Introduction to Wire-Bonding
Wire bonding is a kind of friction welding

- Material are connected via friction welding
- Advantage: Different materials can be connected to each other
- widely used, e.g. in automobile technology
- caution: thermodynamically metastable
Some Facts about Wire Bonding

- Most important interconnection technology on chip level (about $1.5 \times 10^{12}$ bond wires annually)
- Reliable, flexible, cost efficient
- Solid-phase welding process by ultrasonic friction: crystal lattices of wire and substrate are brought into atomic contact
- Friction is generated by ultrasonic oscillation
- Typical frequencies 60 ... 140 kHz
- Welding time approx. 5 ... 30 ms or 1000 to 2000 oscillations
- Thermal support possible but not required
- Mechanical rigidity of bonding surface is crucial
- Bonding surfaces must be clean
A typical Wire Bonder

- Machine basis similar for all technologies
- Automated parts handling or manual loading/unloading
- Magazine-to-magazine operation or in-line configuration
The business end of a bonder..
...is an oscillating, resonant system
Combinations of Materials

**Guiding Principle: Hardness and Roughness similar**

- Most important wire material Au (95% of all bonds)
- Remainder: Al, especially for heavy wire and COB
- Bonding layers: Al (on chip), Ni and Gold
- Under development: Cu (oxidation makes handling difficult)
- Exotic materials: Ag, Pd, Pt, Fe
- General corrosion problems, especially at high temperatures (Thermodynamic metastability!)
Method 1: Gold-Ball Bonding
Method 1: Gold-Ball Bonding
Not-so-typical products

- Au Ball-wedge bonds 25 µm
- 3 layers of loops
- 8 rows of bondpads on circuit board
Method 2: Wedge-Wedge Bonding
Method 2: Wedge-Wedge Bonding
Typical and non-typical products

Bond on Bond (17.5 μm)
Not-so-typical products

• Memory modules for notebooks and digital cameras
• Al wire loops up to 10 mm
High-Frequency devices are different

Bond geometry and technology changes with frequency

- **< 10 GHz**
  - Bondlänge: > 500 µm

- **< 35 GHz**
  - Bondlänge: 250 - 500 µm

- **> 35 GHz**
  - Bondlänge: 150 - 250 µm
Deep Access/Ribbon Bond head is ideal for high frequency devices
Deep Access bond tool and clamp
Reproducible loops of 200µm length and 30µm height
Method 3: Heavy wire bonding
Method 3: Heavy wire bonding
Typical heavy-wire devices: leadframe with multiple bond wires
Typical heavy-wire devices: power module

- Multiple wires for high power
- Stitch bonding
- Dies are die-bonded with solder paste
Fine Pitch Bonding for Heavy Wire

Pitch 490 µm with 250 µm wire
(using modified wedge)
Ribbon Tools

- Bond foot length is critical to machine force capability
- Slotted to suit ribbon size
- Material Tungsten carbide
- Exit slot must be polished
Ribbon Tools and Ribbon

- Ribbon to tool slot critical for consistent position
- Lower portion of tool must have sufficient material to prevent breakage
Ribbon bonds and loops

ADVANTAGES

• Ribbon bonds exhibit little deformation and heel damage

• Nearly any loop height and loop span is easily accomplished

• Higher current carrying capability

• Higher speed compared to wire

DISADVANTAGES:

• “S” shape bonding is nearly impossible

• Chip pads and associated terminating pads must be in line
Aluminum Ribbon has exceptionally high pull strength

Entire work holder weighing 1.3 kilograms suspended by 1.5 mm wide ribbon
The secret of successful bonding

There are only two things to do right:

- Clean surfaces
- Parts to be bonded must be clamped rigidly
Typical bonding surfaces

Typical Metal surfaces used in Chip on Board

<table>
<thead>
<tr>
<th>Metallisation</th>
<th>Bond process</th>
<th>contact system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ni (4…6µm) diffusion barrier / Au (0,05…0,1µm)</td>
<td>ultrasonic (Al)</td>
<td>Al/Ni (Au)</td>
</tr>
<tr>
<td>Ni (4…6µm) bond area</td>
<td>ultrasonic (Al)</td>
<td>Al/Ni</td>
</tr>
<tr>
<td>Ni (4…6µm) diffusion barrier / Au (0,5…1µm)</td>
<td>thermosonic (Au)</td>
<td>Au/Au</td>
</tr>
<tr>
<td>Silver (4…6µm)</td>
<td>thermosonic (Au)</td>
<td>Au/Ag</td>
</tr>
<tr>
<td>Ni (4…6µm), Pd (0,2…0,5µm), Au (0,05…0,1µm)</td>
<td>thermosonic (Au) and</td>
<td>Au/Pd and Al/Pd</td>
</tr>
<tr>
<td></td>
<td>ultrasonic (Al)</td>
<td></td>
</tr>
</tbody>
</table>
Typical bond surface on circuit board

- Gold top layer
- Nickel layer
- Substrate
- Copper layer
Good support is crucial

non-rigid support will not permit good bonding
Stiffer bonding layer is sufficient
Finding good bonding parameters

There are only 3 main parameters to play with

- US energy
- US time
- bonding force

- with a good medium setting, parameter window can be established by varying the 3 parameters in steps of +/- 20%
Bond Formation: What are the Optimum Settings?

- **Lift off**
- **Heel Crack**
- **Pull Force**
- **Process Window**

- Underbonding
- Overbonding

Ultrasonic Energy
Where are things going?

- Narrowest pitch with wedge-wedge bonds
- Bonds are narrower but longer (1.2 x wire dia.)
- Wire diameters 17 to 75 µm standard
- Wires of 12 to 15 µm in development
- Pitches down to 35 µm (roughly 2x wire dia.)
- Extremely short and low bonds for microwave applications: <100 µm
- For certain bond surfaces: Au wire sputtered with Al for room-temperature bonding
## Chip Interconnection Roadmap

<table>
<thead>
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</thead>
<tbody>
<tr>
<td><strong>Packaging - Design</strong></td>
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</tr>
<tr>
<td>Chip -Size [mm²] (High -Performance)</td>
<td>150</td>
<td>170</td>
<td>170</td>
<td>214</td>
<td>235</td>
<td>280</td>
<td>308</td>
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<tr>
<td>(Hand-held)</td>
<td>45</td>
<td>53</td>
<td>57</td>
<td>62</td>
<td>65</td>
<td>72</td>
<td>81</td>
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<tr>
<td>Wire Bonding</td>
<td>75/60</td>
<td>50/50</td>
<td>65/45</td>
<td>55/45</td>
<td>45/40</td>
<td>35/30</td>
<td>25/20</td>
</tr>
<tr>
<td>Ball-Wedge / Wedge-Wedge Pitch [µm]</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>TAB Lead Pitch [µm]</td>
<td>50</td>
<td>50</td>
<td>40</td>
<td>50</td>
<td>30</td>
<td>30</td>
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<tr>
<td>Flip Chip</td>
<td>250</td>
<td>180</td>
<td>150</td>
<td>120</td>
<td>100</td>
<td>70</td>
<td>50</td>
</tr>
<tr>
<td>I/O Pitch [µm]</td>
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<td></td>
</tr>
<tr>
<td>Substrate-Padsize [µm]</td>
<td>200</td>
<td>170</td>
<td>170</td>
<td>130</td>
<td>130</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Package-Thickness</td>
<td>1.5 - 2</td>
<td>1.2 - 1.7</td>
<td>1.0 - 1.2</td>
<td>1.0 - 1.2</td>
<td>0.8 - 1.0</td>
<td>0.5 - 1.0</td>
<td>0.5-0.65</td>
</tr>
</tbody>
</table>
Where are things going? – Quality

Quality is becoming ever more a crucial aspect (but cost has to stay low)

Yesterday:
parts with the specified quality were selected

Today:
Parts with the specified quality are produced

Tomorrow:
Not only produce the specified quality but prove that the specification is met
Key objective of quality assurance: Process control

Prevent rejects before they occur

Recognise and control trends...
Key objective of quality assurance: Process control

...especially when limits shrink
Quality Assurance in Wire Bonding

There are far more possibilities than just pull- and shear testing

- Bond Process Control assures optimum quality for each bond
- Post Bond Inspection allows 100% inspection and trend monitoring
- Automated pull testing gives spot testing at excellent price/performance ratio
- Data Tracer permits 100% tracking of key process data which are also relevant for other steps (e.g. die bonding)