

# Gold: The High Reliability Choice in Semiconductor Packaging

By

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## Abstract

*The reliability of gold in microelectronic packaging makes it the standard, by which all other materials must be judged. Even though the price of gold has risen significantly in this decade the usage of gold in microelectronic packaging has continued to grow and as consumer demand for high-end electronics continues to increase this trend looks set to continue.*

*Efforts to make the most cost-effective usage of gold through spot plating, plating thickness reduction and the usage of thinner bonding wire have been successful. Gold wire remains the main wire material for ball bonding in microelectronics assembly and has proven reliable in billions of devices over many years. However, high gold prices are increasingly forcing a shift towards cheaper copper wire, despite concerns over reliability. As a result there is a need to obtain higher quality reliability data with gold and copper wires supported by state of the art analytical methods. This will help quantify and validate the relative merits of the two metals in this critical application.*

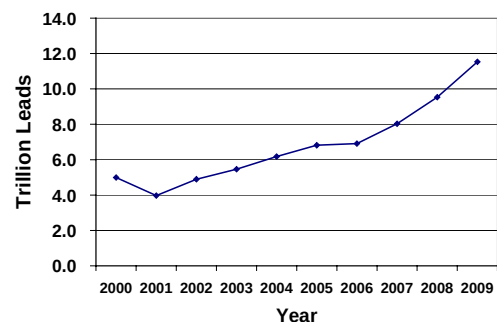
*Design-for-recycling should also be an important consideration in material selection. The precious metals (mainly gold) constitute a very substantial proportion of the material value of waste electronic and electrical equipment (WEEE) and gold can be considered as a key component of the economic viability of WEEE recycling*

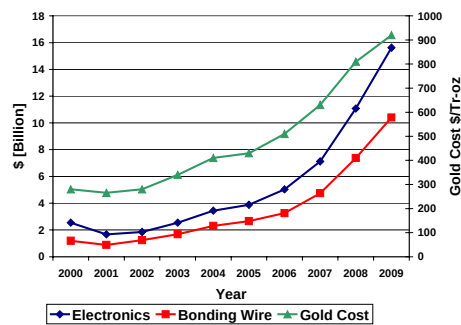
**Keyword:** Gold, copper, electronics, semiconductor packaging, interconnects, reliability, design for recycling

## World Market Trends

Semiconductor packaging is a major consumer of gold and other precious metals. Consuming over 6%<sup>1</sup> of all gold used in 2002, gold bonding wire represents almost 70% of the gold used in electronics. Figure 1<sup>2</sup> shows the annual usage of peripheral leads, those that are normally wire bonded. Although alternative technologies (flip chip, copper ball bonding) have grown and taken market share they still represent a smaller (<10%) portion of the

**Figure 1 Annual Usage of Peripheral (Wire Bond) Leads**



**Figure 2. Annual Electronic Industry Gold Usage [Billion \$]**

interconnect market and have allowed the gold wire usage to more than double since 2000.

Figure 2 shows gold usage for the electronics industry in Billions of USD\$. It also shows the usage of gold bonding wire. The price of gold/troy-oz is also shown scaled to the right side of the graph. The graph shows very clearly that the tripling in the gold price is a major component in the rise in electronics and wire gold usage costs. The combination of increased usage and the rise in gold cost have increased the electronics industries gold usage costs to almost \$16 billion in 2009.

Increased gold costs have failed to diminish usage at least partly because the gold cost for a typical 2.5mm long wire bond is < \$.001/lead. It is only in the aggregate, when annual costs are considered, that gold usage becomes a large cost factor. When the reliability risk for expensive, high lead count devices is considered, the < \$.001 lead cost is justified.

With the rise in precious metal prices it becomes more important to understand the engineering requirements that drive the demand.

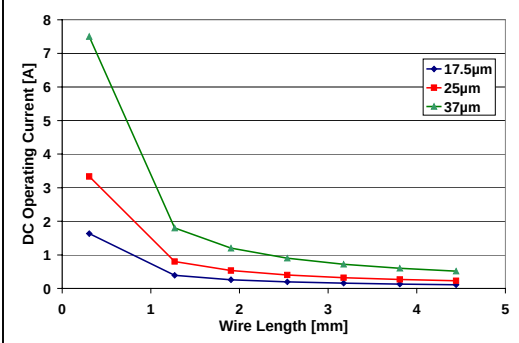
**Table 1 Weldable Alloy Combinations (From American Welding Society Handbook)**

|    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Al | Al | Be | Cu | Ge | Au | Fe | Mn | Mo | Ni | Pd | Pt | S  | Ag | Ta | Sn | Ti | W  | Zr |
| Al | Be | Cu | Ge | Au | Fe | Mn | Mo | Ni | Pd | Pt | S  | Ag | Ta | Sn | Ti | W  | Zr |    |
| Be | Cu | Ge | Au | Fe | Mn | Mo | Ni | Pd | Pt | S  | Ag | Ta | Sn | Ti | W  | Zr |    |    |
| Cu | Ge | Au | Fe | Mn | Mo | Ni | Pd | Pt | S  | Ag | Ta | Sn | Ti | W  | Zr |    |    |    |
| Ge | Au | Fe | Mn | Mo | Ni | Pd | Pt | S  | Ag | Ta | Sn | Ti | W  | Zr |    |    |    |    |
| Au | Fe | Mn | Mo | Ni | Pd | Pt | S  | Ag | Ta | Sn | Ti | W  | Zr |    |    |    |    |    |
| Fe | Mn | Mo | Ni | Pd | Pt | S  | Ag | Ta | Sn | Ti | W  | Zr |    |    |    |    |    |    |
| Mn | Mo | Ni | Pd | Pt | S  | Ag | Ta | Sn | Ti | W  | Zr |    |    |    |    |    |    |    |
| Mo | Ni | Pd | Pt | S  | Ag | Ta | Sn | Ti | W  | Zr |    |    |    |    |    |    |    |    |
| Ni | Pd | Pt | S  | Ag | Ta | Sn | Ti | W  | Zr |    |    |    |    |    |    |    |    |    |
| Pd | Pt | S  | Ag | Ta | Sn | Ti | W  | Zr |    |    |    |    |    |    |    |    |    |    |
| Pt | S  | Ag | Ta | Sn | Ti | W  | Zr |    |    |    |    |    |    |    |    |    |    |    |
| S  | Ag | Ta | Sn | Ti | W  | Zr |    |    |    |    |    |    |    |    |    |    |    |    |
| Ag | Ta | Sn | Ti | W  | Zr |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Ta | Sn | Ti | W  | Zr |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Sn | Ti | W  | Zr |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Ti | W  | Zr |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| W  | Zr |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
| Zr |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |

### Gold Properties

Gold's properties make it the high reliability materials selection, providing the mechanical, electrical and corrosion properties that enable long-term reliability that would otherwise be unachievable by lower cost materials.

Table 1, from the American Welding Society Handbook shows metal combinations that can be ultrasonically welded. Gold is one of the best materials for ultrasonic welding, it forms stable intermetallics and is extremely corrosion resistant.

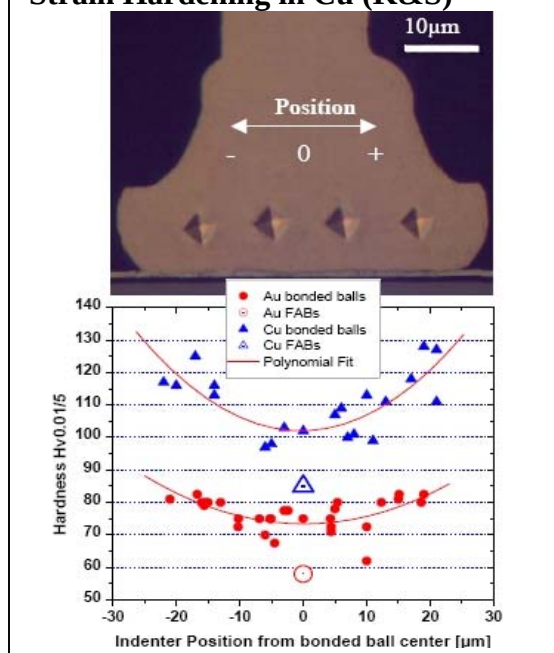
**Figure 3 Safe Design Current for Au Bonding Wire**

It's excellent electrical properties make it the best choice in a wide range of packages. Figure 3<sup>3</sup> shows safe (< 83°C temperature rise) design currents for typical gold bonding wires. Gold's excellent electrical and thermal

conductivity enable it to carry large currents safely. Only copper and silver have better electrical properties.

Gold's mechanical properties, high ductility and low yield strength, allow easy forming and bending of leads and contacts. Since gold has no oxides, electrical contacts form readily and maintain low contact resistance for extended life in harsh environments. Figure 4<sup>4</sup> compares the hardness of gold ball bonds and copper ball bonds. Gold has both lower hardness and also strain hardens less, allowing easier ultrasonic bonding with less chance of chip damage (cratering) than copper.

**Figure 4 Vickers Hardness of Au vs Cu Ball Bonds showing the Effect of Strain Hardening in Cu (K&S)**



Gold is a noble metal, it doesn't corrode in the presence of moisture (as copper does) and unlike Ag it doesn't present electro-migration issues.

The combination of Gold's properties:

- High electrical and thermal conductivity

- Low flow stress, high ductility and low strain hardening coefficient
- Corrosion resistant, doesn't electro-migrate

Make Gold the best choice for high reliability semiconductor packaging.

### Effects on Reliability

Gold's reliability in semiconductor packaging make it the most commonly used interconnect material. In 2009 more than 13 trillion peripheral chip interconnects were produced with gold ball bonding accounting for approximately 90% of the total. In well-controlled IC manufacturing processes, with high-volume manufacturing and good materials control, it is not unusual for gold wire bond defects to be in the range of <50ppm<sup>5</sup>. As copper wire bonding comes on stream the costs of qualification, meeting or exceeding this standard of excellence, will be a formidable task. Just a few additional package defects, in packages that have hundreds of wire bonds and contain expensive die and packaging materials, will offset the costs of gold wire.

Gold wire bonding to gold plated contact leads (a monometallic system) is more than twice as reliable than a bi-metallic system<sup>6</sup>. Semiconductor packaging qualifications are rigorous and can include thermal cycling, thermal aging, thermal shock, pressure cooker, Highly Accelerated Stress Test with and without bias current, vibration, shock.

### Cost Reducing Trends

Minimization strategies, reducing the thickness of gold plating and metallization layers and reducing the diameter of gold bonding wire, have been employed wisely. Gold plated

leads in Ball Grid Array packages (BGAs) that once had gold thickness of 1.0 to 1.75 $\mu\text{m}$  now are being produced with 0.5-0.75 $\mu\text{m}$  thickness, a 70% reduction in gold without sacrificing yield or productivity. Spot plating is widely used for electronic packaging. Only those regions of the package that require plating are treated. Reduction of bonding wire diameter from 25 $\mu\text{m}$  to 23 $\mu\text{m}$  can result in a 15% gold reduction, and newer stronger bonding wires are available so that equivalent strength and conductivity are maintained.

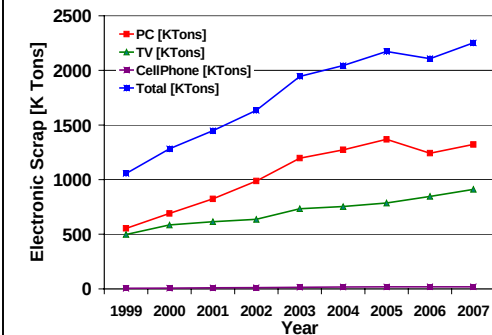
### Shift to Copper Wire

Whilst gold wire has been the main wire material and has proven reliable in billions of devices over many years, high gold prices are forcing a shift towards cheaper copper wire. However, recent studies with copper wires  $\leq 25\mu\text{m}$  reveal problems with reliability in temperature cycling (TCL)<sup>7,8</sup> and stress-corrosion of the Cu-Al phase during pressure cooker testing (PCT)<sup>9</sup>. 'Squeeze out', which is thinning of the bond pad at the regions of highest stress may result in chip damage and reduce TCL and PCT reliability. There is a need to obtain higher quality reliability data with gold and copper wires supported by state of the art analytical methods. This will help quantify and validate the relative merits of the two metals in this critical application.

### Recycling Issues

Recycling of waste electronic and electrical equipment (WEEE) is a growing global issue. Figure 5 shows the annual tonnage of electronic scrap generation in the USA by source.

**Figure 5 USA Annual Electronic Scrap Generation [ K Tons]**



In 2007 2.3 million tons of such waste were generated in the USA. Of this 414,000 tons (18%) were recycled<sup>10</sup>. States like California already have aggressive recycling, end-of-life programs in place. Increasingly the original equipment manufacturer is being made responsible for the financing, collection, recycling and safe disposal of WEEE. The 82% of electronics equipment that ends up in landfills will not be acceptable in the future. It represents both an environmental hazard and a very large unmet opportunity for recyclers.

Precious metals (mainly gold) constitute a very substantial proportion of the material value of WEEE. Recycling scrap computer PCB materials can yield as high as 400g Gold/1000 Kg waste<sup>11</sup> in addition to copper, palladium and silver. Gold can represent up to 65% of the material value of a computer PCB and 67% of the value of a scrapped cell phone<sup>12</sup>. For this reason gold can be considered as a 'helpful supporter' of the economic viability of WEEE recycling, a fact that should be considered when planning 'design-for-recycling'.

For a manufacturer of electronic goods that has a direct interest in the end-of-life collection of WEEE, designers and engineers working

on product design and procurement should at least be aware of the contribution gold makes to the economic viability of WEEE recycling. This applies not just to the gold reclaimed but the ability to collect - at the same time - other valuable commodities including plastics.

It should also be noted that gold bearing scrap generated during the electronics manufacturing process has high value. Manufacturing strategies that are structured to capture and reclaim this value feed directly into bottom line profitability. Gold recyclers can provide containers for scrap devices, wire, wipes and solutions. They can advise and assist on the most profitable methods for reclamation.

## Conclusions

The use of gold in microelectronics continues to grow with consumer demand for electronic products.

With the high price of gold further efforts to minimize gold usage, by developing processes with less gold and by substituting alternate materials when possible, will also be employed, particularly in the bonding wire market. To ensure reliability is maintained at the current high levels there is a need to obtain higher quality test data with gold and copper wires supported by state of the art analytical methods. This will help quantify and validate the relative merits of the two metals in this critical application.

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