Thermosonic Wire Bonding

General Guidelines

Application Note – AN1002

1. Introduction

1.1. Wire Bonding Methods

Wire bonding is a solid state welding process, where two metallic materials are in intimate contact, and the rate of metallic interdiffusion is a function of temperature, force, ultrasonic power, and time. **There are three wire bonding technologies:** thermocompression bonding, thermosonic bonding, and ultrasonic bonding.

Thermocompression bonding is performed using heat and force to deform the wire and make bonds. The main process parameters are temperature, bonding force, and time. The diffusion reactions progress exponentially with temperature. So, small increases in temperature can improve bond process significantly. In general, thermocompression bonding requires high temperature (normally above 300°C), high force, and long bonding time for adequate bonding. The high temperature and force can damage some sensitive dies. In addition, this process is very sensitive to bonding surface contaminants. Thermocompression is, therefore, seldom used now in optoelectronic and IC applications.

Thermosonic bonding is performed using a heat, force, and ultrasonic power to bond a gold (Au) wire to either an Au or an aluminum (Al) surface on a substrate. Heat is applied by placing the package on a heated stage. Some bonders also have heated tool, which can improve the wire bonding performance. Force is applied by pressing the bonding tool into the wire to force it in contact with the substrate surface. Ultrasonic energy is applied by vibrating the bonding tool while it is in contact with the wire. Thermosonic process is typically used for Au wire/ribbon.

Ultrasonic bonding is done at room temperature and performed by a combination of force and ultrasonic power. The pressure used in ultrasonic bonding and thermosonic bonding is much lower, and welding time is shorter than for thermocompression bonding. Though Au wires to Au pads bonds can be made by ultrasonic bonding, ultrasonic bonding is primarily used for Al wires on either Au or Al pads, and has been the dominant technique for large-diameter Al wire in power electronics device applications. The comparisons of these three wire bonding technologies are shown in Table 1.

Table 1. Wire Bonding Technologies

Wire Bonding	**Thermocompression**	**Thermosonic**	**Ultrasonic**
Ultrasonic Power[1]	No	Yes	Yes
Bonding Force	High (15-25g)	Low (0.5-2.5g)	Low (0.5-2.5g)
Temperature	High (300~500°C)	Middle (120~240°C)	Low (room temperature)
Bonding Time	Long	Short	Short
Wire Material	Au	Au	Au, Al
Pad Material	Au, Al	Au, Al	Au, Al
Sensitivity to surface Contamination	High	Medium	Medium
Application (Ball/Wedge)	Wedge	Ball and Wedge	Wedge

1) Setting the proper power is essential for the thermosonic and ultrasonic bonding techniques. To ensure quality bonds, increase the power setting without exerting or over-stressing the wire. Over-stressing is taking place when the pull testing device indicates a low break (see Fig.2).

1.2. Ball Bonding vs. Wedge Bonding

There are two types of wire bonds: ball bonding and wedge bonding (see Fig.1). Ball bonding is much faster than wedge bonding. Ball bonding requires only three axes of movement (X,Y,Z) while wedge bonding requires four axes of movement (X,Y,Z,θ). In ball bonding, only gold (Au) wire can be used while gold and aluminum (Al) wires are used commonly in wedge bonding. This is because Al wire will oxidize during the electronic flame off (EFO) process to form the ball. The comparisons of ball bonding and wedge bonding are shown in Table 2. Though wedge bonding is slower than ball bonding, wedge bonding offers many benefits, for example, deep access, fine pitch, and low and short loops. That is why wedge bonding has been used extensively in microwave and optoelectronics applications.

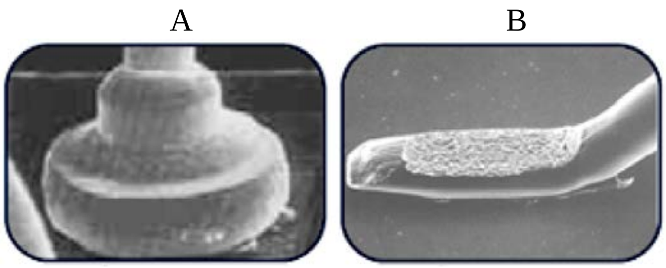


Figure 1. (A) Ball bonding, (B) Wedge bonding

Table 2. Comparison of Ball Bonding and Wedge Bonding

Applications	Ball Bonding	Wedge Bonding
Bonding Techniques	Thermocompression (T/C) Thermosonic (T/S)	Thermosonic (T/S) Ultrasonic (U/S)
Temperature	T/C: 300°C T/S: 120°C to 240°C	Al wire—U/S at room temperature; Au wire—T/S 120°C to 240°C.
Wire Size	Small (< 75µm)	Any size wire or ribbon
Pad Size	Large (3 ~ 5 times of wire diameter)	Smaller pad size than a ball bond. Good for the optoelectronic and microwave application. The pad size = 2-3 times of wire diameter
Pad Material	Au, Al	Au, Al
Wire Material	Au	Au, Al
Speed	Fast (typically: 10 wires/sec)	Relatively slow (typically: 4 wires/sec)

1.3. Variables that Affect the Wire Wedge Bonding Process

1.3.1. Effect of Bonding Tool and Wedge

Wedge material is typically Titanium Carbide or Ceramics for gold wires or ribbons. A titanium carbide wedge is cheaper and easier to manufacture than a ceramics wedge. For aluminum wires, Cemented Tungsten Carbide is commonly used as wedge material. Cemented Tungsten Carbide wedge can easily be contaminated with gold, causing excessive tool degradation. Thus, cemented tungsten carbide wedge is not good for Au wires.

In ultrasonic bonding and thermosonic bonding, it is important for the wedge to transmit the ultrasonic power to the interface between wire and bonding pad. That requires a good wedge foot design. For a gold wire with a diameter larger than 1 mil (25µm), a cross groove on wedge foot is required to achieve a good bond. The extra mechanical 'gripping' action of the cross groove gives the tool/wire interface a higher ultrasonic coupling energy to the bond surface. For an Au wire with a diameter less than 0.8 mil (20µm), a flat face is commonly used. Aluminum wire application commonly requires a concave foot design. The minimum foot size is 1.5-2.5 times the wire diameter.

1.3.2. Effect of Substrate

The key parameters of the bond pad include pad metallization, gold or aluminum metallized surface thickness, and pad cleanliness. The minimum gold thickness requirement for wire/ribbon bonding is 40 microinches or 1µm. A thicker gold layer will have a favorable effect on bondability. It is very important to keep the bond pad free from contamination (organic and inorganic). Contaminations on bond pads will degrade the bondability and reliability of wire bonds. UV Ozone cleaning and plasma cleaning are two methods commonly used to remove organic contaminations.

1.3.3. Effect of Bonding Process Variables

Bonding process variables include ultrasonic power, bonding force, bonding time, and temperature. Design of experiments method is commonly used to determine the proper process settings foe adequate bonding. Finding the optimal bonding settings is not an easy task because there are interactions between process variables. A high quality bond can be characterized as high pull strength (or shear strength in ball bonding) and consistent tail length. Possible failure modes are nonstick, foot-lift, and heel-break. Non-stick means that no bonding was made. Foot-lift means that the whole bond lifts during destructive testing, while heel-break means that the wire broke at heel during a destructive test and the foot of the wire still remains at the bond pad. The heel-break is a preferred failure mode. There is a strong relationship between pull strength and wire deformation as shown in Figure 2.

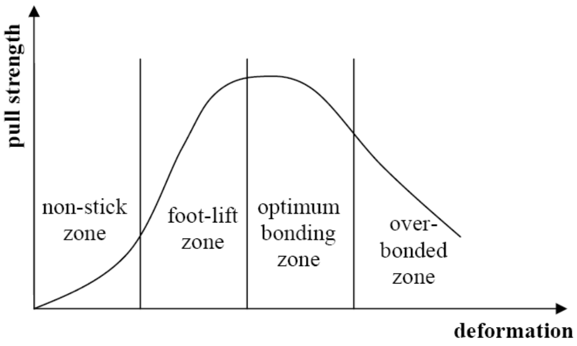


Figure 2. Relationship between Pull Strength and Wire Deformation

1.4. Summary

Thermosonic wedge wire bonding is the most common method used for wire bonding in optoelectronic devices. As indicated above, it is a combination of the thermo-compressive and ultrasonic bonding schemes, where the wire is attached to the metal pad at elevated temperature while vibrating it at an ultrasonic frequency and applying force, pushing it towards the pad's surface.

2. Cosemi’s Wedge Wire Bonding Parameters

Cosemi Technologies conducted a limited study of **thermosonic wedge wire-bonding** in order to better understand the bonding parameters and their effect on the bonding quality. The study was done on Cosemi’s SPD2010-4 dies. This document provides a brief summary of this limited study.

Please note:

a) The bonding conditions below (pad temperature, force, power, time) are not necessarily the most optimal, and they may vary with machine model.
b) Bond Power is the first parameter that needs to be adjusted when any bondability problem is encountered; before the bond force
c) The dies in this study were attached to TO-46 header using conductive silver epoxy (Epotek H2OE/S). Die Attach Curing at 100°C for 30 minutes.

2.1. Experimental Bonding Parameters

	Experiment 1	**Experiment 2**	**Experiment 3**
Bonding Temperature (°C)	140	200	190
Power (W) (1st/2nd bond)	0.30/0.25	0.25/0.20	0.25/0.20
Force (g) (1st/2nd bond)	1.75/2.5	1.25/2.0	1.5/2.5
Bonding Time (msec)	3.0	3.0	3.0

3. Experimental Results

3.1. Experiment 1: Bonding temperature T = 140°C

3.1.1. Parameters:

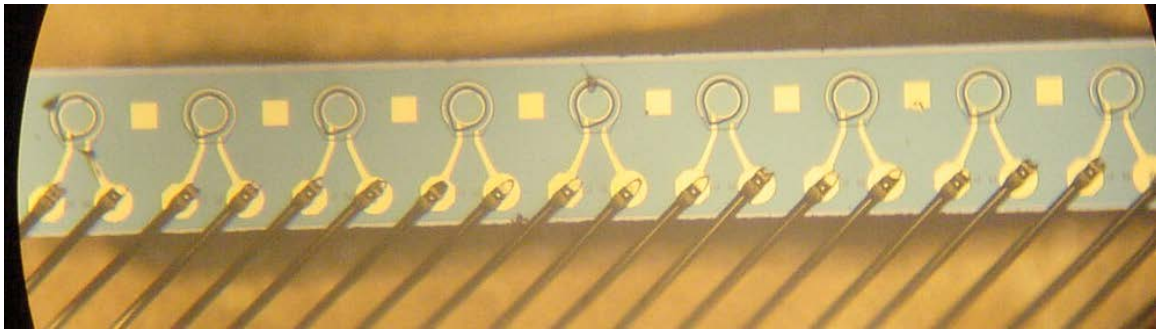
a) Device: SPD2010-12 Rev.A
b) Wire: Au, 1 mil.
c) Power: 1st Bond (header) = **0.3W**. 2nd Bond (die pad) = **0.25W**
d) Force: 1st Bond (header) = **1.75g**. 2nd Bond (die pad) = **2.5g**
e) Bond time: 1st Bond (header) = **3.0 msec**. 2nd Bond (die pad) = **3.0 msec**.
f) Die temperature: **140°C**

3.1.2. Wire-Pull Test Data:

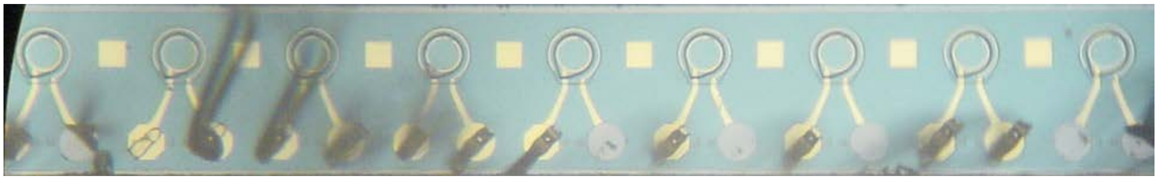
	W# 011			W# 013			W# 015	
	#1	#2		#1	#2		#1	#2
1	6.1	7.2	1	8.4	5.3	1	8.9	5.7
2	6.8	7.0	2	7.4	4.7	2	8.3	6.5
3	6.5	8.3	3	7.4	6.5	3	6.4	7.1
4	6.2	6.5	4	7.3	6.6	4	7.8	5.7
5	6.4	5.5	5	**3.0**	6.1	5	6.2	5.9
6	6.7	6.0	6	6.6	**3.9**	6	**2.3**	6.2
7	**1.9**	6.2	7	7.5	**3.7**	7	5.5	6.7
8	7.2	**1.6**	8	6.9	7.0	8	6.8	6.7
9	6.6	9.4	9	6.7	6.9	9	6.3	6.1
10	6.5	8.8	10	6.4	7.1	10	7.8	5.9
11	7.5	**3.0**	11	5.8	7.6	11	5.5	5.8
12	7.0	8.6	12	7.5	7.2	12	6.8	5.9
13	7.8	**2.5**	13	5.5	**3.1**	13	6.3	6.0
14	8.2	9.2	14	6.6	8.2	14	5.5	6.9
15	7.2	**1.0**	15	5.9	7.2	15	6.0	6.0
16	**2.5**	10.0	16	8.1	7.0	16	5.6	6.5
17	7.9	7.1	17	6.5	6.3	17	5.4	6.8
18	8.3	8.9	18	5.9	**3.0**	18	4.6	6.8
19	7.5	7.9	19	**3.9**	6.3	19	5.2	6.2
20	6.9	6.9	20	7.5	6.5	20	6.3	6.1
21	6.1	5.8	21	5.4	8.0	21	8.0	6.8
22	7.1	7.7	22	6.2	6.5	22	**2.5**	6.4
23	6.3	5.2	23	6.8	6.4	23	7.0	5.4
24	9.4	7.2	24	7.5	5.4	24	6.6	5.1

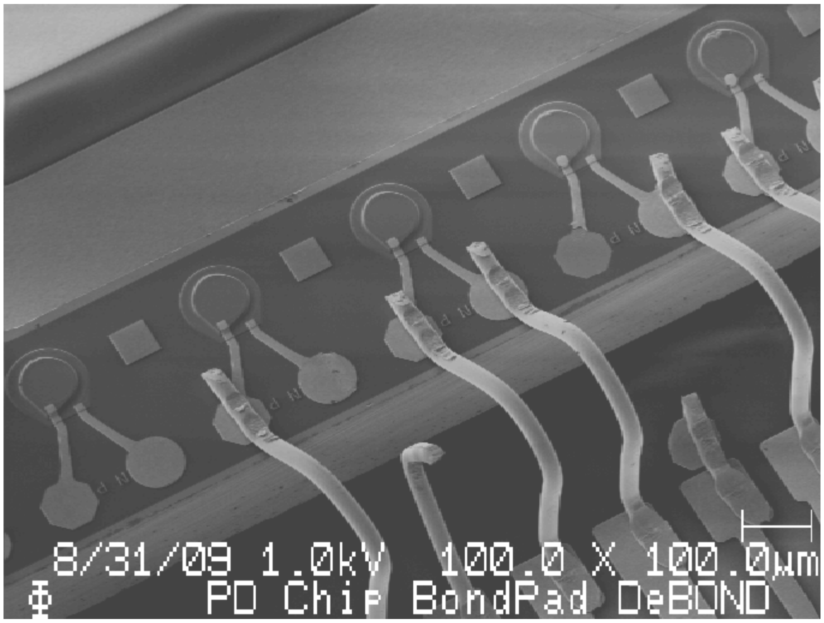
Note: Bond pads lifted during wire-pull test are shown in red, bold font.

3.1.3. Post Wire-Bonding Images:



3.1.4. Post Wire-Pull Test:





Note: The clean bond peeling, revealing smooth pad surface, indicates poor wetting.

3.2. Experiment 2: Bonding temperature T = 200°C

3.2.1. Parameters

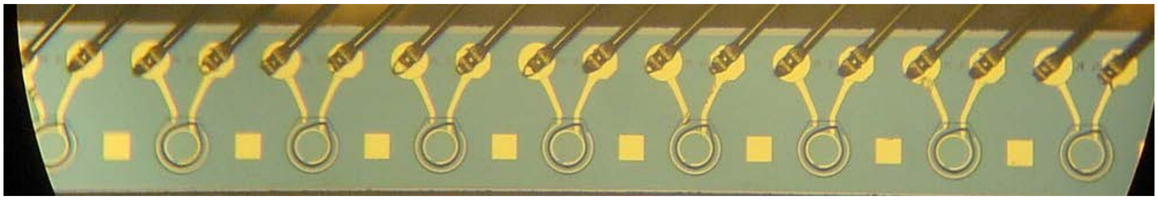
a) Device: SPD2010-12 Rev.A
b) Wire: Au, 1 mil.
c) Power: 1st Bond (header) = **0.25W**. 2nd Bond (die pad) = **0.20W**
d) Force: 1st Bond (header) = **1.25g**. 2nd Bond (die pad) = **2.0g**
e) Bond time: 1st Bond (header) = **3.0 msec**. 2nd Bond (die pad) = **3.0 msec**.
f) Die temperature: **200°C**

3.2.2. Wire-Pull Test Data (ALL passed)

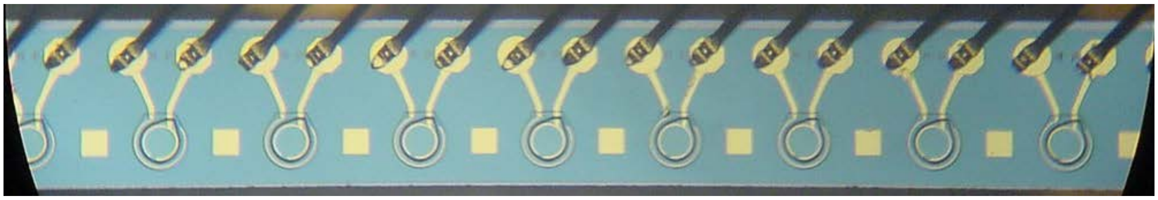
	W# 011			
	#1	#2	#3	#4
1	12.2	12.0	11.3	11.2
2	13.4	9.8	11.6	9.9
3	12.3	9.7	10.4	11.5
4	7.9	8.1	10.7	8.2
5	10.2	9.5	9.4	8.0
6	9.8	9.8	11.1	9.8
7	10.2	8.9	11.0	10.4
8	9.8	9.6	11.3	10.4
9	9.6	9.9	9.4	10.2
10	9.8	9.5	10.7	10.1
11	9.5	10.0	9.3	6.2
12	9.5	10.2	10.8	9.0
13	9.8	9.5	10.4	10.5
14	9.8	10.2	8.3	8.8
15	9.7	9.8	10.7	9.7
16	10.2	9.0	10.7	5.9
17	9.6	10.0	11.5	5.2
18	9.6	10.0	10.4	11.2
19	11.9	9.9	8.7	8.6
20	11.5	10.3	10.4	10.4
21	11.1	9.2	8.5	8.7
22	13.0	9.7	8.1	9.2
23	12.1	9.2	10.4	10.3
24	9.6	12.6	9.5	8.7

	W# 013			
	#1	#2	#3	#4
1	11.1	13.0	7.9	11.8
2	11.0	12.4	9.5	7.9
3	10.1	11.2	8.4	10.6
4	11.9	9.5	9.6	9.5
5	10.1	7.9	7.6	10.2
6	9.4	9.6	9.8	9.7
7	9.1	9.0	9.5	9.5
8	9.6	10.7	10.1	9.2
9	9.4	10.6	9.3	8.8
10	6.2	9.0	10.5	9.3
11	9.2	10.2	9.5	8.2
12	9.3	10.8	9.6	8.9
13	9.8	11.2	9.1	9.4
14	8.7	10.8	7.9	9.1
15	8.6	11.6	8.1	8.5
16	11.1	10.7	9.4	9.0
17	9.7	10.6	8.6	8.9
18	10.0	11.9	8.2	8.7
19	10.1	11.5	6.9	8.3
20	10.3	9.9	8.9	9.3
21	9.9	11.0	8.7	7.7
22	10.1	5.4	8.2	8.2
23	8.7	7.4	8.2	7.3
24	8.2	8.1	10.4	7.9

3.2.3. Post Wire-Bonding:



3.2.4. Post Wire-Pull Test:



3.3. Experiment 3: Bonding temperature T = 190°C

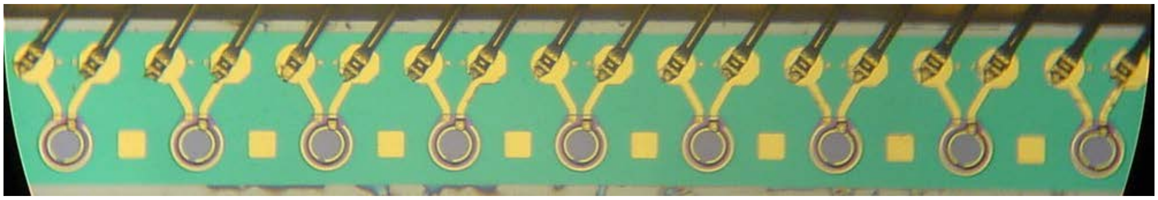
3.3.1. Parameters

a) Device: SPD2010-12 Rev.A
b) Wire: Au, 1 mil.
c) Power: 1st Bond (header) = **0.25W**. 2nd Bond (die pad) = **0.20W**
d) Force: 1st Bond (header) = **1.5g**. 2nd Bond (die pad) = **2.5g**
e) Bond time: 1st Bond (header) = **3.0 msec**. 2nd Bond (die pad) = **3.0 msec**.
f) Die temperature: **190°C**

3.3.2. Wire-Pull Test Data (ALL passed)

	#1	#2	#3	#4
1	**8.1**	**4.1**	**9.4**	**5.8**
2	**8.5**	**9.4**	**9.7**	**7.5**
3	**5.0**	**9.2**	**8.4**	**8.1**
4	**4.3**	**9.6**	**8.8**	**8.0**
5	**5.0**	**10.4**	**8.5**	**8.3**
6	**5.7**	**4.3**	**11.0**	**6.8**
7	**4.6**	**4.5**	**11.8**	**7.4**
8	**4.8**	**5.1**	**11.3**	**6.5**
9	**5.7**	**9.6**	**9.6**	**7.5**
10	**6.2**	**6.5**	**9.2**	**8.0**
11	**5.6**	**4.2**	**9.4**	**7.6**
12	**8.2**	**4.6**	**10.2**	**7.3**
13	**5.5**	**4.8**	**11.9**	**7.3**
14	**6.5**	**5.2**	**11.2**	**7.4**
15	**4.9**	**4.6**	**9.0**	**7.3**
16	**5.0**	**4.1**	**11.3**	**6.8**
17	**4.7**	**6.2**	**8.4**	**6.3**
18	**4.5**	**10.1**	**7.9**	**8.1**
19	**5.2**	**4.7**	**9.5**	**10.7**
20	**4.6**	**9.2**	**11.8**	**9.8**
21	**5.0**	**9.8**	**10.0**	**6.9**
22	**9.6**	**10.3**	**9.9**	**10.8**
23	**6.3**	**5.0**	**7.4**	**11.3**
24	**9.4**	**12.9**	**7.2**	**10.4**

3.3.3. Posr Wire-Bonding:



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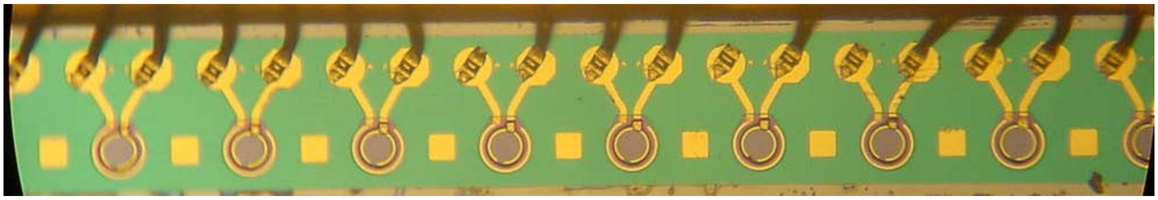

4. Summary

4.1. Summary of Experimental Results

	Experiment 1	Experiment 2	Experiment 3
Bonding Temperature (°C)	140	200	190
Power (W) (1st/2nd bond)	0.30/0.25	0.25/0.20	0.25/0.20
Force (g) (1st/2nd bond)	1.75/2.5	1.25/2.0	1.5/2.5
Bonding Time (msec)	3.0	3.0	3.0
Pull Test Failures/Total Tested	14/144	0/192	0/96
Bonding Pull Test Result	FAIL	PASS	PASS

4.2. Cosemi’s limited study indicates that when using thermosonic wire bonding, the pad temperature must be at or above 190°C (Cosemi have successfully operated at up to 230°C).

4.3. For ball wire-bonding the power, force, and time parameters may be different than those listed above.