Gold’s Other Uses

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Good afternoon, ladies and gentlemen. I would like to thank the LBMA for inviting me to give this talk. In this presentation I will give an overview of some other uses of gold excluding jewellery.

For many years, gold has been considered a symbol of wealth and adored for its beautiful rich yellow colour, resulting in its use for jewellery and decoration purposes. But this precious metal has distinct and unique properties, which make it valuable for industrial applications.

Although gold is a precious metal like the platinum group metals (platinum, palladium, rhodium, ruthenium, osmium and iridium), the metal has not been developed significantly outside the jewellery and electronic fields. The result was that, unlike the platinum group metals, little industrial uses have been commercialized for gold.

Approximately 80% of annual gold mined is consumed for jewellery production. Of the remaining 20%, the main industrial usage is the electronic industry (approximately 9%). Some other minor applications include dentistry, decoration, coins and investment.

The question could therefore be asked, if jewellery and electronic uses were excluded, what is left to talk about? This said, a renaissance in industrial gold research and development is underway, driven mainly by the discovery of the catalytic properties of gold. The perception that gold is too precious to be useful is changing.

In this presentation I will introduce you to new industrial uses of gold, and not spend much time on existing uses such as dental and decorative applications. Gold’s excellent biocompatibility, corrosion resistance and mechanical strength have engraved the use of the metal and its alloys in dental applications, such as crowns, bridgework and with porcelain enamels.

Electronics

Let’s look briefly at the use of gold in electronics, as this is a major industrial application. Some of the unique properties of gold such as its nobility, malleability, and excellent heat and electrical conductivity make it the material of choice for electronic use, especially in applications depending on reliability, such as telecommunication, automotive use and defence. The use of gold in electronics has increased by 27 tonnes in 2004 to a total of 261 tonnes, due to rising economic
growth and accompanied higher demand for consumer products, according to the GFMS survey of 2005. This is the third consecutive year of growth to meet higher demand from consumers, producing circuitry applied in e.g. laptops and cellular phones, as well as by the semi-conductor industry. Some of the forms in which gold is applied for electronic use are indicated in the slide.

Other Industrial Uses

Various research and development programmes focusing on new industrial uses for gold have received funding from the gold mining houses and/or government programmes over the past decade.

Project AuTEK is a collaboration between the three major mining houses (AngloGold Ashanti, GoldFields and Harmony) in South Africa and Mintek, Council for Minerals Technology, to find new industrial uses for gold. AuTEK Americas has been launched this year, and funding mechanism is similar to the South African analogue: government matches funding from the mining houses. The technical work within Project AuTEK- RSA focuses on three main R&D fields, namely catalysis, nanomaterials and biomedical applications. I will expand on these three fields in terms of new industrial uses during this presentation.

Gold Catalysis

Traditionally, gold metal was thought to be too inert and noble to be an active catalyst. However, if the metal is highly dispersed as nanoparticles (2 to 10 nm in size) on a metal oxide support, an active catalyst for various reactions results.

Gold catalysis can be divided into three main application fields: environmental, chemical processing and fuel cells. I will give some examples of each.

Environmental

Gold catalysts can easily oxidise carbon monoxide to carbon dioxide at ambient temperature. This activity is even enhanced in the presence of moisture. One potential application making use of this unique property of gold catalysts is the use in respirators. Currently a copper manganese oxide catalyst is used in respirators for carbon monoxide oxidation. This material deactivates easily, especially in the presence of moisture. Respirators that are cost-effective, lighter and have a longer lifetime for escape purposes can be obtained with gold-based catalysts.

Chemical Processing

The potential of gold as an important catalyst in chemical processing is well established. The conversion of ethyne to vinyl chloride using a gold carbon catalyst was an early and very significant breakthrough in gold catalysis. Gold catalysts have been found to be about three times more active than the commercial mercuric chloride catalysts.

The direct gas-phase synthesis of propene oxide (PO, used extensively in the production of polyurethanes from propene) using molecular oxygen in the presence of hydrogen offers the opportunity to eliminate chlorine from the
production process, as well as reduce water consumption and salt by-products. There is significant industrial interest in this application, and pilot plants are understood to be operating in industry. Bayer researchers have claimed an 8% yield of propene oxide with 95% selectivity.

Potential opportunities for gold-based catalysts in the food industry include the selective oxidation of lactose and maltose to lactobionic acid and maltobionic acid, the conversion of glucose to sorbitol and gluconic acid, and the oxidation of glycerol to glycercic acid.

Vinyl acetate monomer (VAM) has been produced industrially for some time from acetic acid, ethene and oxygen using palladium-gold (Pd-Au) catalysts in a fixed bed process. The first fluidised bed process for VAM has now been commissioned by BP for a new plant in Hull, United Kingdom. The process, which requires only a single reactor, uses a new Au/Pd catalyst developed in collaboration with Johnson Matthey. Vinyl acetate is used in the manufacture of emulsion-based paints, wallpaper paste and wood glue.

**Fuel Cells**

Recent research has suggested that gold-based catalysts could be effectively employed in hydrogen processing and related fuel cell systems. Four possible areas have been identified where gold catalysts could be advantageously applied in fuel cell hydrogen supply systems and in the fuel cell itself:

- The water gas shift (WGS) for clean H2 production
- Selective oxidation/removal of CO from H2 feedstocks or within the fuel cell membrane to prevent poisoning of the Pt fuel cell catalyst.
- As a CO tolerant electrocatalyst to catalyse the hydrogen reaction within the fuel cell.
- Oxygen reduction in alkaline fuel cells.

**Gold Nanomaterials**

A nanoparticle consists of a few atoms forming a cluster with size in the nanometer range. A nanometer is a millionth of a millimeter. Considerable attention has been focused during the last few decades on developing and optimising methods for the preparation of gold nanoparticles to size and shape e.g. spherical and non-spherical (triangles and hexagons) particles, as applications of nanostructured materials are dependent on these properties. The colour of ultrasmall gold spheres or clusters, also known as nanoparticles, has been known for centuries as the deep red ruby colour of stained glass windows in cathedrals and domestic glassware. The colour results from the plasmon resonances in the metal cluster.

Most gold nanoparticles are produced via chemical routes. Biosynthesis, investigated by Project AuTEK, is an alternative route used to create gold nanoparticles with yeast and bacteria resulting in non-spherical particles. These particles have different properties to conventional spherical particles and could further increase the use of gold.

Gold nanoparticles are easily functionalised to further exploit their properties. The term monolayer protected clusters (MPCs) defines surface functionalisation of these nanoparticles.
by self-assembled monolayers. A cluster of gold atoms or a gold nano-particle can be stabilised by a monolayer of, for example, alkanethiolated or phosphine ligands. Gold MPCs provide commercial interest in materials science, biological science and various chemical platforms. One example where gold nano-properties are second to none is in the area of medical diagnostics and therapies. Since gold nanoparticles have such good light-scattering properties, as well as easy functionalisation and biocompatibility, they are ideal for a wide range of biological and pharmaceutical applications such as bio-labeling and other types of diagnostics. Research conducted at the University of Liverpool in collaboration with Project AuTEK aims to improve these MPC gold nanoparticles even further, by designing stable, water soluble, biocompatible and functionalised nanoparticles.

Gold is a critical component in certain therapies, more specifically, in the treatment of cancer by hyperthermia and thermoablation. These two therapies use heat to kill cancer cells. In the case of hyperthermia, the cancerous tissue is heated to enhance conventional radiation and chemotherapy treatments, while in thermoablation the tissue is heated so that the cancer tissue is destroyed by the localised heat. There are two methods one can use to provide heating, infra-red absorption and the application of an oscillating magnetic field to magnetic nanoparticles. At the University of Rice, silica nanoparticles are being developed that are coated with gold nanolayers to form a gold shell around a glass core. By changing the thickness of the gold shell, one can control the wavelength of light that is absorbed by the gold/silica nanoparticle.

Tuned to capture infrared light and coated with cancer-specific antibodies, the nanoshell becomes a precision-guided cancer treatment and works as follows (see diagram).

(1) To diagnose and treat cancer, thousands of gold-coated nanoshells are injected into the patient’s bloodstream. Each gold-coated nanoshell is about 10,000 times smaller than a white blood cell. Inside the bloodstream, the nanoshells are taken up naturally by the tumour cells via antibodies stuck to their surface.

(2) Each tumour is covered by approximately 20 nanoshells and a brief exposure to near-infrared light by a very simple handheld laser, which passes harmlessly through tissue and illuminates the shells. The doctor then delivers a more intense near-infrared dose resulting in heat generated at the tumour.

(3) Free-floating electrons on the outer gold shells concentrate the intensified near-infrared energy, heating each individual nanoshell and burning the tumour cells without burning nearby tissue. The tumour tissue heats up to about 55 degrees Celsius.

What makes this technique unique is that the wavelength of light required is in the near-infrared, and body tissue is transparent to light of this wavelength. Therefore, this is an uncomplicated non-invasive technique of cancer therapy, and preliminary tests will begin next year on patients with soft-tissue tumours, like breast, brain or prostate cancer.

The technique of using magnetic nanoparticles to destroy cancer tissue is already commercially available. One of the obstacles of using these magnetic nanoparticles is that the nanoparticles are not biocompatible. This means that the magnetic nanoparticles have to be injected directly into the cancerous tissue. Research at Los Alamos National Laboratory is focused on coating magnetic nanoparticles with thin layers of gold, since gold is biocompatible and easily functionalised for biological markers. This will allow easier transportation of the magnetic nanoparticles to the cancerous sites, such as orally.

Biomedical Applications of Gold Compounds
Gold has excellent biocompatibility. The use of gold in medicine in the form of a chemical, pure metal or in alloy form is well known. The use of gold in medicine has been exploited throughout the history of civilisation. Gold dust and flakes have been used medicinally by the Chinese as early as 2500 BC.

In the late 1800s it was found that potassium gold cyanide, which is generally used in gold plating solutions, was bacteriostatic towards the tubercle bacillus. Gold therapy was introduced in the 1920s for tuberculosis. The suspicion that the tubercle bacillus was a causative agent for rheumatoid arthritis led to Jacques Forestier popularising the use of gold(I) salts in the treatment of rheumatoid arthritis in the early 1930s. Rheumatoid arthritis is an inflammatory disease characterised by progressive erosion of the joints resulting in deformities, immobility and great deal of pain. Auranofin is a gold salt in capsule form which is often used for treating inflammatory arthritis. It is believed that the gold salt decreases the inflammation of the joint lining. This effect can prevent destruction of bone and cartilage.

The discovery of the anti-tumour activity of cisplatin, cis-[PtCl2(NH3)2], in 1969 promoted the search for other metal-containing anti-tumour drugs. The first comprehensive studies of the anti-tumour potential of gold compounds were published in the 1980s. Anti-tumour developed gold(I) drugs have a mitochondrial mode of action, meaning that these drugs accumulate in the mitochondria, more commonly referred to as the powerhouse of the cell. On accumulation the drugs become toxic, causing cell death.

Selectivity is determined by the structure of the drug, which allows it to differentiate between healthy and unhealthy cells. Au(III) anti-tumour compounds, which are presently investigated, are isoelectronic and isostructural to Pt(II), and are expected to have a similar mode of action to the platinum analogues, i.e. targeting DNA.

Chrysotherapy (chrysos – Greek for gold) is the use of chemicals containing gold for the treatment of diseases. The chrysotherapy research platform continues to extend with anticancer, anti-microbial, anti-malaria and anti-HIV gold compounds being investigated. Gold’s biocompatibility has ensured its use in medicine throughout the history of civilization, and novel biomedical uses for gold can be expected in the future.

**Gold 2006**

The first industrial gold conference was held in 2000 in Cape Town South Africa, with a follow up in 2003 in Vancouver, Canada. A significant growth in gold R&D has resulted during this short time span with an increase in papers from 30 to more than 150. The next industrial gold conference will be held in Limerick, Ireland during September 2006.

**Conclusions**

Gold has unique properties that can be utilised successfully for industrial applications. The perception that gold is a precious metal and can only be considered as storage of wealth and appreciated for its beauty is changing. I have only shown you some of the novel applications that gold could be used for industrially in the years to come.

Ladies and gentlemen, thank you for your attention.

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