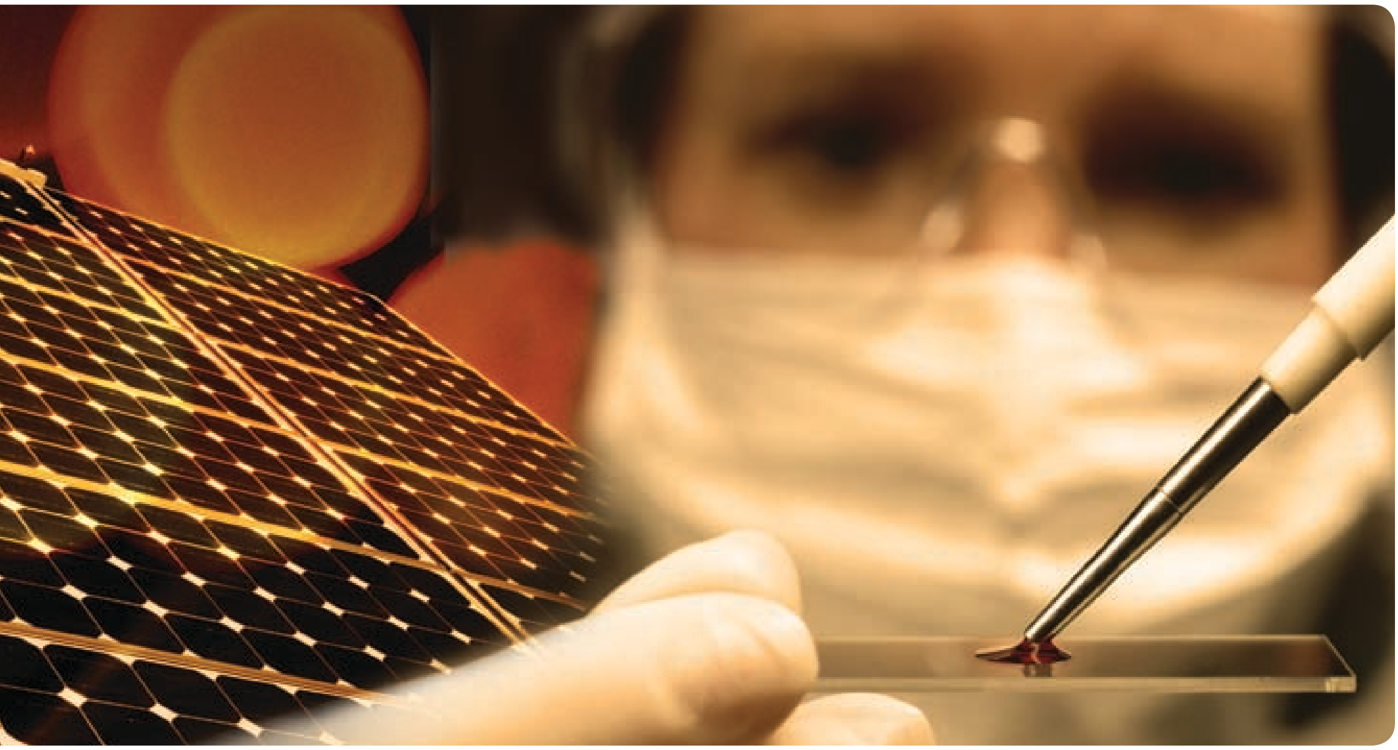
WORLD GOLD COUNCIL

GOLD FOR GOOD
Gold and nanotechnology in the age of innovation



gold

About World Gold Council

The World Gold Council's mission is to stimulate and sustain the demand for gold and to create enduring value for its stakeholders. The organisation represents the world's leading gold mining companies, who produce more than 60% of the world's annual gold production in a responsible manner and whose Chairmen and CEOs form the Board of the World Gold Council (WGC).

As the gold industry's key market development body, WGC works with multiple partners to create structural shifts in demand and to promote the use of gold in all its forms; as an investment by opening new market channels and making gold's wealth preservation qualities better understood; in jewellery through the development of the premium market and the protection of the mass market; in industry through the development of the electronics market and the support of emerging technologies and in government affairs through engagement in macro-economic policy issues, lowering regulatory barriers to gold ownership and the promotion of gold as a reserve asset.

The WGC is a commercially-driven organisation and is focussed on creating a new prominence for gold. It has its headquarters in London and operations in the key gold demand centres of India, China, the Middle East and United States. The WGC is the leading source of independent research and knowledge on the international gold market and on gold's role in meeting the social and economic demands of society.

In the industrial sector, WGC promotes the application of gold in the electronics industry based on its proven durability and reliability. The organisation's unrivalled breadth and depth of understanding of the industrial uses for gold affords it a unique position to help facilitate and accelerate commercialisation of cost effective, gold-based innovations. WGC achieves this through innovation partnerships and venture investments which support research and development of new practical applications for the metal by industrial partners.

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Executive summary

Nanotechnology offers the potential to overcome many of the serious issues facing mankind over the coming decades. Climate change, pollution control and prevention, access to clean water, falling energy reserves and the diagnosis and treatment of diseases such as cancer all represent significant challenges to man and the planet. New scientific and technological breakthroughs will be needed to deliver solutions. Over the last decade almost $50 billion of government funding has been invested into nanotechnologies, and this investment is now starting to bear fruit with a steady stream of commercially viable nanotechnologies which are positively impacting human health, the environment and technology.

Gold is at the forefront of this 'nanotechnology revolution'. Gold nanoparticles exhibit a variety of unique properties which, when harnessed and manipulated effectively, lead to materials whose uses are both far-ranging in their potential and cost-effective. *Gold for Good – Gold and Nanotechnology in the Age of Innovation* highlights the rich, fascinating history and exciting future of gold nanotechnology and explores the answers to two questions; why is gold so unique and useful at the nanoscale and, most importantly, what applications can it be used in for the wider good of society.

The earliest medical uses of gold can be traced back to the Chinese in 2500BC. Yet it has been the dawn of the nano-age that has really broadened the potential of gold in biomedical applications. Tumour-targeting technologies which exploit gold's inherent bio-compatibility are being developed to deliver drugs directly into cancerous tumours. Additionally, simple, cost effective and sensitive diagnostic tests are being developed for the early detection of prostate and other cancers.

Gold nanoparticle-based technologies are also showing great promise in providing solutions to a number of environmentally important issues, from greener production methods of the chemical feedstocks we need to produce our everyday goods and foodstuffs, to pollution control and water purification. For example, gold-based catalysts are being developed that can effectively prevent the release of highly toxic forms of mercury into the atmosphere. The metal is also being used in meeting the challenge of constructing cost effective and efficient fuel cells, a key 'clean-energy' technology of the future.

As the worlds of electronics and nanotechnology increasingly interact in the future, it seems highly likely the electronics industry's use of gold as a critical material will continue. Gold is being developed for conductive nanoparticle inks for plastic electronics because of its material compatibility, inherent durability and proven track record of reliability. Gold nanotechnologies have also been shown to offer functional benefits for visual display technologies like touch sensitive screens and potentially for use in advanced data storage technologies including advanced flash memory devices.

Clearly gold is at the very core of many scientific and commercial breakthroughs in nanotechnology which are having a positive impact on lives around the world. This paper serves to illustrate both the progress to date and the bright future of gold nanotechnology in a range of vital fields.

Introduction

What is nanotechnology?

Nanotechnology is a relatively recent branch of science concerned with controlling the properties of materials by working on the scale of a few nanometres, or the size of a few atoms. The most important aspect of nanotechnology is that it is a ‘bottom up’ technology. This means that instead of taking our usual ‘top down’ approach, we work in a way that is closer to the method nature uses for creating materials.

Humans have spent the last twenty thousand years taking materials that they find in the environment and forcing them to do something useful. If we wanted to cut something, we initially used shards of flint, and then progressed through bronze, iron and steel to diamond coatings. If we wanted to store information we moved from papyrus to paper and eventually to silicon.

By contrast, nature takes a ‘bottom up’ approach, and builds the perfect materials for the job. For example, DNA for data storage, or a self healing support structure for our bodies called bones, that while rigid, is flexible enough to absorb most of the knocks and tumbles we suffer during our lifespan.

While nature has evolved these materials over three billion years of random evolution, starting at the ‘bottom’ rather than at the ‘top’ has been the dream of scientists and engineers for over fifty years. Finally, with our combined understanding of materials science, biology, physics and chemistry, nanotechnology is helping us create materials and processes that are driving the development of a range of ever more sophisticated, effective and sustainable solutions to key issues affecting human health, the environment and technology.

Gold and nanotechnology

Gold has been regarded as precious for as long as humans have existed, and has been associated with gods, kings and immortality. Today, nanotechnology is enabling gold to help address critical global problems from cancer treatment to climate change.

Although nanotechnology is thought of as a new branch of science that has only emerged over the past decade, gold nanoparticles have been used, albeit unwittingly, for several thousand years. Roman artisans knew that mixing gold chloride into molten glass, a technique that produces tiny gold spheres, gives the glass a rich ruby colour (or possibly mauve if a combination of larger and smaller particles are produced). This technique produced much of the red colour in glass items from the famous Lycurgus Cup to stained glass windows of cathedrals across Europe.

Of course these ancient artisans were not aware that the optical properties of gold change when you create particles a few nanometres in diameter. Our modern concept of chemistry was totally unknown, and the primitive chemistry of the time, or alchemy as it was known, was more concerned with finding ways of turning more common elements such as lead into a big lump of gold, rather than finding new uses for gold.

Although nobody realised it at the time, there was a kind of alchemy going on, one that involved using small amounts of gold to produce something of much higher value than its constituent parts.

The next major step in the development of nanotechnology, in 1857, again involved gold when Michael Faraday found that gold colloids (solutions that contain a suspension of tiny particles) had special optical and electrical properties. Faraday used phosphorous to reduce gold chloride, which once again produced a suspension of gold nanoparticles. While Faraday and others developed techniques for reliably producing colloidal gold (vigorous stirring seemed to do the trick) the sub micron world was still a mystery, and although properties of gold nanoparticles could be observed and measured, nobody was quite sure why they behaved in this way.

Gold nanoparticles were once used to colour stained glass windows

With these ancient methods of producing nanoparticles, there was little control over the size of particles created and their concentrations but it worked well enough for its day. But in the era of microscopes so advanced we can see individual atoms, and of computers so powerful that we can model the behaviour of chemicals without setting foot in a lab, the applications of gold nanoparticles are expanding at an ever-increasing pace.

While gold cannot grant immortality, it can be used to understand the nature of diseases like cancer and to provide highly targeted treatments, and it can help to create cleaner vehicles and greener chemistry to reduce the environmental burden on the planet. This report explores the answers to two questions; why is gold so unique and useful at the nanoscale and, most importantly, what applications can it be used in for the wider good of society.

Gold for health

Gold has a long, fascinating history in the biomedical field stretching back almost five thousand years. Unlike other metals it resists tarnishing, so gold has long been associated with gods and immortality, and was therefore naturally associated with health.

The earliest recorded medical use of gold can be traced back to the Chinese in 2500 BC and since then numerous ancient cultures have utilised gold-based medicinal preparations for the treatment of a variety of conditions including smallpox, skin ulcers and measles. More recently, and with rather more success, drugs containing gold have been used in the treatment of rheumatoid arthritis and considerable research has gone into the potential anticancer and antimicrobial activity of gold compounds.

However, it has been the dawn of the 'nano-age' that has really broadened the potential of gold in biomedical applications. The unique properties offered by nano-sized gold particles are currently being studied in exciting and innovative academic research and exploited in a range of potential products heading towards market.

Therapeutics

Whilst the use of gold in the treatment of disease has a long history, gold nanoparticles are now being employed in entirely novel ways to achieve therapeutic effects.

The problem with many currently available cancer treatments is that they cannot be accurately targeted. As it is very hard to get an effective drug, such as paclitaxel, directly to the tumour, large doses are needed in the hope that enough of the drug will reach the diseased cells where it is needed. Unfortunately the drug doesn't distinguish well enough between healthy and diseased cells, and a wide range of side effects often occur, sometimes making the treatment seem worse than the disease.

However, if a way could be found to deliver the drug only to the cancerous cells, a much lower dose would be required, healthy cells would not be affected and side effects could be dramatically reduced. This is the basis of the movie Fantastic Voyage, which used a miniaturised submarine to deliver the payload, but nanotechnology is allowing us to turn science fiction into reality, and without the hassle of miniaturising submarines.

Probably the most advanced example is that of CytImmune's tumour-targeting technology *Aurimune*™, which exploits gold's inherent biocompatibility and unique properties to deliver a therapeutic dose directly into cancerous tumours. Whilst this may seem like the stuff of science fiction, CytImmune has successfully completed Phase I clinical trials (i.e. testing on a small group of people to confirm that the drug works as expected) and is about to embark on wider-ranging Phase II trials where a much larger scale trial is conducted in order to screen for any possible side effects that would have been missed in the initial small group trials.

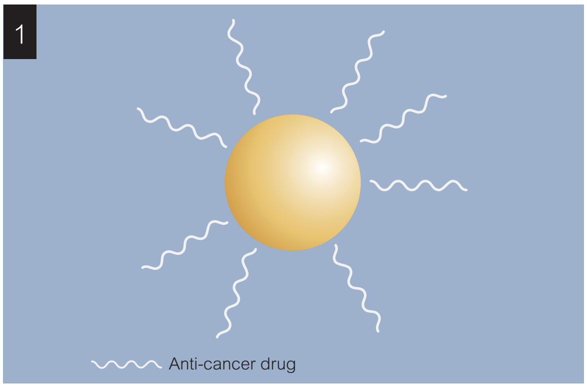
Another company making significant progress towards commercialisation is Nanospectra. Like CytImmune, Nanospectra is utilising gold to treat cancerous tumours, but in a completely different way. The technology, called *Aurolase*™, combines the unique physical and optical properties of gold-coated *AuroShell*™ particles with a near infrared laser source to thermally destroy cancer tissue without significant damage to surrounding healthy tissue. This promising technology is currently in Phase I clinical trials.

Both companies are building pipelines of gold-based therapies, clear proof that the market and investors are encouraged by the clinical data seen to date and excited by the future potential offered by such technologies.

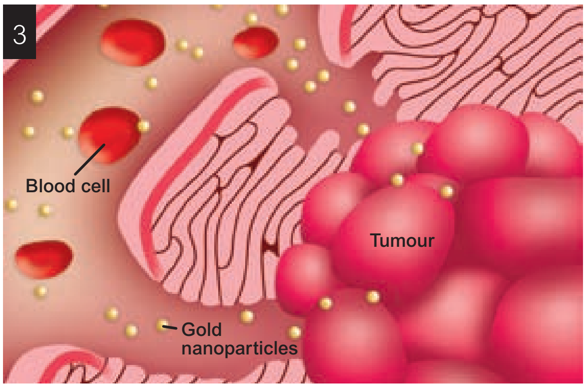
Diagnostics

Diagnostics is an area where nanotechnology, particularly using gold, has the ability to revolutionise the way we deal with disease. Whether it is highly sensitive and low cost diagnostic tests that enable people to be screened for diseases with limited early symptoms such as prostate cancer, or rapid screening for HIV. The earlier a disease is detected then the more effective (and cheaper) the treatment will be, allowing highly targeted drugs to be used instead of surgery.

The principles behind CytImmune's gold-based anti-cancer therapy

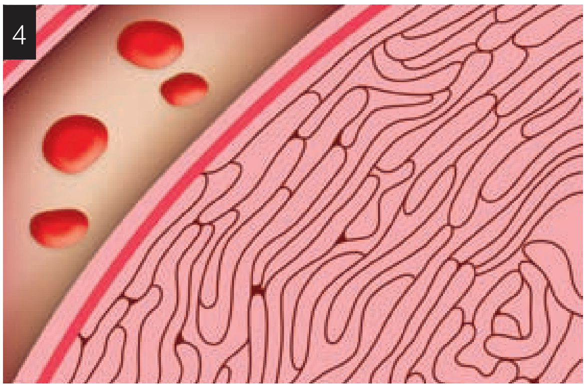


An anti-cancer drug is bound to gold nanoparticles



The therapeutic payload travels unhindered through the bloodstream and is delivered directly to the site of the tumour

The drug-loaded gold nanoparticles are injected into the patient



The tumour is treated, leaving the surrounding healthy tissue largely unaffected

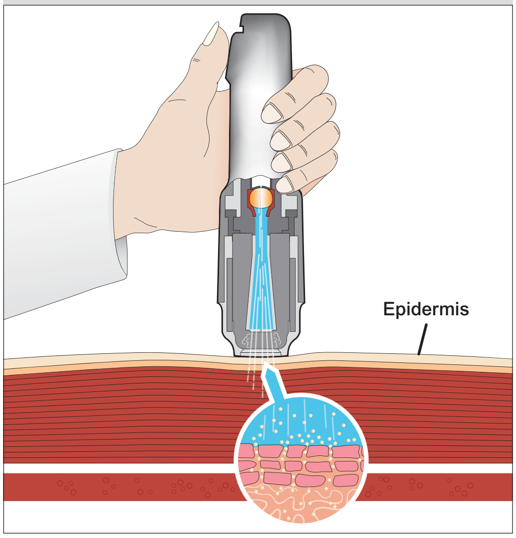
Needleless vaccine delivery?

Gold-based technologies are also being exploited by leading pharmaceutical companies. In 2006, Pfizer, the world's largest healthcare organisation, purchased the small British DNA vaccine company PowderMed.

PowerMed had developed a unique needle-free delivery system, a technique that used gold nanoparticles and allowed vaccines to be delivered through the skin making use of the fact that small particles can pass through gaps between cells while large ones cannot.

Through early phase testing, PowerMed achieved promising human *in vivo* data and had even shown the technology had potential for improved efficacy compared to more traditional vaccine delivery methods. This technology remains an active part of Pfizer's vaccine research programme today.

PowderMed's gold-based vaccine delivery system



Vaccine-coated gold nanoparticles are propelled into the epidermis by a burst of pressurised helium

Nanoparticulate gold is the perfect raw material for robust, rapid diagnostic testing. The minute quantities required make it inexpensive, whilst its stability, sensitivity and reproducibility of manufacture guarantee high quality supplies are always available.

Indeed, diagnostic applications utilising gold nanoparticles are already commercially available. The First Response® pregnancy testing kit, marketed by Church & Dwight, employs gold nanoparticles bound to a specific DNA sequence which is sensitive to the presence of a hormone indicative of pregnancy. Another example is the collaboration of BBInternational and Merck in the design and development of various tests for the detection of food borne pathogens. The Merck Singlepath assay uses gold nanoparticles to detect the presence of salmonella within twenty minutes, while the Duopath assay can be used to identify a range of pathogens including salmonella, E. coli and Campylobacter. A comprehensive study showed that food poisoning led to approximately 5000 deaths annually in the USA alone [1], making the availability of reliable diagnostic tests important.

More recently, the Illinois-based company Nanosphere has delivered a fully integrated diagnostics platform called *Verigene*™ to market. The *Verigene*™ system operates by detecting specific biomolecule targets with gold nanoparticles. These gold-based probes are non-toxic, have a long shelf life and, most importantly, are extraordinarily sensitive. The system can be used to diagnose a broad range of conditions. In addition to a growing pipeline of gold-based diagnostics, Nanosphere also has a tie-up with Eli Lilly, one of the world's leading healthcare companies, which utilises its gold-based technologies in the field of early drug discovery.

Medical diagnostics make up part of a valuable, rapidly-growing market in which gold is playing a significant role. There are dozens of academic, start-up and industrial research groups around the world working in the area, and we expect to see further market penetration in the coming years for the technologies currently under development.

Gold nanoparticles in the battle against HIV/AIDS

According to the World Health Organisation, HIV infection in humans is considered to be at pandemic levels. Worldwide, over 33 million people are believed to be living with HIV, with 2 million suffering an AIDS-related death in 2008 alone [2]. As is often the case, many of these deaths may have been preventable if access to the appropriate diagnostics and therapies had been more widely available.

The Bwindi Community Hospital laboratory staff with the PointCare NOW™ diagnostic system that uses gold nanoparticles

Spurred by this pandemic, pioneering work has been undertaken by PointCare Technologies Inc, a US-based medical diagnostics company. PointCare has a specific mission – to provide better diagnostic care to disadvantaged populations worldwide. Through the commercialisation of technologies developed by scientists over the previous three decades, PointCare has bought to market two products – *AuRICA*™ and *PointCare NOW*™. Both diagnostic devices rely on the unique properties of colloidal gold nanoparticles to allow the measurement of CD4 positive white blood cells. It is these cells which are attacked and destroyed by the HIV virus, so having an accurate measurement of their number is key to knowing how advanced the viral infection is, and how best to begin treating it.

The real strength of this diagnostic test lies in its simplicity and robustness. The colloidal gold itself is extremely hardy, making it suitable for long-term storage and use in the typical African climate. The diagnostic system is portable, simple to use, and provides a readout within minutes meaning many tests can be performed in remote locations.

Antimicrobials

Silver has a long history of being used as an antimicrobial agent, and is used in a number of marketed products. Probably the best known of these is the use of nano-silver impregnated dressings to treat wounds and prevent infections. However, the antimicrobial effectiveness of silver is known to deplete over time, meaning there is significant scope for improving such technologies. Researchers in Germany have dispersed a combination of gold and silver nanoparticles into polymer films. The presence of gold nanoparticles has been shown to enhance the long-term antibacterial action of the films, probably by slowing the rate of silver ion release. A team at the University of London have also developed a gold nanoparticle based photosensitiser that dramatically enhances antimicrobial effectiveness at small doses. This technology has been licensed to Ondine Biopharma Corporation in Canada for continued commercialisation.

The scourge of prostate cancer – can gold lead the charge?

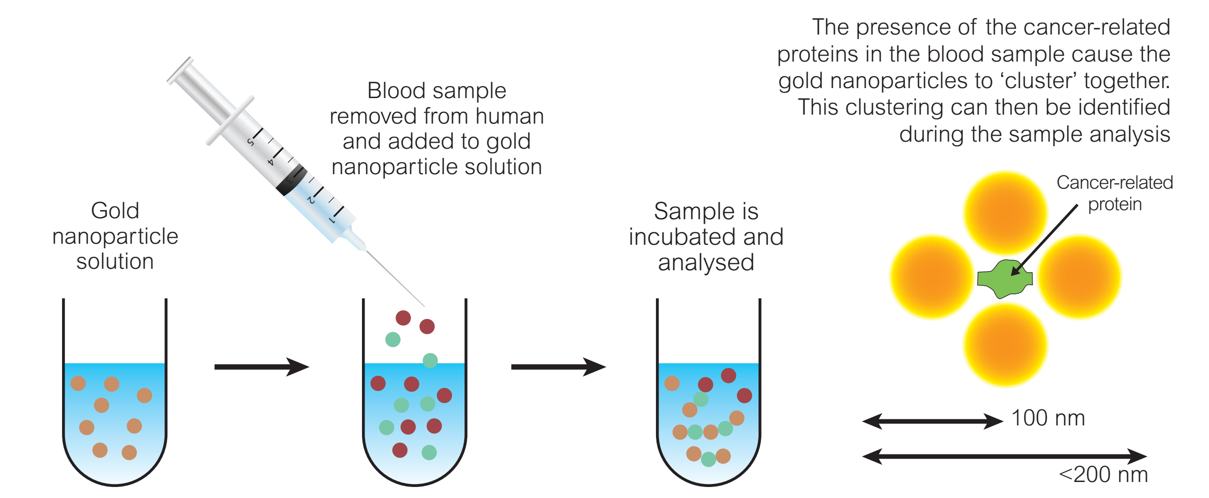
Prostate cancer is the second-most common cancer among men in the United States. It is estimated that more than 2 million American men are currently living with prostate cancer and that one new case occurs every 2.7 minutes. According to the Prostate Cancer Foundation, more than 27,000 men die from the disease each year [3].

A major contributor to these considerable numbers is the fact that there are few symptoms in the early stages of prostate cancer, meaning it is difficult to catch (and treat) the disease early. Currently cancer tests are expensive and inconvenient, so a simple, cheap and sensitive diagnostic kit could potentially save many lives.

This is the target of US-based researchers Professor Qun Huo of the University of Central Florida and Dr Cheryl Baker of M.D. Anderson-Orlando's Cancer Research Institute. Professor Huo's work hinges on engineering gold nanoparticles to attach themselves to specific cancer-related proteins. When these proteins are present in the blood, they sense the gold nanoparticles and form 'clusters' in the solution. It is these clusters that can be measured using a technique called Dynamic Light Scattering, an extremely sensitive particle sizing method. If clusters are shown to be present, the patient can be referred to a doctor for further testing and treatment if necessary.

The World Gold Council recently provided support to accelerate the commercialisation of this promising technology [4].

NanoDLSay a one step immunoassay that uses gold nanoparticles for early-stage cancer detection



Gold for the environment

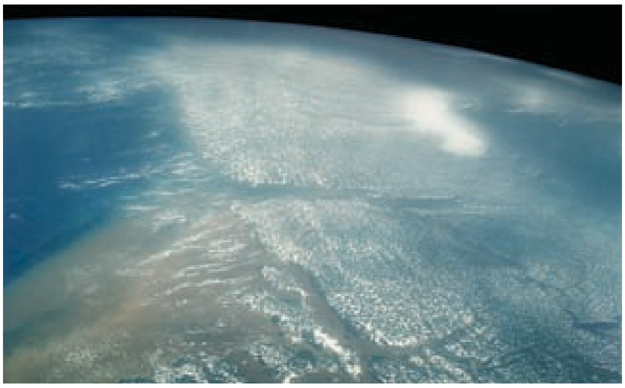
Environmental concerns have never been more prominent. The world faces huge challenges in the coming years as a consequence of ongoing population growth, ever increasing energy needs and the threat of global warming amongst a host of other issues. Gold nanoparticle-based technologies are showing great promise in providing solutions to a number of environmentally important issues, from greener production methods to pollution control and water purification.

Catalysts

The production of most industrially-important substances and chemicals involves the use of a catalyst to improve the efficiency and economics of the process. Size is important in catalysis as the reaction takes place only on the surface of the catalyst.

Getting the right catalyst can have numerous benefits to everything from oil refining to automotive emissions. Using nanoparticles can reduce the amount of precious metal required, and improved catalysts can both lower the temperatures and pressures required in some industrial processes, and improve the selectivity of reactions. This can result in more of the desired chemical being produced, and less waste.

Gold, for many years, was believed to be of no practical use as a catalyst, despite other precious metals like platinum and silver being widely employed. It was only in the 1980s that interest really began to take off in the use of gold nanoparticles as a catalyst in important chemical reactions. It is the understanding and availability of such particles that have led to the exponential growth of interest in gold as a catalyst over the last couple of decades, even culminating in an entire book dedicated to the subject [5].



Environmental challenges will dominate the coming years - gold nanoparticles offer a number of exciting potential solutions

There are many important chemical procedures that have benefitted from the availability of gold-based catalysts. Probably the most commercially established example is that of Vinyl Acetate Monomer (VAM) production. VAM is a key ingredient in emulsion polymers, resins, and intermediates used in paints, adhesives, coatings and textiles amongst others. As an illustration of the industrial magnitude of this process, British Petroleum commissioned a plant in the UK in 2001 for the large scale production of VAM, and even developed a brand new gold-based catalyst in collaboration with Johnson Matthey for use in the new facility. This plant, which has a VAM production capacity of a quarter of a million tons per year, continues its operation today under the ownership of INEOS, the world's third largest chemical company.

Gold is of interest in a variety of other commercially important reactions including the selective oxidation of sugars, the production of methyl glycolate and the water-gas shift reaction amongst others. Patent activity in these areas has been significant, with most major petrochemical and fine chemical manufacturers involved.

Gold catalyst availability

To meet an increasing interest in using gold nanoparticles catalysts commercially, larger scale supplies of catalysts are now available from various sources. 3M has developed a catalyst which is now distributed by UK-based Company, Premier Chemicals, under the trade name NanAucat™. The catalyst, which is nanoparticulate gold on a carbon substrate, is highly efficient with low gold loading, making it commercially viable. Mintek also supply gold-based catalysts on a range of supports under the brand name AuroLITE™.

Mercury control and sensing

Mercury is a highly toxic substance found in small ground deposits all over the world. Approximately 150 tonnes of mercury finds its way into the atmosphere every year, a third of which comes as a direct consequence of coal-fired boiler emissions. As mercury has been linked to Alzheimer's disease and autism, it is anticipated that the US Environmental Protection Agency (EPA) is soon to impose stringent limits on mercury emissions from such boilers in the utilities industry [6]. Couple this with the fact that the US is relying increasingly on the use of coal to produce electrical power, it is clear that any stringent limits could prove difficult (and costly) to meet. As such, there is currently a major focus on identifying methods to more effectively prevent the release of toxic forms of mercury into the atmosphere.

Exciting new research is beginning to emerge which suggests that gold-based catalysts can provide a solution. Studies performed at the US National Energy Technology Laboratory (NETL) in collaboration with Johnson Matthey have shown gold nanoparticles to have considerable promise as mercury oxidation catalysts. Full-scale trials are now underway in one US power station. Further research in this field has also been supported by the World Gold Council at a leading European university [7].

Monitoring and improving air quality around power stations includes control of mercury levels - trials are already under to use gold nanoparticles for this purpose

The effectiveness of any technology solution to the above problem will need to be measured. Here too gold nanoparticles may play a role as there is considerable interest in using gold nanoparticles to 'sense' and quantify mercury levels. Researchers in Australia have developed such a sensor by engineering a gold surface to take the shape of thousands of 'nano-spikes', which significantly increases the surface area of the gold. This allows the surface to more effectively trap molecules of mercury, enabling their number to be quantified.

Air quality

Carbon monoxide (CO) is a colourless, odourless gas which is extremely toxic to humans and animals. CO poisoning can occur with alarming ease and speed and exposure to even relatively low levels of CO can be fatal, making the efficient removal of it from closed atmospheres vital. Often produced as a result of poorly ventilated boilers, CO poisoning hospitalises over 4000 North Americans every year, with 10% resulting in fatalities [8]. Gold nanoparticles provide a simple solution, by allowing the oxidation of CO to carbon dioxide (CO_2), transforming an acutely dangerous gas to a far less toxic substance. What is striking about gold nanoparticle catalysts is that they can catalyse the oxidation of CO at extremely low temperature, even working at temperatures as low as -70°C. This unique property opens up the potential to use cost-effective amounts of gold as a commercially viable CO oxidation catalyst in a range of domestic and industrial applications. For example, a number of companies have already developed respirators which are required in emergency situations for protecting fire-fighters and miners from CO poisoning, and other applications are likely to appear soon.

Water purification

Our planet has no shortage of water, but it is unevenly distributed with much of it being undrinkable due to salinity or pollution. In some cases this is as a result of industrial pollution, in others the local geology means that even well water contains significant levels of heavy metals such as arsenic. However, heavy metals aren't the only problem – other common pollutants include pesticides and halogenated organics. These are all prevalent chemicals in many parts of the world, meaning literally millions of people are at risk of being exposed to contaminated drinking water.

Recent years have seen a sharp rise in the use of noble metal nanoparticles for water purification and contaminant detection. In addition to demonstrating great potential for the oxidation of mercury in gas flues, gold nanoparticles have also been shown to be efficient adsorbents for the removal of significant levels of mercury from water. Other breakthroughs have included the development of catalytically active bimetallic gold-palladium nanoparticles (which have shown real promise in breaking down trichloroethene, a common organic groundwater pollutant), and the development of simple detection methods to determine the concentration of pesticides in drinking water.

Fuel cells

Fuel cells are already accepted as reliable clean-energy power sources for space and military applications, and are now being developed for a wide spectrum of alternative uses, including vehicles. Although widely demonstrated and technically proven, their cost needs to be reduced to make them truly competitive in mass markets. It is here that gold nanotechnology is making a real impact.

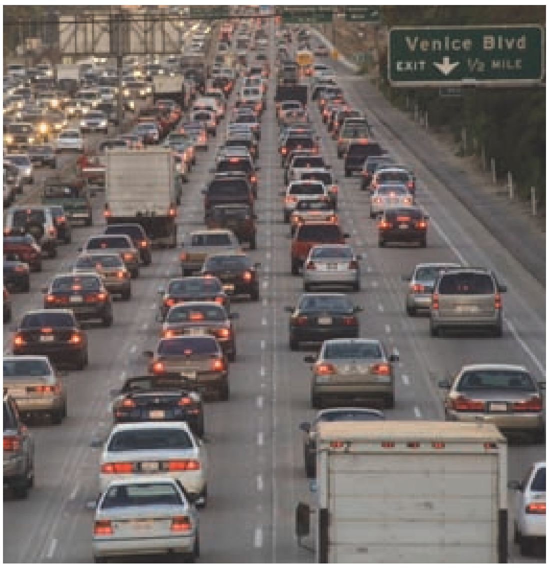
One of the biggest technical challenges regarding the construction of efficient fuel cells is finding cost-effective materials that can withstand the corrosive condition of the cell. Cells must be stacked together to achieve the necessary performance and durability, and gold-coated stainless steel has been recognised as the material of choice for these separator plates [9]. The only issue is cost – what is required is a reduced thickness gold coating which retains the performance of a thicker coating.

Many large car manufacturers have been working on this issue over the past few years, and it seems that the Ford motor company has made a considerable breakthrough. They are developing metallic bipolar plate technology with thin gold-coated stainless steel (under the brand name Au Nanoclad™) provided by Daido Steel [10]. They report that the use of Au Nanoclad™ provides a cost effective way of delivering the required electrical conductivity and corrosion resistance. Additionally, gold-coated stainless steel shows anodic passivation, i.e the thin gold layer heals itself, making it tolerant of coating defects including surface scratches during manufacturing, and reducing production costs of the bipolar plate.

Nanostellar Inc. – Developing a new generation of autocatalysts

Proclaimed as a 2008 Technology Pioneer by The World Economic Forum, Nanostellar Inc has developed a new catalyst product, NS Gold™, a formulation for use in the automotive industry that, for the first time, includes gold alongside traditional platinum and palladium metals. Autocatalysts have historically used platinum group metals to control harmful elements in automotive exhaust; carbon monoxide (a poisonous gas), hydrocarbons (from partially burned fuel that gives off diesel or petrol odour), particulate matter (or smoke - which contains cancer causing compounds) and NOx (smog forming compounds). The inclusion of gold, as a partial replacement of more expensive platinum, enables manufacturers of light and heavy-duty diesel engines to reduce these emissions at lower cost, making an important contribution to future automotive emissions control.

The World Gold Council (WGC) signed an agreement in December 2007 with Nanostellar. Under this agreement, the WGC invested to facilitate the commercialisation and marketing of the technology [11]. The viability of using gold in this application has now been recognised by the industry [12].



Energy-efficient glazing coatings

Since the 1960s gold has been used as a thin coating on building glazing to improve energy efficiency in the building. Ordinary window glass is almost completely transparent to solar radiation (from the ultra violet to the infrared wavelengths). Large glazing areas in buildings can cause significant heating of interior rooms and offices and increased loading on air conditioning installations. Vacuum deposited films of gold have excellent infrared shielding capability and the design of glazing to reduce this affect has sometimes used thin gold coatings on the glass. A good example of the use of gold in architectural glazing is illustrated by the Royal Bank Plaza building in Toronto. The building has 14,000 windows all coated with pure gold (70,000g in total). The gold reduces heating and ventilation costs inside the building.

There are three significant drawbacks with this technology. Firstly, manufacturing gold-coated glass is an expensive process (due to the use of vacuum technology rather than precious metal cost). Secondly, modern architectural tastes are not necessarily drawn to a gold colour. Thirdly the high reflectance of gold can cause irritating glare in surrounding environments.

Nanomaterials may have the answer; gold nanoparticle coatings can accurately ‘tune’ the reflective capability of the glazing at a reasonable cost and with the added advantage that a more appealing range of glazing colours can be obtained (blues and greys).

A team from the University of Technology, Sydney has already demonstrated the principle of this technology and recently a U.K. Government-funded consortium including Pilkington Glass and precious metal company Johnson Matthey demonstrated a proof-of-concept principle using gold-based coatings. A key requirement is to avoid the vacuum deposition process which is both costly and slow. Researchers from the University of Oxford working with Pilkington have recently developed a simple, rapid and low-cost approach to large-area deposition using spray coating.

Solar cells

Over the longer-term, in addition to the solar shielding applications highlighted above, uses of gold nanomaterials in glazing could have utility in generating heat - so-called ‘solar harvesting’. Taking this idea a stage further into the realm of solar cells, early research has shown gold nanomaterials may be used as an efficiency improving additive for a range of solar cell designs; the gold nanoparticles enhance the optical absorption in the range of visible light.

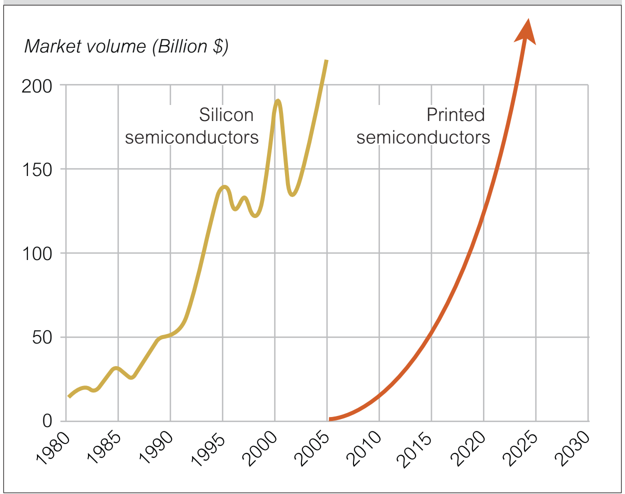
Might gold nanoparticles have a role in advanced energy efficient glazing coatings?

Gold for technology

Gold is well-established as a key material in the electronics industry. Gold bonding wire, electroplated contacts, solder alloys, thick film pastes and metallised coatings together use around 300 tonnes of gold per year.

As the worlds of electronics and nanotechnology increasingly interact in the future, whether through the use of new compounds for dissipating heat as dimensions shrink, or in new applications in plastic electronics, it seems highly likely the electronics industry's use of gold as a critical material will continue.

Rapid growth in printed electronics is predicted - durable, conductive gold nanoparticle inks will be vital for some applications in this market



Source: Market forecast SIA, IDTechEx 2006

Conductive inks for plastic electronics

Whether or not printable electronics develop into the huge market that is being predicted as shown above, there will no doubt be an increasing need for metallic inks that, following low temperature sintering, display excellent conductivity.

Although nano-inks made from copper and silver will form the bedrock of demand in this market, it is believed gold inks will also find use, either for reasons of material compatibility or because of gold's inherent durability and proven track record of reliability.

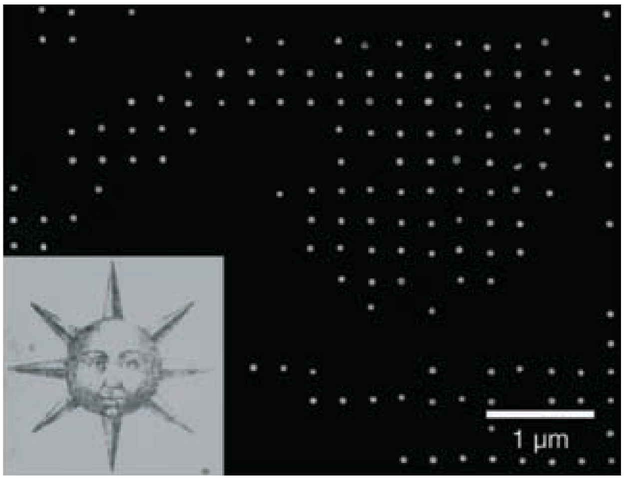
The key will be in the development of inks that can be applied by some conventional technology, such as ink-jet printing, and which require only low sintering temperatures to cure (metallise) the inks. Low temperatures are necessary to allow the inks to be used on the widest possible range of substrates including polymers. Both UK company Johnson Matthey and US-based NanoMasTech have recently developed such inks which are capable of delivering excellent conductivity.

Electronic tracks printed at low temperature using gold nanoparticle inks

Recently, the Department of Electrical Engineering and Computer Science, University of California, Berkeley investigated gold nanoparticles as a potential candidate for lead-free electronic packaging applications. Its optimised gold inks are able to sinter at temperatures as low as 120°C and achieve conductivities of up to 70% of bulk gold. The inks have been proposed as promising candidates for next-generation lead-free solders.

IBM has demonstrated a new nano printing technique it believes will lead to breakthroughs in future computer chips, optics and biosensors. The recreation of Robert Fludd's 17th century drawing of the sun – the alchemists' symbol for gold – was created by precisely placing 20,000 gold particles, each about 60 nanometers in diameter [13].

IBM believes the technology could have even wider application potential. In biomedicine, this printing process could be applied to generate large arrays of biofunctional beads that could be used for rapid screening for cancer cells or heart attack markers. The gold nanoparticles can also interact with light, and with this method optical materials with new properties could be printed, perhaps for use in optoelectronic devices.



Robert Fludd's 17th century drawing of the sun created by IBM using 20,000 gold nanoparticles

Touch sensitive screens

Gold nanoparticles have been shown to offer functional benefits to visual display technologies, solving one of the industry's most pressing problems, the increasing shortage of the metal indium. Indium is required to create touch sensitive screens for devices such as the iPhone and the electronic-ink displays used in E-Book readers. As the area is experiencing rapid growth, and there are estimated to be less than fifteen years supply of indium available, a solution is urgently needed.

Transparent conducting films based on nanocomposites of double walled carbon nanotube (DWNT) and gold are being evaluated. Such films need to be highly conductive and transparent, and many attempts using carbon nanotubes have failed to match the conductivity of currently used materials such as Indium Tin Oxide (ITO). It is now believed that the sheet resistance can be reduced significantly by reducing carbon nanotube resistance through the addition of gold nanoparticles to the films, thus overcoming bottlenecks in both the use of touch screens and of carbon nanotubes.

High density data storage

A seemingly never-ending requirement for storage of digital data continues to stimulate the investigation of a broad range of innovative technologies in high density data storage.

The use of optical rather than magnetic properties for data storage has been of interest for nearly thirty years and although CDs and DVDs are part of daily life, optical storage, while cheap, still cannot cope with storing the huge amounts of data generated by entertainment.

A solution may be on the cards using the same size of DVD but vastly increasing its storage capacity from 8.5 Gb to over 10 Tb (10,000 Gb). Current disks store data in a series of pits in the surface of the disc which are read by a laser. A pit is a digital 'zero' and a non pit is a digital 'one.' By adding a gold nanorod to react to different frequencies of light, and to allow the light to be polarised adds three additional dimensions thus boosting the potential storage. The researchers are now working with Samsung Electronics to commercialise the technology [14].

Future high density data storage could employ gold nanorods

A similar approach is being applied to non volatile memory storage – more commonly referred to as flash memory of the kind found in USB sticks and an increasing number of PCs such as the MacBook Air. By using a layer of gold, or a mixture of gold and cobalt, researchers in South Korea have been able to add more dimensions of data to flash memory. The more commonly used polycrystalline silicon and silicon nitride only allow a single storage level, either a ‘one’ or a ‘zero’ but the gold nanoparticle approach allows a number of different charge levels to be stored on a single memory element, thus allowing far higher storage density to be achieved.

Adding more storage capacity to flash memory can be achieved by using gold nanoparticles

Advanced dyes and pigments

The use of gold nanoparticles to colour objects is not new; the dye and glaze known as ‘Purple of Cassius’ consists of gold nanoparticles precipitated onto tin oxide particles. It has been used since 1659 to produce red to purple vitreous enamel glazes for use on high value pottery and porcelain. Our new found ability to precisely control the size of nanoparticles is leading to a range of new optical applications, from fashion to architecture.

Gold nanoparticles have also occasionally been used to dye textiles, a practice that dates back hundreds of years. However more recently this unusual use was revitalised by researchers at University of Victoria, New Zealand who have used gold nanoparticles as novel colourants for high quality wool. This technology is aimed at high value markets, linking the high value and prestige of gold with premium quality merino wool. Recipients of the ‘Innovator Award’ from chemical company Bayer, this research group is pursuing commercialisation of the technology and have progressed to a small pilot scale operation, with the production of demonstration textiles for customers.

With applications in mind, companies are beginning to offer gold nanoparticles on commercial terms. Swiss company Metalor has recently launched a range of gold nanoparticles for pigment applications. Although the cost of the precious metal will likely make these niche products, they do display virtually unlimited stability against UV exposure, good thermal stability and high colouring strength. Most interestingly, because they can be ‘tuned’ to have a unique optical signature, they have potential applications in security inks for anti-counterfeiting measures.

The application of thin gold layers to glass and ceramic objects using inks to produce a decorative effect is a technique that, in various forms, has been used for centuries. Historically gold inks were based on gold powders dispersed into natural resinous materials, which after firing and burnishing gave the desired lustrous decorative gold effect.

Inkjet printing using gold nanoparticle-based inks

Today gold nanoparticles may also be used as a precursor in mixtures designed to produce these thin, continuous coatings of metallic gold. Recently, Johnson Matthey demonstrated even newer gold nanoparticle formulations capable of being printed on paper at room temperature, potentially a technology for rapid printing in pure gold for luxury greeting cards, gifts, certificates or writing manuscripts and religious texts.

Where next?

The opportunities and possibilities identified in this report are just a subset of the amazing scope to use gold in the era of nanotechnology. These opportunities continue a story that started almost two millennia ago. Now, as a readily available and well understood material, gold nanoparticles are ready to be deployed in the battle against disease, in meeting environmental challenges and to contribute to technologies that improve our lives.

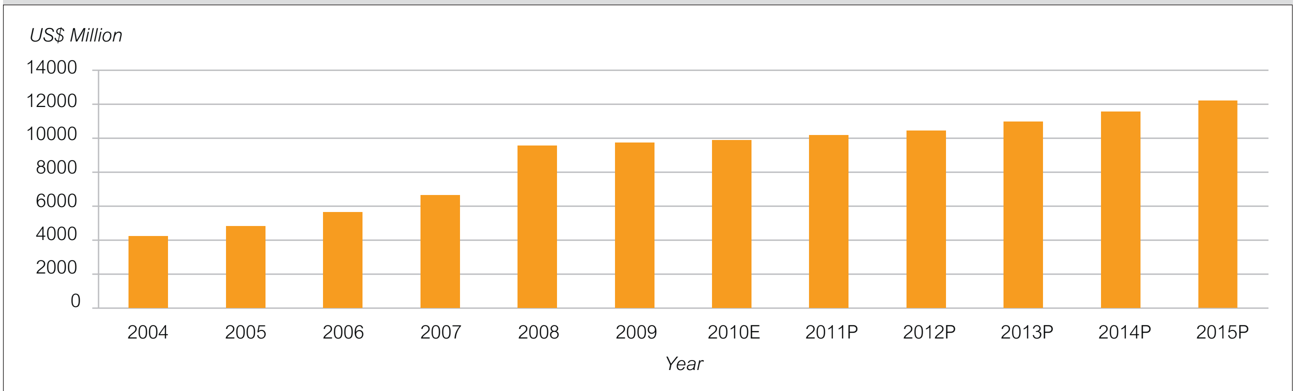
Looking beyond the technologies highlighted here, what might the 'Gold for Good' story be in the longer-term, perhaps 20 years from now? Certainly nanotechnology has been the focus of an ever increasing number of research programs around the world, with almost $50 billion of government funding being pumped into nanotechnologies over the past decade and much more destined to follow. This has, and will continue, to create the basic science that will underpin even newer technologies and so the applications we highlight here are considered to be only the beginning for gold nanotechnology in the age of innovation. What might we look forward to in the areas of health, environment and technology – the themes we have highlighted in this report?

In monitoring our health today only specialised labs can generally perform the tests required to identify diseases or pathogens. Tests can take weeks to complete and, in many cases, are costly. In the future, medical diagnostics are likely to be 'point-of-care' type systems using quick and inexpensive kits, perhaps purchased through the local pharmacy. The stability, sensitivity and reproducibility of manufacture of nanoparticulate gold makes it the ideal material to use for this task in the initial diagnosis of a range of conditions, and has the potential to be one of the key technologies deployed in the battle against future pandemics.

Green or sustainable chemistry, the philosophy of encouraging the design of products and industrial processes that reduce or eliminate the use and generation of hazardous substances, is destined to become a key element of society's plans to reduce environmental pollution. It will be part of the much talked about new 'cleantech' industry. A key part of this philosophy, producing important everyday chemicals from renewable feedstocks rather than oil, is still at a very early stage, but current research indicates that gold nanoparticles are highly effective catalysts for the necessary reactions. There is increasing evidence that gold may one day be a key ingredient in the commercialised processes used by the 'cleantech' industry.

Finally, our thirst for faster, smaller consumer technology products is straining current semiconductor chip design principles. How can we increase the overall computing power of chips without increasing energy consumption? Using light, not electricity, as the basis for future generations of chips has huge potential. The ability of gold to "shine" in a different way at the nanoscale may one day lead to its use in building new optical chips for a range of cutting edge technologies.

Global government funding of nanotechnologies continues to support the development of gold-based technologies



Source: Cientifica Ltd

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