Going for gold

Richard Holliday and **Paul Goodman** report on gold's growing importance for the modern electronics industry

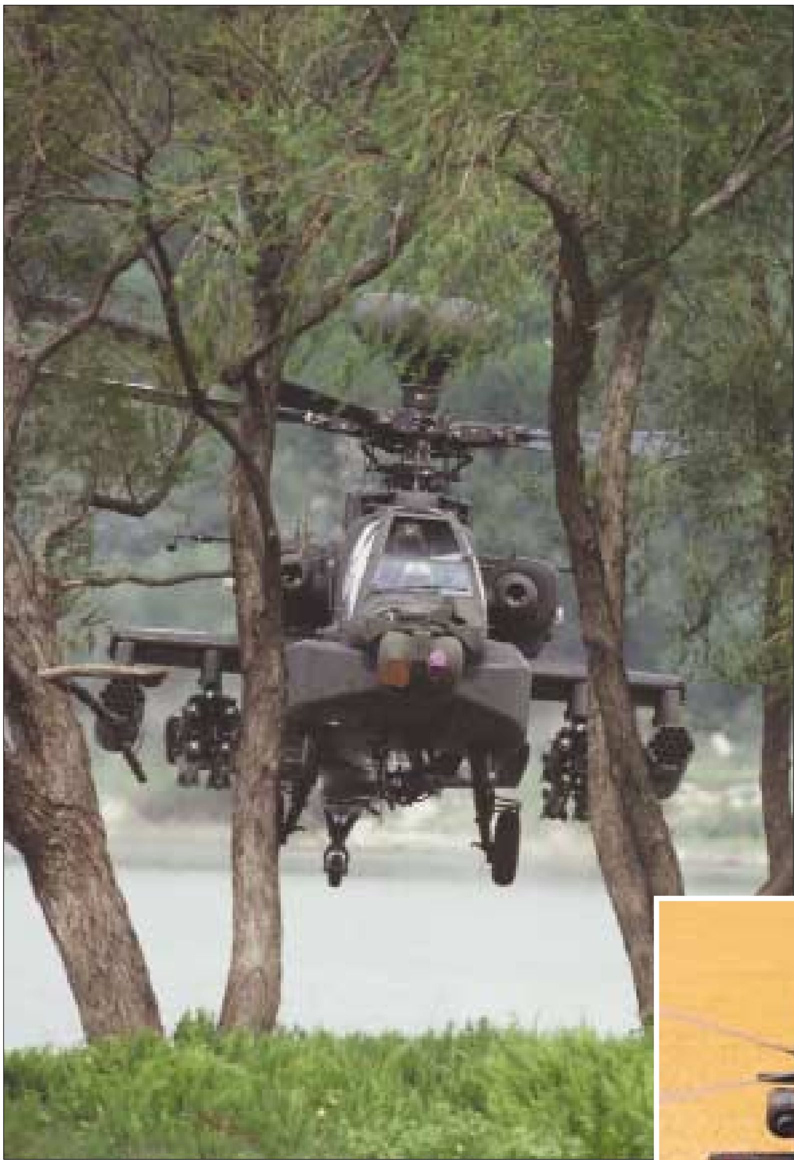
Gold is the pre-eminent noble metal, prized throughout history for its beauty, permanence and rarity—an enduring store of wealth and the basis for countless decorative, ceremonial and religious artefacts. In the modern world, gold's unique chemical and physical properties mean that this regal metal is now finding increasing use in a wide range of industrial applications. Gold has outstanding resistance to corrosion and excellent bio-compatibility, is easy to work and has high thermal and electrical conductivity. Only silver and copper are better conductors of electricity, but cannot match gold's resistance to tarnishing or corrosion.

Uses of gold in electronics

In electronics, gold's immunity to environmental effects is possibly its most significant property—allowing the technical performance of gold electroplating or gold bonding wires to remain essentially unchanged by time. The mobile phone and PC markets have been fuelling a rising demand for gold in the electronics sector, and during 2000 it was estimated that around 280 tonnes found its way into electronics and electrical components[1]. Where the voltages are small, the circuitry complex, or reliability must be high, gold is usually the preferred choice.

Gold-plated contacts and connectors are the most important use of gold in the electronics industry. Examine your mobile phone and you will almost certainly see gold-plated contacts. Take apart an old computer and there will probably be gold-plated edge connectors on the circuit boards. The choice of optimum material for a contact or a connector is complex, and compromises are usually needed, but gold is generally considered the best material for low-voltage, low-current and low-contact-force applications. When two gold surfaces are brought together into intimate contact, the resulting electrical connection offers unrivalled low resistance and stability. In many cases, small quantities of nickel or cobalt are added to produce 'hard gold' increasing hardness and reducing wear in sliding operations, e.g. on PCB edge connectors. To minimise cost, the thickness of gold used is always the minimum compatible with the performance required, although this will clearly depend on the operating environment. Connectors for use in clean, ambient environments may require as little as 0·1 μm of gold, whereas some under-the-bonnet automotive applications may require 2 μm or more. A layer that is too thin can be porous, and may fail to prevent corrosion of the underlying layers.

In recent years, a perception of high cost has prompted the use of a number of alternative coatings, for example palladium-nickel, despite the fact that palladium coatings can catalyse the



AH-64 Apache attack helicopter. Gold-plated connectors are specified in military or aerospace applications where reliability and safety are critical

formation of insulating polymeric materials on the conducting surfaces. In addition, recent increases in the cost of palladium have meant that gold-based coatings are actually much more cost effective than is sometimes believed (palladium was over $1000/oz in January 2001, compared to gold at around $280/oz).

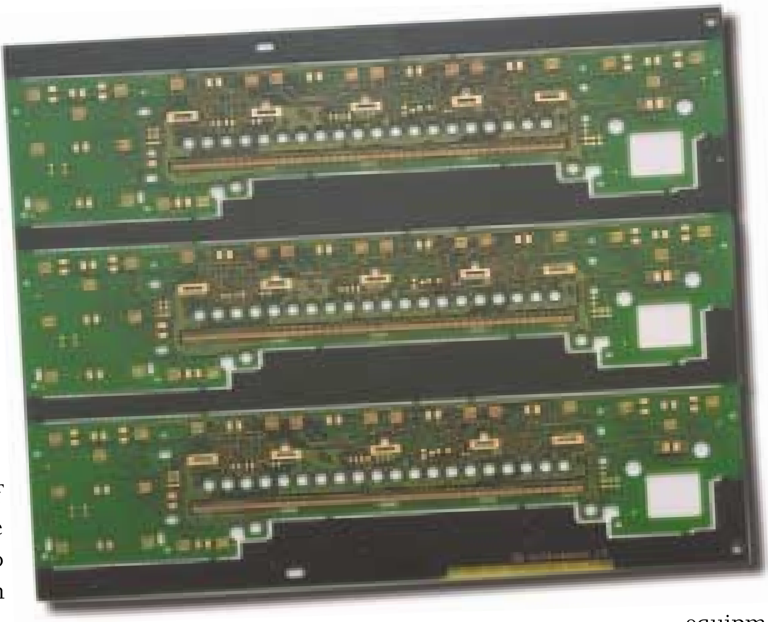
The second largest application for gold in electronics is in the form of gold bonding wire, probably consuming around 100 tonnes of gold each year. Wire bonding is the method used to form electrical connections within an electrical device or assembly, the bonds connecting pads on the semiconductor surface to the inside of the package terminals or to other devices. Gold remains the foremost material for this application. Using gold, automated systems can achieve bonding rates of the order of 20 bonds per second, with wire diameters typically less than the width of a human hair. Gold's pre-eminence in this application is due to the very high reliability of the bonds, high production rate, and the inertness of the gold wires, ensuring that they do not corrode during the life of the chip. Aluminium is also used, but in a number of respects is inferior to gold. It's a much more reactive metal, and as such is prone to oxidation and corrosion, necessitating the use of hermetically-sealed ceramic packages. At only eight bonds per second, bonding rates are also much lower. Finally, wedge-shaped bonds are required—in contrast to the more space-efficient ball bonds used in gold wire bonding. There have been studies on ultra-fine wires of copper, silver and palladium, but none of these metals can match the bonding reliability of gold.

As the trend to increased component density continues, there will probably be a need for better heat transfer away from components, and solder die attachment may be appropriate in some instances. Where semiconductor chips generate significant heat during use, high melting point gold-based solders can be used for attachment. These solders have better thermal conductivity than polymer based materials, such as silver-loaded adhesives.

As an excellent light reflector, gold is also used in optoelectronic devices including optical switches. One of the largest new uses of gold is as sputtering targets for the deposition of very thin (50-100nm) gold layers on writeable compact discs and DVDs. Other applications of gold in electronics are numerous, though consuming relatively small quantities of the metal. Metallic conductors can be deposited by screen printing with a gold-based thick-film ink. These hybrid circuits are increasingly used for high-frequency communications and for some automotive applications, where reliable operation at high temperatures is required.

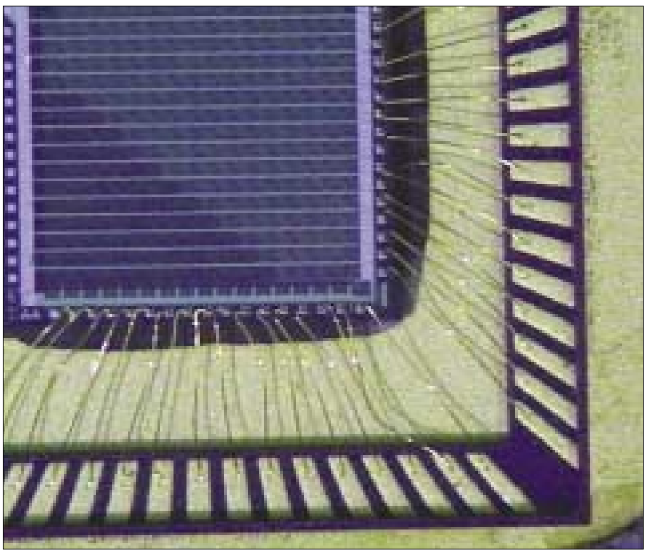
Gold's excellent solder-wetting properties play a valuable role in the electronics industry. Bare copper tarnishes rapidly, necessitating some form of protective layer to maintain the solderability of copper laminate printed circuit boards during storage. A number of protective coatings are used, but electroless nickel (the deposition of an approximately 2 μm layer of nickel by chemical reaction rather than electrolysis) followed by immersion in a gold solution (forming a gold layer of some 0·07 μm by a displacement reaction) gives the best protection.

Somewhat thicker gold coatings are also used to protect component leads from tarnishing, and on connector pins, one end of which may need to be soldered to a PCB or to wiring. The protection increases with thickness, but if the gold is too thick, brittle joints will be formed as a result of the formation of tin/gold intermetallic phases. This can be prevented by ensuring that the gold dissolved in the solder is at a concentration of less than 4%. As a useful guide, it also helps to limit the thickness of the gold coating to a maximum of 0·5 μm.



Gold-plated circuit board contacts (picture courtesy of Degussa Galvanotechnik GmbH)

Currently, high-melting-point solders based on lead are used where the operating temperature is over 150°C, for example in aircraft, light bulbs or some automotive applications. However, under the proposed RoHS (Restriction of Hazardous Substances) Directive[2], manufacturers may be required to use alternative materials to the listed banned substances, including lead—although high melting point solders may be exempt. A few tin-based (lead-free) alloys with high melting points are available, although all have melting points below the 300°C limit required for some high-power components. The only lead-free solders with melting points close to and above 300°C are gold-based solders and these may increase in popularity. Use of gold solders will enable manufacturers to state that their products are lead-free.



Gold bonding wires

Recycling waste

Across the European Union, an estimated six million tonnes of electronic and electrical equipment was generated in 1998. The EU expect this to increase by 16—28% in five years and is planning to introduce a directive on WEEE[3] (Waste Electrical and Electronic Equipment) in the near future. Currently, only a few categories of scrap are recycled in significant volumes, namely large white goods, some IT equipment and some telecom equipment. ICER (Industry Council for Electronic Equipment Recycling) estimates that in the UK in 1998 the recycled percentages for large white goods, IT equipment and telecoms equipment were 88%, 40-50% and 50% respectively[4].

The high proportion of IT and telecoms kit currently recycled is attributable principally to the quantities of precious metals found in such equipment. In some circumstances, the worth of the precious metals recovered can exceed the recycling costs, yielding a profit to the recycler. The gold content of scrap computer PCBs can be as high as 400g/tonne[5]. Copper, palladium and silver are also recovered in the recycling process. Different categories of electrical goods vary significantly in their scrap value. For example, PCBs represent only 1% of the bulk of brown goods (TV sets, hi-fi equipment etc)—the remaining volume being taken up by casing, screens wiring etc, all devoid of useful quantities of precious metals. Add to this the fact that the typical brown goods PCB yields only 20 g of gold per tonne, and it is obvious why brown goods have no scrap value and represent a net cost to the recycling process.

The introduction of the WEEE Directive could require the recycling of most electronic and electrical equipment, even where this involves a net cost. Mandatory recycling on this scale, it has been estimated, will cost equipment manufacturers over £2 billion per annum. One likely consequence of the WEEE Directive could thus be a move by manufacturers towards ‘design for recycling’, i.e. selecting materials at the product design stage that minimise the overall lifetime costs. For example, it’s possible

WGC and ERA

World Gold Council (WGC) is an international organisation through which gold mining companies collectively promote and expand the demand for gold by consumers and institutions. In addition to its gold jewellery and investment promotional activities, the WGC encourages the greatest possible use of gold in industry. This last activity is supported by the WGC's subscription-free, scientific journal, Gold Bulletin (see www.gold.org for details). The WGC also provides limited research funds to support short-term, pure and applied R&D projects, with particular emphasis on feasibility studies focused on new or expanded uses of gold in industrial applications. Proposals for funding support under the GROW (Gold Research Opportunities World-wide) programme can include any industrial application that has the potential to increase industrial consumption of gold or its alloys. Researchers in academia or industry with suitable research proposals are invited to contact the Council for details.
ERA Technology Ltd has over 30 years experience in evaluating the technology and reliability of electronic components and equipment and provides a comprehensive consultancy service in several areas of expertise. These include comprehensive reviews of specific areas of technology, guidance and advice on implementing the changes required by the new RoHS and WEEE directives and failure analysis. The causes of failure of electronic components and electronic circuitry are identified and corrective action is recommended.

that the directive will require all hazardous materials, including lead, to be removed from end-of-life equipment, prior to disposal in special landfill sites. This will incur a labour cost and a landfill charge. One way of reducing such charges would be a greater use of gold-alloy solders, such as gold-tin, as an alternative to high-lead-content solders in high-temperature applications. The initial costs would be higher, but there would be no disposal costs associated with the solders, resulting in lower lifetime costs for the product.

40 GHz microwave device produced in thick film gold by Microtel using ERA μ-Screen printing technology

Another, more indirect, effect of the legislation could be to encourage the reuse of modular PCBs—salvaged from old equipment for use in new products. This approach has already been developed by Xerox for photocopiers, and reports indicate that it has resulted in large cost savings. Widespread adoption of reusable modular PCBs is likely to stimulate the use of gold within the electronics sector—the PCBs will need reliable long-life connectors, implying the use of gold as the plating material. The WEEE Directive states that, as a recycling option, modular PCBs are preferable to smelting and refining, as less energy is used and emissions are lower. As the final form of the directive is developed over the coming months, the costs associated with disposal and recycling will become clearer, and the costing of alternative material and design solutions to meet engineering specifications will be developed in more depth.

New technology

In recent years, a wide range of new technologies and developing markets have stimulated the industrial application of gold. Many of these are visible in our everyday lives, such as the use of gold plating and bonding wires in the rapidly increasing smart card market. Other uses are not so visible, but no less important, such as the increasing use of gold in automotive applications, including ignition control electronics, anti-lock brakes and electronic fuel injection. Where safety and reliability are important, gold-plated contacts and connectors can be relied upon to perform as required, even after many years of inactivity. Crash sensors for airbags are a classic example of this last type of application, for which gold is essentially irreplaceable.

Sometimes a change in a seemingly unrelated technology can affect the need for a specific material. For example, in the past, as a way of minimising cost, connectors on fuel tank sensors were generally silver plated. Today, however, the move to low-sulphur petrol has led to a switch to gold plating. The sulphur is removed by converting the sulphur compounds into sulphides, and the small amounts of sulphide remaining in the fuel would tarnish silver connectors.

Many of the technological trends for the 21st century will significantly affect the types of materials used in electronic devices, including a trend towards a greater use of gold. Microwave communications technology is becoming more important, resulting in the increased use of gallium arsenide and gallium nitride semiconductors. This in turn is stimulating the demand for gold and gold alloys, which combine high electrical conductivity with compatibility with these high-frequency compound semiconductor materials[6].

In the quest for radically higher processing rates, it is likely that future information processing technology will involve highly integrated electronic devices, designed and fabricated on the nanometre scale. With its inherent resistance to oxidation and mechanical robustness, gold should prove an indispensable element in nanoscale processing.

Work on gold nanowires as a potential nanometre interconnect material is under way in research centres around the world. For example, researchers at the University of Delaware in the US have developed self-assembling and self-repairing gold microwires, based on tiny particles of gold suspended in an aqueous solution. Using electrodes inserted into the solution and an alternating electric field, the researchers were able to form gold wires more than 5 mm long, and of the order of 1 μm in diameter. It has been shown that these wires can be used as microscopic sensors for certain chemicals, including thiols and cyanides. The University researchers have also proved the principle of making electrical connections, by using this technique to assemble rudimentary circuits.

In a separate development, optical processing, including complex all-optical switching, is seen as an important element in the design of future optical networks. Many of the components that enable such networks will be based on non-linear optics. Dr Masatake Haruta of the Research Institute for Green Technology, Japan, is currently investigating the properties of non-linear optical effects created by embedding gold nanoparticles in glass materials[7].

Gold plays a vital role in the contemporary electronics industry, and in many applications where performance and cost are important, gold remains the long-term technical and commercial material of choice. Future technologies will demand material properties that can only be found in gold and its alloys. Gold will continue to be prized for its intrinsic beauty but, without doubt, it will also be of the utmost importance to the electronics industry for many years to come.

Developing gold nano-wires (picture courtesy of University of Delaware)

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Links

www.gold.org
www.era.co.uk

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