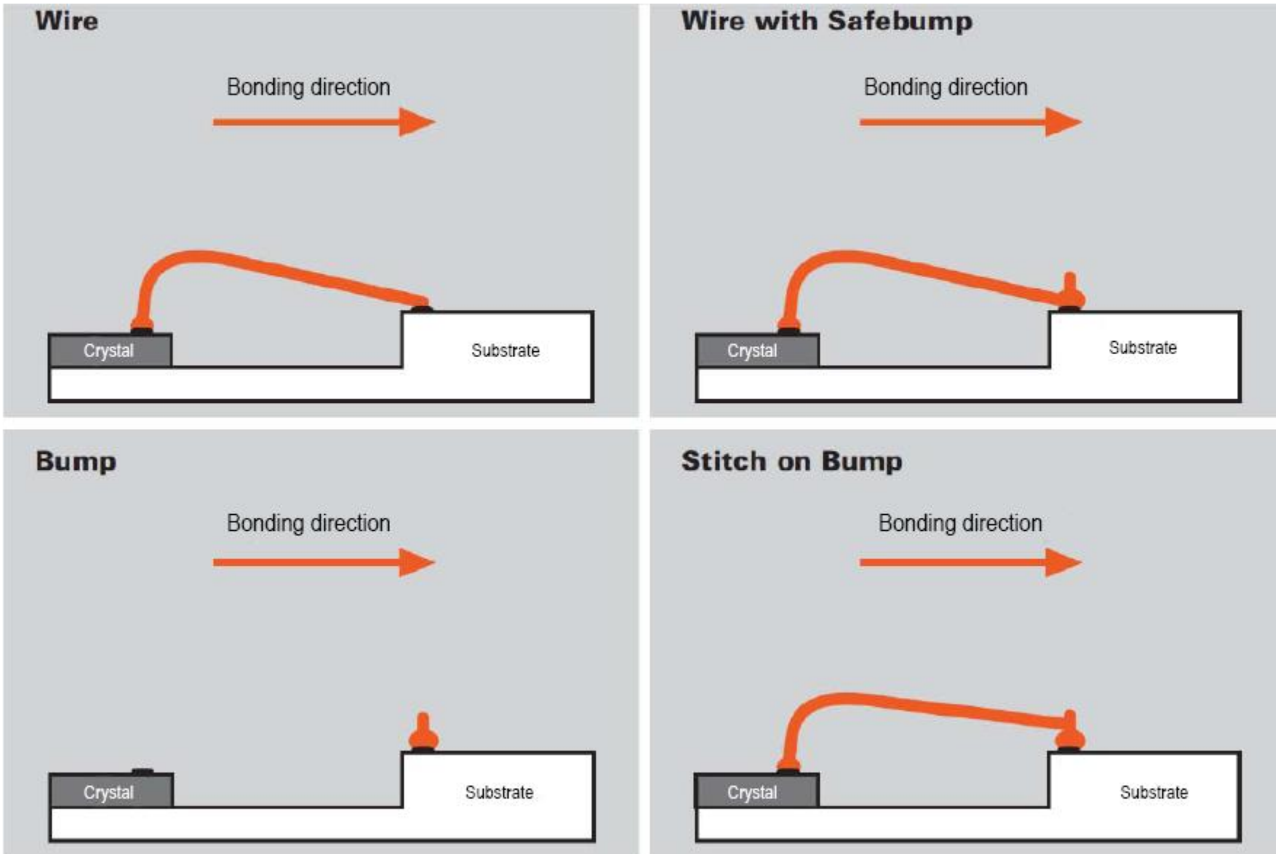



Figure 5. Process of different bonds formation

*«Wire»* mode is the standard ball-wedge bonding method. As mentioned above, the second point of this bond has kept process engineers worrying for many years, especially at the development and manufacture of products with high requirements to reliability. However, there are several manufacturer provided methods to effectively increase strength of a standard ball-wedge bond that will be discussed below.

*The «Wire with Safebump» or «Security Bump»* mode is divided into two stages. In forming a bond, an additional "security ball" is bonded on the obtained wedge. This bond strength increases, however, there is no final homogeneous bond and there are possible problems at the boundary of the ball-wedge-substrate contact (Fig. 6). [6]

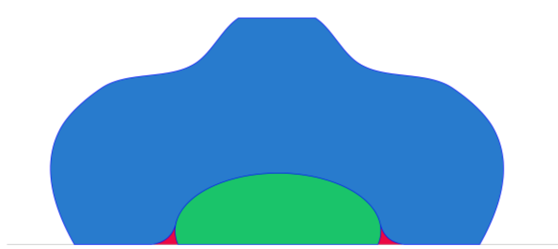


Figure 6. Layout view of «*Security Bump*» bond. Potentially problematic zone is given in red.

Non-standard, however, no less effective method «*Safe Wire*» or «*Security Wire*» can be used with sufficiently large contact pads. At that, an additional loop smaller in size, which provides for higher reliability, is made on the formed bond (Fig. 7). [9]

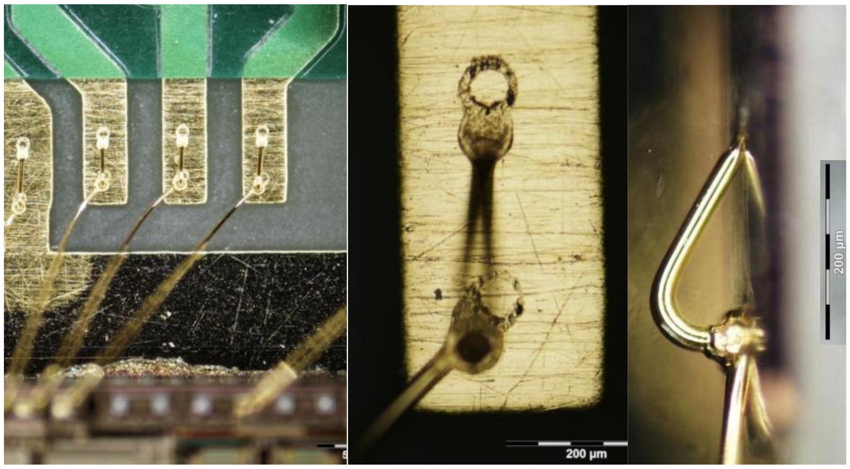



Figure 7. «*Safe Wire*» mashing

The *«Stich on Bump»* bonding (also called «*Ball Stitch On Ball*» (BSOB), «Stand-Off Stich» (SOS), or «Reserve Bonding») divides the process into two stages: a series of separate balls is formed first, then standard bonding is performed by the bonder, through which the second point of the wedge is bonded on the earlier formed ball. This method unlike the «*Wire with Safebump*» brings better results in case a homogenous bond is formed [6]. This mode optimization requires selection of a tool (capillary) with a face angle FA of 8°; this will ensure better contact with the ball at the wedge formation thereon [2].

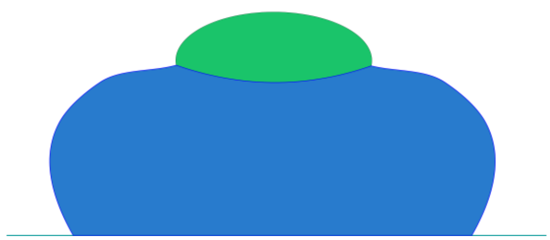


Figure 8. Layout view of *«Stitch on Bump» bond*

This mode is meant for solving the following tasks [2; 6]:

- Formation of less than 50 μm high low-profile wire bond;
- Formation of a delicate crystal bond that may by damaged when a wedge type bond is used;
- Improvement of wire contact on poorly soldered materials or contact pads. First, the contact area of a ball with a problematic contact pad will be larger; second, the bonding parameters for this ball can be corrected causing better adhesion. It will not be difficult to fix the wedge on the earlier formed ball;
- Formation of a bond on a relatively small contact pad or on a contact pad close to a physical obstacle.

**Bonding process**

Once the new work software is prepared, required materials and tools are selected, a process engineer should refine the bonding process. As the equipment enables adjustment of multiple parameters, the *Monitoring Mode* is a very useful tool. This option moves the system to the step-by-step mode enabling visual monitoring of the bonding process. A few series of test bonding allow quick enough process refining, accurate localization of errors made in the software, and efficient correction thereof.

Concerning the automatic bonding, the operator here is not “a biobot” also, who presses the needed buttons at the needed time. Software F&S Bondtec has special *DLC (Deformation Limit Control)* module responsible for displaying visual data about the bonding process in the bonding software base window. Without any special additional training the operator monitors each bond deformation degree in the real-time mode, thus evaluating quality of the bond and monitoring correct functioning of the equipment.

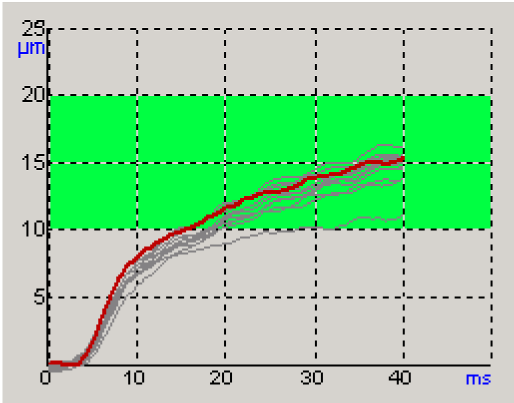



Figure 9. DLC-module window

Main functions of DLC module:

- Wire deformation monitoring for the start and end wire bonds;
- Process window limits setting;
- Automatic stop of the equipment when any parameter is beyond the preset limits;
- Operator’s visual process monitoring;
- Monitoring of the whole series of mashed wires (Fig.9 shows deformation of a current wire in red);
- Wire condition monitoring (loss, break, etc.).

*DLC Analysis* module allows to save and scroll through the deformation and bonding parameters data. If necessary, this information can be processed off-line and stored to confirm quality of the bonding process.

**Readjustment**

Readjustment is not uncommon in working with laboratory and small batch products. The main operations described below do not require any personnel of special qualification:

1. Wire reel replacement. A major difficulty of this operation is a need to pass wire through the guides using microtweezers, clamp and work tool. The *Feed-in Air* function that activates supply of purified compressed air to the wire guide channel facilitates the said task.

2. Work tool (capillary) replacement or substitution. The work tool is fixed on the waveguide by means of a copper screw, using tweezers and torque screwdriver, coming with the module.

Frequent **contamination of the work tool** (capillary) is one of most ugly problems related to frequent readjustments and production of a wide range of small batch products. As long as the optimum parameters have not been determined yet and the optimization process is in progress, a situation when the ball plugs the capillary hole once the free ball (FAB) is formed and the test bonding is carried out, is inevitable.

We first attempted for several times to use the manufacturer's recommended method of cleaning the hole with aqua regia. Before doing this, we had to stop the system, remove the plugged tool, go to our Company's chemical laboratory, and chemically clean the tool. Given that we use tools, which inner diameter does not exceed 33 μm, this method proved ineffective.

A more convenient way to combat this problem was found later on – a *Capillary Unplugging Tool*. *CUT* is a strong hair, which diameter corresponds to that of the used wire or calculated to the wire diameter-tool diameter relationship formula. In this case, it is not necessary to remove the tool from the bondhead. Using the tweezers, take wire out of the channel, then remove remaining wire, contaminations or a ball that plugged the channel using CUT as a gunstick.

**Check operations**

Once the bonds are formed, quality thereof can be evaluated visually or mechanically. Due to a standard optical microscope and mobile work table, automatic tester 5600C will enable optical check and a series of mechanical tests without leaving the workplace.

Stationary bond strength testers, which price is comparable to that of the bonding equipment, in average stand idle for more than 90-95% of the operation time. It takes 1-2 minutes only for the multifunctional equipment F&S Bondtec to transform a bonder into an automatic bond tester. 56xx series base platform with all-purpose bondhead holders enables replacement thereof without use of any special tools.

Standard holders can be installed on the system's body aimed at temporary storage of the main/additional bond- or test heads (Fig.1). To avoid any occasional damage to the heads and components thereof, it is strictly recommended to use the said holders for temporary storage only, for instance, when turning bonders into testers. "Shock-cases" with antistatic sealants are more suitable for the purpose of continuous storage.

A test head is also a multi-functional platform for holding the needed test cartridges fixed thereon with a female ring. Once a cartridge is installed, the system will automatically identify its type and offer to have a series of calibration operations.

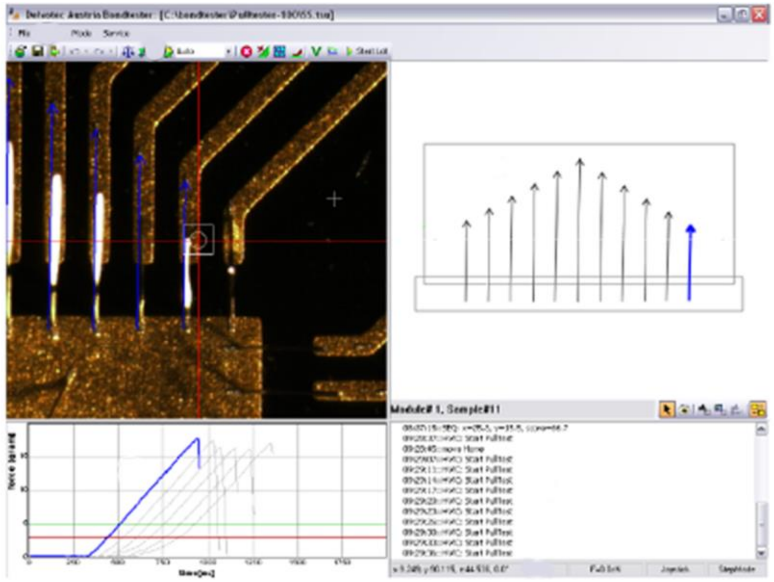
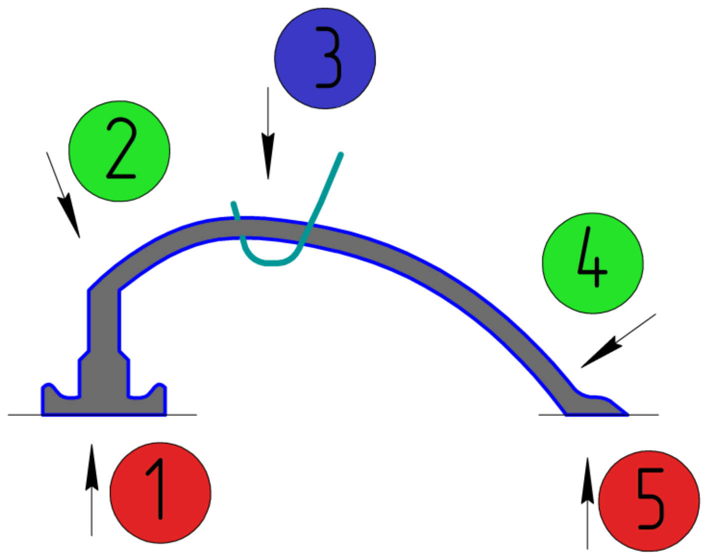


Figure 10. Automatic tester window

This tester enables three main modes of operation: manual, semi-automatic, and automatic. In the manual mode the operator can influence measurements results by shifting the point of hook-to-loop application, for instance, thus changing a force applied to the bond. The software allows translation of the bonding work program, containing bond points coordinates, loop shape and height, and also fixed points, to the environment for the test programs development. The hook application point like the test tool paths will be calculated automatically. The process engineer only needs to formulate parameters and choose a needed test. In other words, after a series of test bonding, you immediately get a semi-finished product for test software development, which is significantly time-saving.

The tests we carry out comply with the methods described in MIL-STD-833. At that, several conditions shall be met: first, all tests shall be automatic to enable correct application of forces during testing; second, the chosen tools shall match the used wire and be calibrated.

Wire break point is most important during the tests: the optimum break points are as follows – neck (2) or heel (4) of the bond (Fig. 11). In this case we can speak about the correctly chosen tools, materials, and process.




| Destruction mode | |
|---|---|
| **1** | Bonded ball break |
| **2** | Neck break first bond |
| **3** | Wire break |
| **4** | Heel break second bond |
| **5** | Bonded wedge break |

Figure 11. Wire break points at pull-test to MIL-STD-833

Regarding point 3 break, analysis and selection of a test tool (hook) is recommended.

Regarding point 1 break, take note of such bonder's settings as power and clamping force. Attention shall also be paid to contact pads cleanness that may require an additional cleaning or surface activation operation.

Regarding point 5 break, turn attention to such work tool parameters as diameter (T) and face angle (FA). If the required work tool is not available, use the «*Wire with Safebum» or «Safe Wire*» bonding modes.

Wire fragility in point 2 break area is due to a free ball (FAB) formation at sparking (EFO). This area *HAZ (Heat Affected Zone*) is formed owing to a thermal effect, causing grains in the material to grow, thus reducing strength thereof by more than 20% relative to that of the remaining wire. HAZ is the weakest part of a mashed loop, even with the properly selected process, this zone is threatened by the risk of break to the utmost [1].

To compensate for consequences of this problem, reduce a time of exposure to the sparking device module (EFO) in the process of an air ball formation (FAB).

In order to strengthen the point 4 bond, it is necessary to change the standard bonding method to the «*Stich on Bump*» or «*Reserve Bonding*». Based on our experience, this is the only true way.

The automatic tester enables 100% non-destructive inspection of mashed bonds prior to sealing. However, keep in mind that the shear test is not harmful to a bond, while the pull-test deforms loops and remaining bond strength makes 60-70% of the initial value [4].

**Conclusion**

F&S Bondtec equipment is a multi-purpose platform to form a process corresponding to a set production task that allows using the widest range of standard process tools and materials for various tasks. It actually takes several minutes to turn this bonder into a tester, so that the product's process can be quickly optimized.

Specialists of Morion, Inc. have quickly mastered F&S Bondtec equipment and set up the serial production of a new type product with the operating frequency range from 5 to 52 MHz and temperature stability of up to $0.1x10^{-6}$. This product has been certified and complies with the requirements of STRATUM III, COSPAS/Sarsat.


Figure 12. Miniature precision temperature-controlled crystal oscillator manufactured by Morion, Inc. with use of F&S Bondtec equipment

The full catalogue of our products is available at: http://www.morion.com.ru

**Bibliography**

[1] George Harman «Wire Bonding in microelectronics», third edition, 2010

[2] «Bonding Capillaries. Bonding Evolution», SPT processing guide, 2013

[3] M. Shmakov, V.Parshin, Y.Teplyakova "Technology of thermosonic microbonding by the ball-wedge-ball method and microbonds monitoring" , TvEP №7 2007

[4] Siegfried Seidl, Josef Sedlmair, S. Valev « F&K Delvotec automatic head for bond testing: a step towards fault-free production », TvEP №1 2010

[5] OST 11073.013-83 Integrated circuits. Test methods. Part 4. (Visual inspection methods).

[6] David J Rasmussen, Rodney Thompson «Improved Bond reliability through the use of Auxiliary Wires (Security Bumps and Stand-Off Stitch)», 2010

[7] Jaesik Lee «Process Quality Improvement in Thermosonic Wire Bonding», University of Waterloo, Canada, 2008

[8] J. Gomes, M. Mayer, B. Lin «Development of a Fast Method for Optimization of Au Ball Bond Process», University of Waterloo, Canada, 2014

[9] Zsolt Illyefalvi-Vitéz «Application of Safety Bonding Methods to Gold Wire Bonding to Improve Yield and Reliability», Budapest University of Technology and Economics Electronics Technology Department, 2012