Speciality Products and Services

Wire Bonding Capabilities and Design Rules

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1.0 Introduction

The dominant process for interconnecting semiconductor chips to the outside world is an ultrasonic welding process called wire bonding. Welding is a process where an intermetallic alloy is formed from the materials to be joined. Generally, intermetallic alloys are stronger but also more brittle than their constituents. There are two major variations of the wire bonding process: ball bonding and wedge bonding

2.0 Wire bonding Techniques

2.1 Ball bonding

In this technique, wire is passed through a hollow capillary, and an electronic-flame-off system (EFO) is used to melt a small portion of the wire extending beneath the capillary. The surface tension of the molten metal form a spherical shape, or ball, as the wire material solidifies. The ball is pressed to the bonding pad on the die with sufficient force to cause plastic deformation and an Ultrasonic pulse is used to produce a thermosonic bonding of the wire and the underlying metallization. The capillary is then raised and repositioned over the second bond site on the substrate, a precisely shaped wire connection called a wire loop is thus created as the wire moves. Deforming the wire against the bonding pad with another ultrasonic pulse makes the second bond (wedge bond), having a crescent or fishtail shape made by the imprint of the capillary's outer geometry. Then the wire clamp is closed, and the capillary ascends once again, breaking the wire just above the wedge, an exact wire length is left for EFO to form a new ball to begin bonding the next wire. An illustration of this bonding technique and the resulting bonds are shown in figure 1 to figure 3 below.

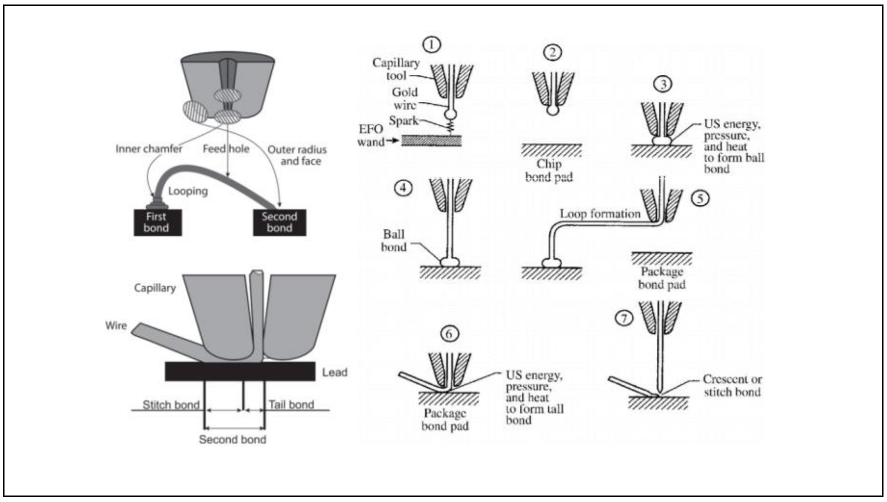

Figure 1:- Ball Bonding technique.

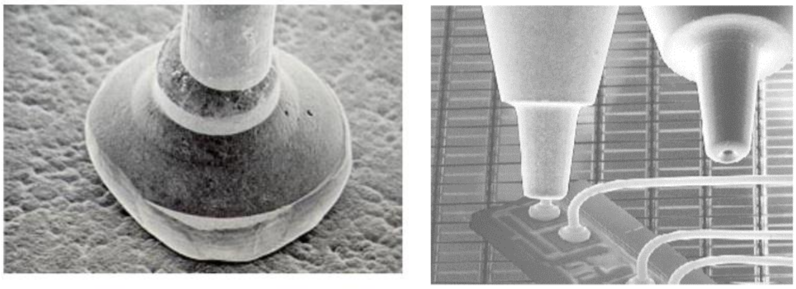

Figure 2:- Ball Bonding.

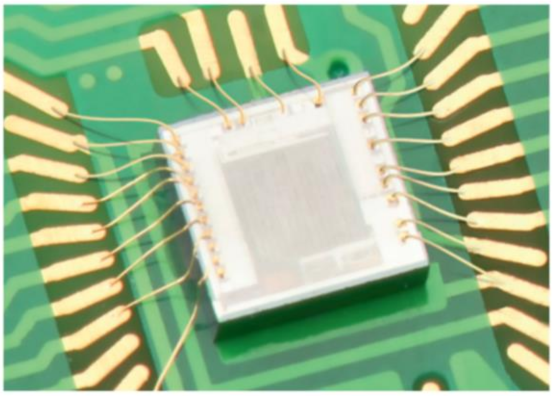

Figure 2:- Ball Bonding.

2.2 Wedge bonding

Wedge bonding is named based on the shape of its bonding tool. In this technique, the wire is fed at an angle usually 30-60^{o} from the horizontal bonding surface through a hole in the back of a bonding wedge. Normally, forward bonding is preferred, i.e. the first bond is made to the die and the second is made to the substrate. The reason is that it can be far less susceptible to edge shorts between the wire and die. By descending the wedge onto the IC bond pad, the wire is pinned against the pad surface and an Ultrasonic pulse bond is performed. Next, the wedge rises and executes a motion to create a desired loop shape. At the second bond location, the wedge descends, making a second ultrasonic bond. During the loop formation, the movement of the axis of the bonding wedge feed hole must be aligned with the center line of the first bond, so that the wire can be fed freely through the hole in the wedge. Wedge bonding technique can be used for both aluminum wire and gold wire bonding applications. The principle difference between the two processes is that the aluminum wire is bonded in an ultrasonic bonding process at room temperature, whereas gold wire wedge bonding is performed through a thermosonic bonding process with heating up to 150^{o}C. Aluminum ultrasonic bonding is the most common wedge bonding process because of the low cost and the low working temperature. An illustration of this bonding technique and the resulting bonds are shown in Figure 4 to figure 6 below.

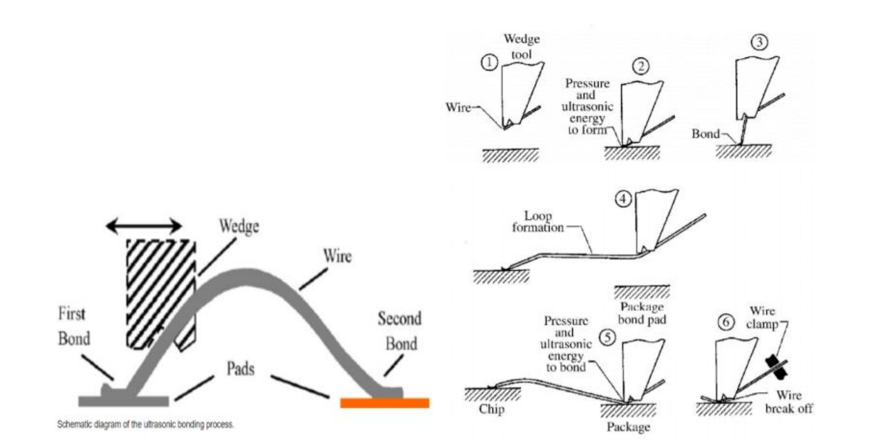

Figure 4:- Wedge Bonding technique.

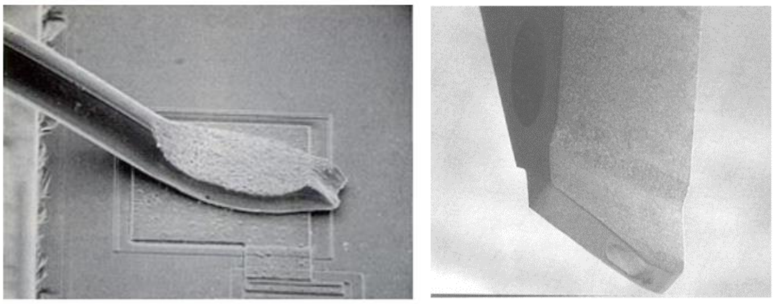

Figure 5:- Wedge Bonding.

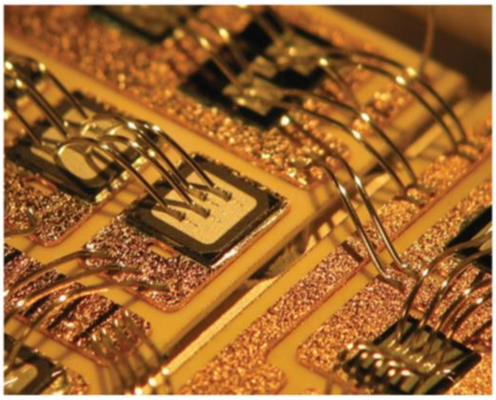

Figure 6:- Wedge Bonding.

3.0 Available Bonding Types

SP&S have the ability to perform both ball bonding and wedge bonding and have the following materials and wire sizes available.

3.1 Ball Bonding

Gold Wire 17µm.
Gold Wire 25µm.
Gold Wire 50µm.
Copper Wire 25µm.

3.2 Wedge bonding

Gold Wire 17µm.
Gold Wire 25µm.
Gold Wire 50µm.
Aluminium Wire 25µm.

3.3 Wire Properties

Bulk Properties of Pure Metals

Properties	Units	Gold	Copper	Aluminum
Melting Point	°C	1063	1083	658
Density	g/cm^3	19.3	8.9	2.7
Lattice Constant (@20 °C)	10^{-10} m (Å)	4.079	3.615	4.049
Lattice Structure	–	FCC	FCC	FCC
Specific Heat (@20 °C)	J/g K	0.126	0.386	0.900
Thermal Conductance	kW/m^2 K	31.1	39.4	22.2
Coefficient of Linear Thermal Expansion	ppm/K	14.2	16.5	23.1
Electrical Resistivity (@20 °C)	10^{-8} Ω m	2.2	1.7	2.7
Electrical Conductivity (@20 °C)	10^{7} / Ω m	4.55	5.88	3.65
Vickers Hardness	MN/m^2	216	369	167
Youngs Modulus	GPa	78	130	70
Modulus of Elasticity	GPa	79	123	71
Tensile Strength	N/mm^2	120 – 220	210 – 370	100 – 200

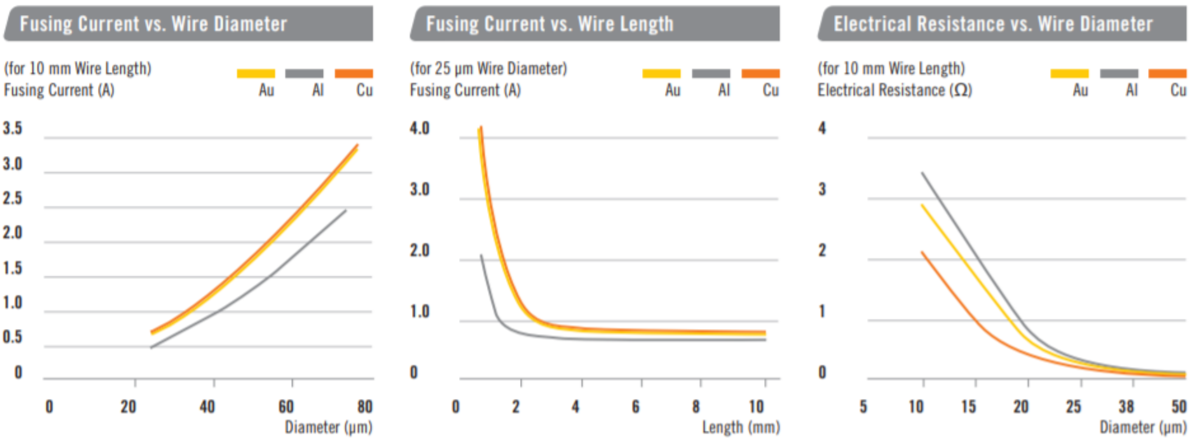

Figure 7:- Wire bond material Properties.

4.0 Design Rules

To ensure that a device can be wire bonded their dimensions and metallurgy should conform to the following design rules. These rules should apply to all samples being supplied to SP&S for wire bonding. However, it is understood that in some cases this may not be possible. In these cases, the SP&S team should be contacted at the design stage to improve the chances of successful interconnection after manufacture. At the design stage in all cases it is preferable that a member of the SP&S team be contacted if possible.

Note: No guarantee of successful wire bonding is given, even to samples that adhere to all of the design rules contained in this document.

4.1 Ball Bonding Dimensions

4.1.1 - 25um Au Wire dimensions

Dimension Type	Dimension ≥
Chip Pad X/Y	80µm
Chip Pad Pitch	160µm
Substrate pad length	300µm
Substrate pad width	150µm
Chip to pad Substrate distance	1.5 x chip thickness
Space between substrate pads	100µm

Table 1:- Dimension design rules. 25um Au Wire.

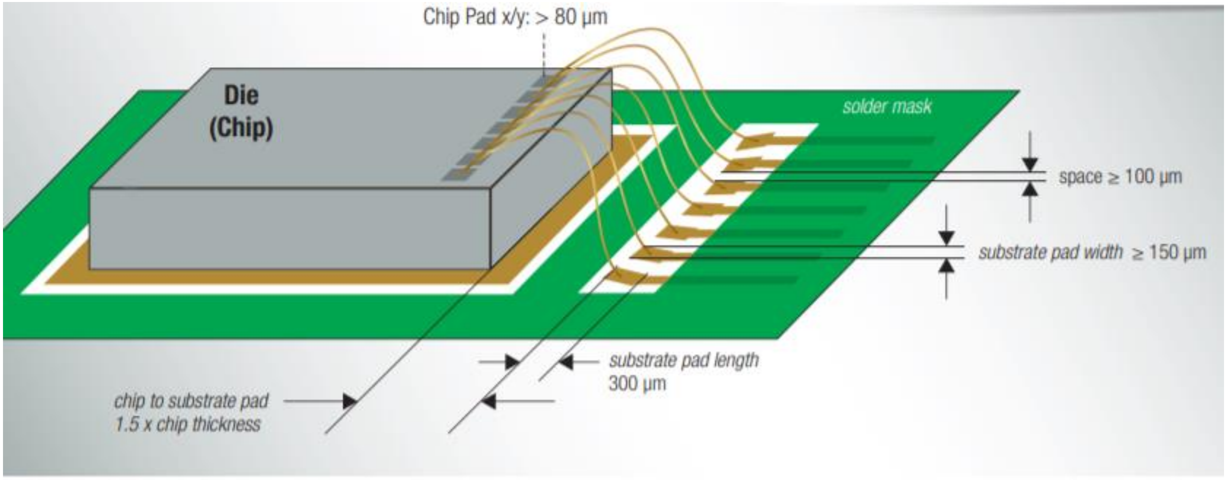

Figure 8:- Dimension design rules. 25um Au Wire.

Notes:

- Both substrate and die pads should not be in a cavity (for example solder mask). This is particularly important for the wedge bond.
- Pads should not be in close proximity to vertical structures higher than 4mm.

4.1.2 - 17um Au Wire dimensions

Dimension Type	**Dimension ≥**
Chip Pad X/Y	60µm
Chip Pad Pitch	120µm
Substrate pad length	300µm
Substrate pad width	150µm
Chip to pad Substrate distance	1.5 x chip thickness
Space between substrate pads	100µm

Table 2:- Dimension design rules. 17um Au Wire.

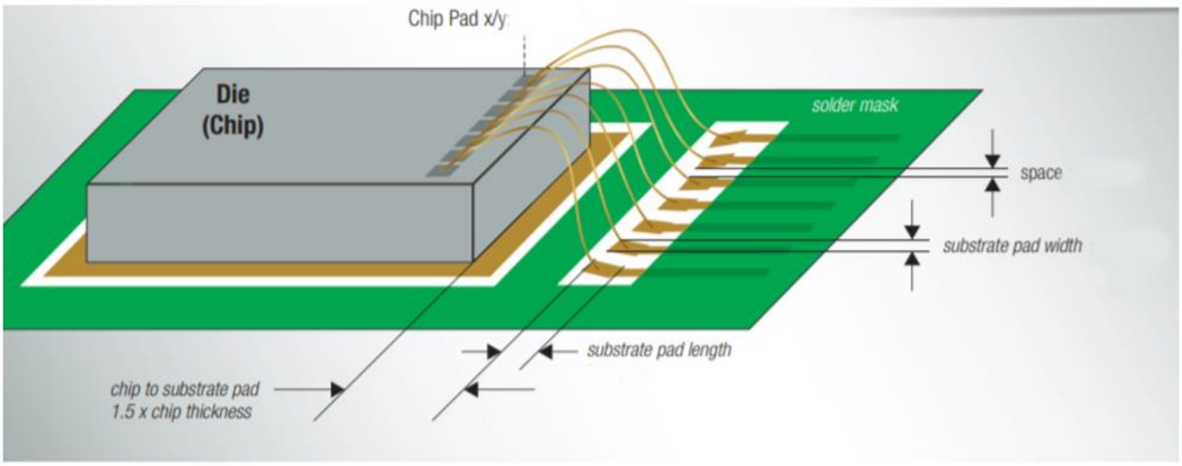

Figure 9:- Dimension design rules. 17um Au Wire.

Notes:

- Both substrate and die pads should not be in a cavity (for example solder mask). This is particularly important for the wedge bond.
- Pads should not be in close proximity to vertical structures higher than 4mm.

4.1.3 - 50um Au Wire dimensions

Dimension Type	**Dimension ≥**
Chip Pad X/Y	150µm
Chip Pad Pitch	300µm
Substrate pad length	600µm
Substrate pad width	250µm
Chip to pad Substrate distance	1.5 x chip thickness
Space between substrate pads	100µm

Table 3:- Dimension design rules. 50um Au Wire.

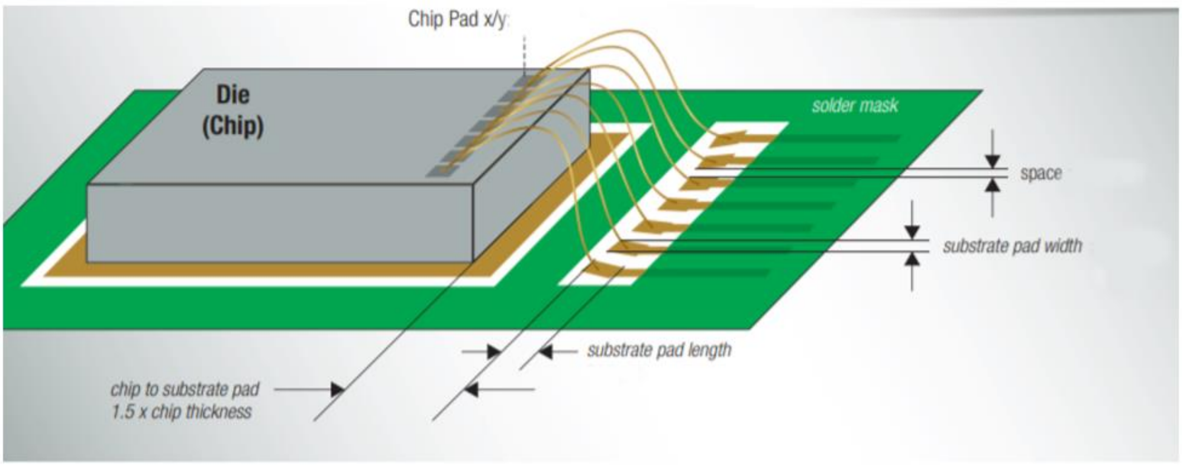

Figure 10:- Dimension design rules. 50um Au Wire.

Notes:

- Both substrate and die pads should not be in a cavity (for example solder mask). This is particularly important for the wedge bond.
- Pads should not be in close proximity to vertical structures higher than 4mm.

4.1.4 - 25um Cu Wire dimensions

Dimension Type	Dimension ≥
Chip Pad X/Y	80µm
Chip Pad Pitch	160µm
Substrate pad length	300µm
Substrate pad width	150µm
Chip to pad Substrate distance	1.5 x chip thickness
Space between substrate pads	100µm

Table 4:- Dimension design rules. 25um Cu Wire.

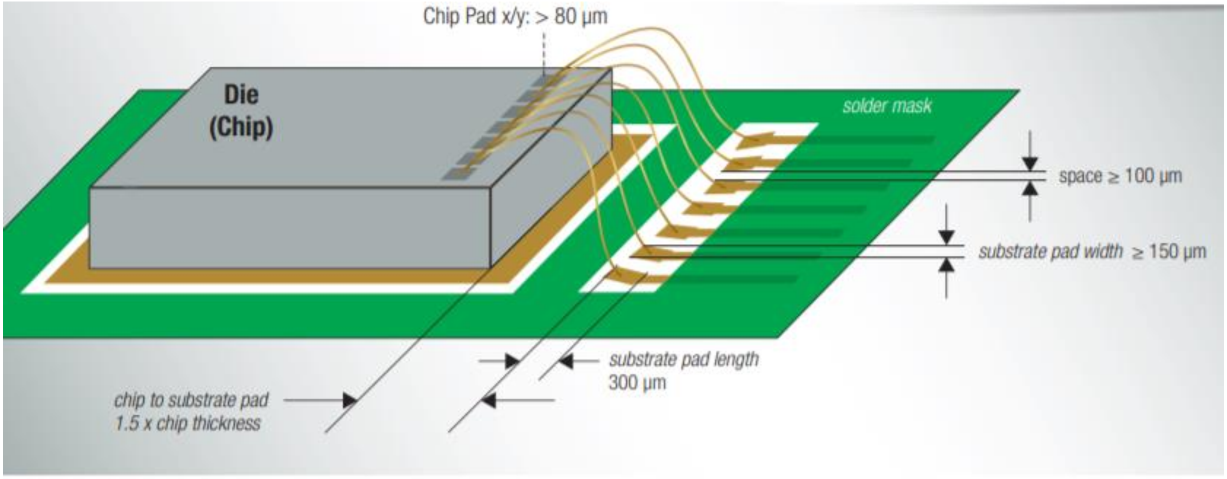

Figure 11:- Dimension design rules. 25um Cu Wire.

Notes:

- Both substrate and die pads should not be in a cavity (for example solder mask). This is particularly important for the wedge bond.
- Pads should not be in close proximity to vertical structures higher than 4mm.

4.2 Wedge Bonding Dimensions

4.2.1 - 25um Al Wire dimensions

Dimension Type	Dimension ≥
Chip Pad X/Y	80µm
Chip Pad Pitch	160µm
Substrate pad length	300µm
Substrate pad width	150µm
Chip to pad Substrate distance	1.5 x chip thickness
Space between substrate pads	100µm

Table 5:- Dimension design rules. 25um Al Wire.

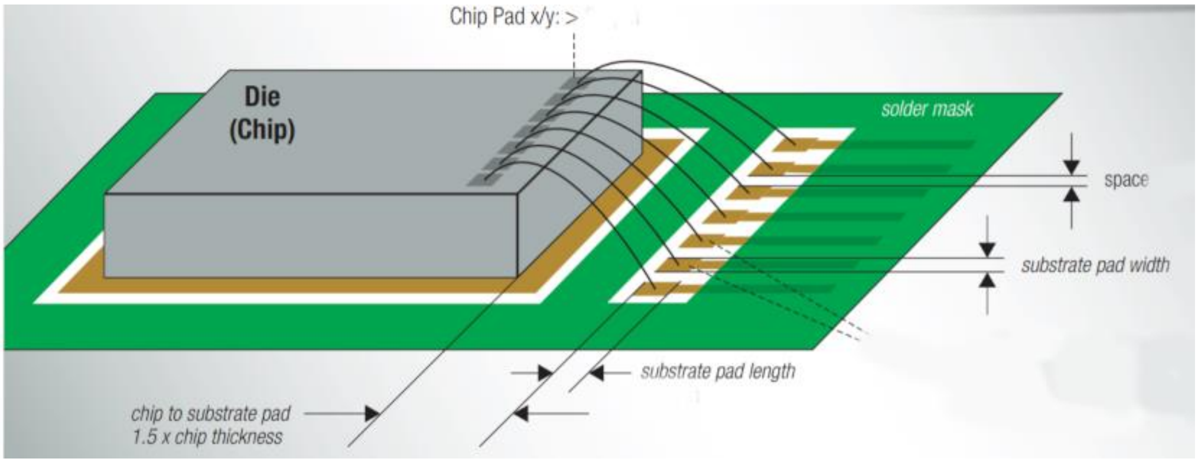

Figure 12:- Dimension design rules. 25um Al Wire.

Notes:

- Wedge bonding can only be done in a straight line from die to substrate
- Both substrate and die pads should not be in a cavity (for example solder mask). This is particularly important for the wedge bond.
- Pads should not be in close proximity to vertical structures higher than 4mm.

4.2.2 - 17um Au Wire dimensions

Dimension Type	**Dimension ≥**
Chip Pad X/Y	60µm
Chip Pad Pitch	120µm
Substrate pad length	300µm
Substrate pad width	150µm
Chip to pad Substrate distance	1.5 x chip thickness
Space between substrate pads	100µm

Table 6:- Dimension design rules. 17um Au Wire.

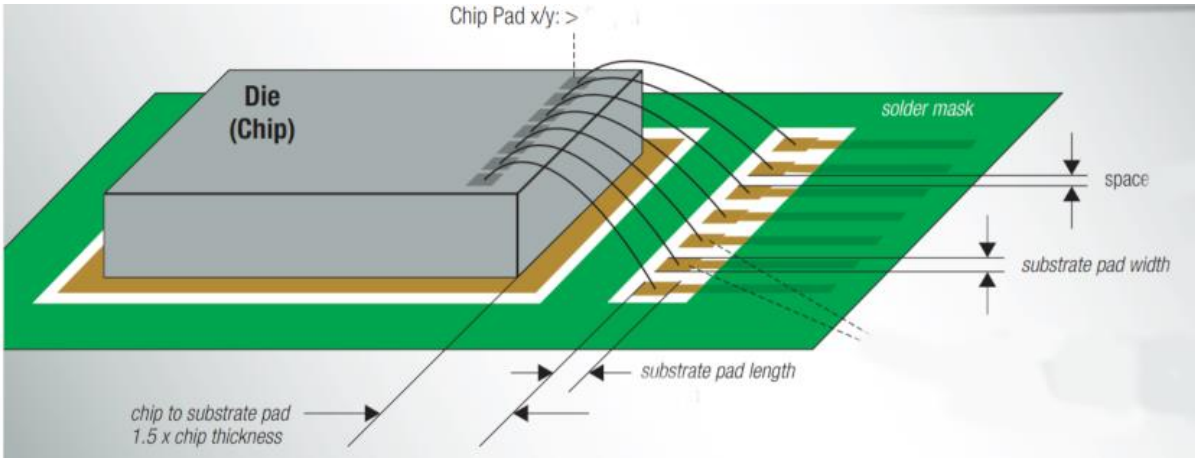

Figure 13:- Dimension design rules. 17um Au Wire.

Notes:

- Wedge bonding can only be done in a straight line from die to substrate
- Both substrate and die pads should not be in a cavity (for example solder mask). This is particularly important for the wedge bond.
- Pads should not be in close proximity to vertical structures higher than 4mm.

4.2.3 - 50um Au Wire dimensions

Dimension Type	**Dimension ≥**
Chip Pad X/Y	120μm
Chip Pad Pitch	300μm
Substrate pad length	600μm
Substrate pad width	250μm
Chip to pad Substrate distance	1.5 x chip thickness
Space between substrate pads	100μm

Table 7:- Dimension design rules. 50um Au Wire.

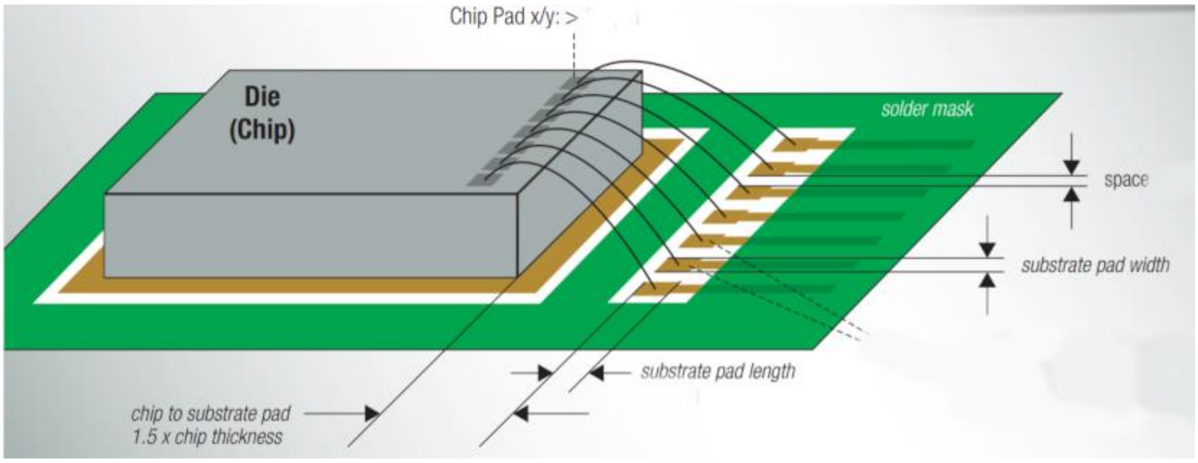

Figure 14:- Dimension design rules. 50um Au Wire.

Notes:

- Wedge bonding can only be done in a straight line from die to substrate
- Both substrate and die pads should not be in a cavity (for example solder mask). This is particularly important for the wedge bond.
- Pads should not be in close proximity to vertical structures higher than 4mm.

4.2.4 - 25um Au Wire dimensions

Dimension Type	**Dimension ≥**
Chip Pad X/Y	80µm
Chip Pad Pitch	160µm
Substrate pad length	300µm
Substrate pad width	150µm
Chip to pad Substrate distance	1.5 x chip thickness
Space between substrate pads	100µm

Table 8:- Dimension design rules. 25um Au Wire.

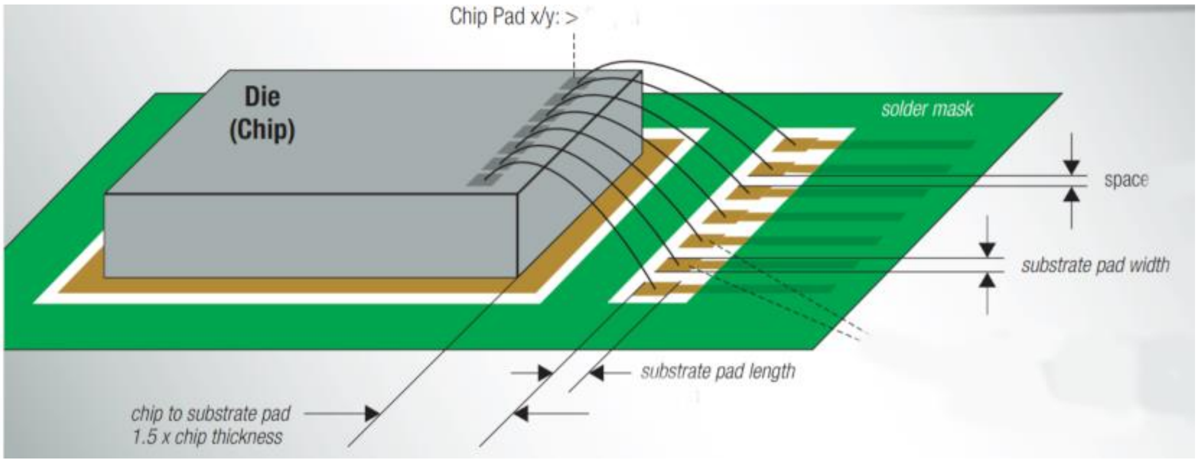

Figure 15:- Dimension design rules. 25um Au Wire.

Notes:

- Wedge bonding can only be done in a straight line from die to substrate
- Both substrate and die pads should not be in a cavity (for example solder mask). This is particularly important for the wedge bond.
- Pads should not be in close proximity to vertical structures higher than 4mm.

4.3 Wire bonding metallurgy

In the wire bonding process, different pad metallisation's can be used. Therefore, different metallurgical systems can be formed with different reliability behaviours. The standard typical metallurgical systems are:

4.3.1 Au-Au system

Gold wire bonded to a gold bond pad is extremely reliable because the bond is not subject to interface corrosion, intermetallic formation, or other bond-degrading conditions. Even a poorly welded gold-gold bond will increase in strength with time and temperature. Gold wire welds best with heat although cold ultrasonic Au-Au wire bonds can be made.

4.3.2 Au-Al system

Au-Al welding system is the most commonly used in the wire bonding process. However,in long term reliability terms this bonding system can easily lead to formation of Au-Al intermetallic compounds and associated Kirkendall voids.

4.3.3 Au-Cu system

Bonding gold wires to bare copper lead frames can cause the formation of three ductile intermetallic phases (Cu_3Au, AuCu, and Au_3Cu) with overall activation energies of 0.8 to 1 eV. The formation of these intermetallic compounds can decrease the bond strength at higher temperatures (200-325^oC) as a result of Kirkendall voiding. The degradation is apparently dependent on the microstructure, weld quality, and impurity content of the copper. Cleanliness of the bonding surface is extremely important to ensure good bondability and reliability in Cu-Au systems. In addition, if polymer material is used for die attach, the polymer must be cured in an inert atmosphere to prevent oxidation.

4.3.4 Au-Ag system

The Au-Ag wire bond-system is very reliable for very long times at high temperatures. This bond system does not form intermetallic compounds and does not exhibit interface corrosion. Bondability problems can be caused by contaminants like sulfur. Thermosonic Au-Ag bonding is usually performed at high temperature (approximately 250^oC) which dissociates thin silver-sulfide films thus increases bondability of silver.

4.3.5 Al-Al system

The aluminum- aluminum wire bond system is extremely reliable because it is not prone to intermetallic formation and corrosion.

4.3.6 Al-Ag system

Aluminum wire bonded to a silver pads can be used. The Ag-Al phase diagram is very complex, with many intermetallic phases. Kirkendall voids can occur in this metal system, but typically at temperatures higher than the operating range of the microcircuits. In practice, Ag-Al bonds are seldom used because of their tendency to degrade due to interdiffusion and to oxidize in the presence of humidity.

4.3.7 Al-Ni system

The main difficulty encountered when bonding to nickel plating is bondability rather than reliability due to nickel surface oxidation. Thus, packages should be bonded soon after they are Ni-plated, protected in an inert atmosphere, or chemically cleaned before bonding.

4.3.8 Cu-Al system

Copper wire can be bonded to both gold and aluminum substrate. Au-Cu system has been discussed above. For Cu-Al system, there exist five intermetallic compounds favoring the copper-rich side. Thus, there is the possibility of various intermetallic failures similar to those of Au-Al system. However, intermetallic growth in Cu-Al bonds is slower than in Au-Al bonds. The intermetallic growth in Cu-Al bonds does not result in Kirkendall voiding bur lowers the shear strength at above 150^{o}C due to the growth of a brittle $CuAl_2$ phase.