THE SILVERINSTITUTE

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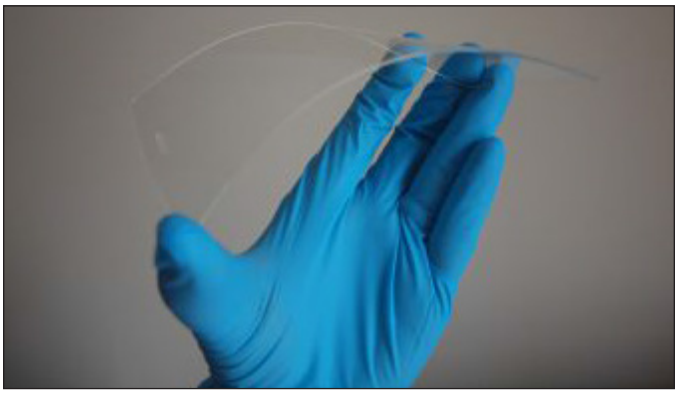
Silver News

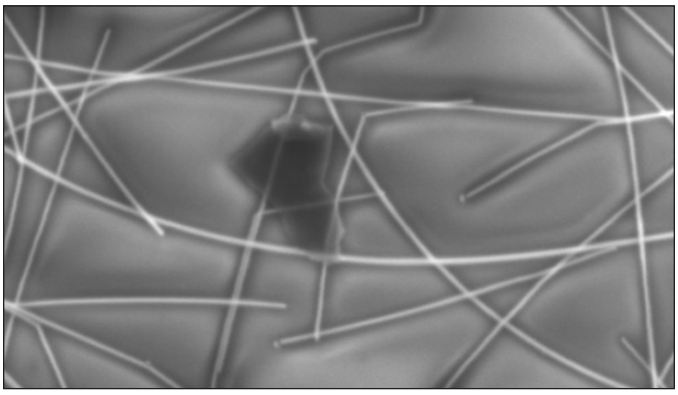
Silver and Graphene Combine to Make More Flexible Yet Stronger Touchscreens

By Trevor Keel, PhD., Technical Consultant to The Silver Institute



MATTHEW LARGE

Improved transparent electrodes are required to power the flexible displays and devices of the future.



MATTHEW LARGE

A Scanning Electron Micrograph of the teams' silver/graphene hybrid films. The scale bar is 1μM, or 1/1000th of a millimeter.

By combining silver nanowires and graphene -- a form of carbon -- a team of UK scientists has made a material that could produce touchscreens that are stronger and more flexible than those currently available.

As we reported in the August, 2016, edition of *Silver News* (*Silver and Next Generation Touch Screens*), silver nanowires represent a promising alternative to the material most commonly used to power touchscreen devices -- indium tin oxide (ITO). ITO is both optically transparent and conductive, but it does have drawbacks that have spurred the search for alternative materials in recent years. Indium itself is relatively expensive and has high supply risk elements, making it a costly and somewhat uncertain component for manufacturers. Indeed, since our report in August 2016, the price of indium has risen by about 20%. Additionally, ITO is brittle and is known to have serious performance flaws on flexible displays, a product area predicted to see significant future growth within the electronics sector. These factors make the search for alterative materials increasingly pressing.

"The reason current touch screen devices are brittle is due to the use of ITO to make the touch sensors. As this material is brittle, it needs to be supported with a suitably hard, inflexible substrate [like glass]," said Matthew Large, PhD., of the University of Sussex, UK, and lead investigator of the research team. "Our hybrid material is super-flexible, and could be produced on cheaper, more robust plastic substrates. When one of these new devices is dropped, the flexing of the screen allows it to absorb the impact energy without cracking, and without affecting the device performance."

Large added: "In our latest work we've found that the combination of silver nanowires with a small amount of graphene creates a hybrid transparent electrode material that radically outperforms either material on its own."

What is graphene, and why does it combine so effectively with silver nanowires? Graphene is a single layer of carbon atoms arranged in a simple hexagonal lattice, however, this apparent simplicity belies

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a host of fascinating properties. Graphene is extremely strong, and is an excellent conductor of both heat and electricity. Its existence has been recognized for many years, but it was only in 2004 that it was isolated and fully characterized, leading to the researchers being awarded the Nobel Prize for Physics in 2010.

The combination of silver and graphene holds considerable promise for future flexible displays and screens. The materials complement each other perfectly, and, according to Large, offer a range of benefits. "There are several advantages to the way we prepare these new electrodes. The first is that while the performance improves the cost goes down significantly. This is because we can use less material overall to achieve the same results. Second, we have the ability to put our graphene down selectively on the surface, allowing us to produce device patterns in a single step using a [simple stamping technique]. Last, we have seen an improvement in our electrodes' resistance to atmospheric tarnishing as well as their response to being flexed multiple times."

With any new material, a major concern often centers on the ability for scaling up to commercially-viable quantities. In this case, the silver/graphene hybrid films appear to lend themselves to large-scale manufacture. According to the team, the method of patterning the graphene particles onto the nanowire film offers a suitable route for direct scale-up using commercially-available spraying machines and patterned rollers.

Recent announcements from Heraeus, the German technology group that focuses on precious and special metals, further bolster the viability of large-scale silver nanowire touchscreen technology. Their new line of conductive polymers was launched in November 2017, and relies on silver nanowires for superior conductivity and flexibility.

The ongoing search for ITO replacements continues, and it appears that silver is at the front of the pack. It may not be too long before touchscreens and displays rely on the metal for improved functionality, clarity and strength.

The research, published in the American Chemical Society's journal *Langmuir*, details the team's efforts to combine silver nanowires and graphene.

Highlights of the GFMS/Thomson Reuters/ Interim Silver Market Review

The silver market is expected to switch to a small annual physical surplus of 32.2 million ounces in 2017, after posting annual physical shortfalls for four consecutive years, according to the *GFMS/Thomson Reuters's Interim Silver Market Review*, that was presented in New York City at the Silver Institute's Annual Silver Industry Dinner in November.

Other highlights of the report include:

• The silver price has averaged US$17.13 per ounce as of 10th November, compared to US$17.23 per ounce seen over the same period last year.

• Total silver supply is forecast to remain broadly flat in 2017, standing at 1,008.4 million ounces (Moz), as slightly higher scrap supply and a drop in net de-hedging are expected to offset lower mine production. Global mine output is set to reach 869.7 Moz this year, representing a year-on-year drop of 2%. 2017 global silver production level is forecast to be 3% below the 2015 record level.

• Following five consecutive years of declines, global scrap supply is forecast to rise slightly this year to 141.6 Moz, up just 1% year-on-year, driven largely by higher Asia flows.

• Total physical demand is forecast to drop by 5% in 2017, to a total of 976.1 Moz, led by a sharp fall in retail investment, although an upturn in silverware demand, and a modest recovery in jewelry and industrial fabrication should help to offset some of that decline. Silver coin & bar demand is forecast to drop by 37% year-on-year, led by a sharp decline in North America.

• Jewelry fabrication is expected to recover slightly to 207.1 Moz, up by 1% year-on-year.

• Following a modest year-on-year decline in 2016, industrial fabrication is forecast to rise by 3% this year, to a total of 581.4 Moz, led by strong gains in the solar industry and modest increases in demand from electronics and brazing alloys & solders. Global silver demand from the solar industry is forecast to increase by 20% in 2017, to almost 92 Moz.

A complete review of the 2017 silver market will be released with the publication of *World Silver Survey* 2018, on April 12, 2018. Click here for the 2017 Interim Silver Market Review Press Release (PDF)

SILVER PRICE RANGE, US$/OZ

GFMS

Source: Thomson Reuters Eikon

THOMSON REUTERS

Getting Silver to Fight Germs on Cue

Silver nanoparticles are excellent for killing germs but they often have a drawback. The particles tend to conglomerate, which lessens their antibacterial abilities because the surfaces become less exposed. Scientists at Kumamoto University, Keio University and Dai Nippon Toryo Co., Ltd., in Japan tried to solve the problem by coating the particles with gold. While this broke up the conglomerates it lessened the silver's antibacterial properties as the gold blocked silver from reaching the bacteria.

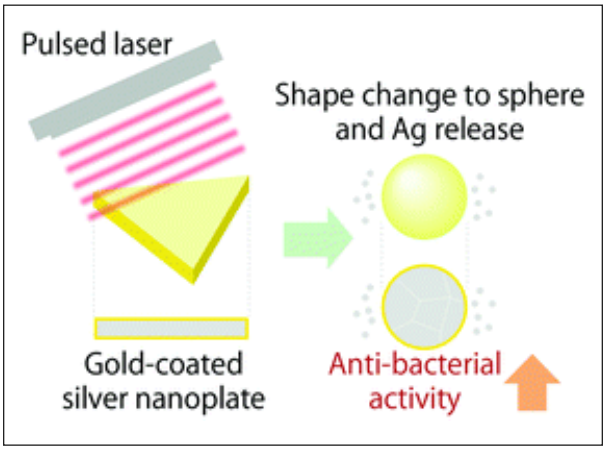
What did help, however, was hitting the silver-gold nanoparticles with pulsed laser beams.

The laser pulses changed the shape of the silver-gold nanoparticles from triangular to spherical due to the metals melting from the laser pulse's heat. Before being showered with laser pulses, the nanoparticles were about half triangular and half spherical. After being lased, the particles were 94 percent spherical. This shape allowed more of the silver to come in contact with the bacteria. The researchers also believe that the laser produced defects in the gold coating's structure that allowed more silver ions to escape, further increasing the silver antibacterial action.

"We have developed a method to activate the antibacterial properties of silver nanoparticles at will," said Professor Takuro Niidome, leader of the research group, in a prepared statement. "Our experiments have shown that, while non-irradiated gold-coated silver nanoparticles have only minor antibacterial properties, the effects are significantly increased after pulsed laser irradiation. We hope to develop this technology further as a method of managing bacteria that have developed antibacterial resistance."

He noted that the irradiated silver-gold nanoparticles were almost 100 percent effective against *E. coli*. Another benefit of the technique is that the gold-coated silver particles could remain clumped together and nearly inactive until its antibacterial power was unleashed when desired by the laser beam. This could allow antibacterial action on demand.

The research can be found in the Royal Society of Chemistry journal Nanoscale.



NANOSCALE

The antibacterial activity of gold-coated silver nanoparticles increases after being struck by laser beams.

Silver-Copper-Boron Nanoparticle May Reduce Diabetic Amputations

Osteomyelitis, or bone infection, is a major complication of diabetes, itself a growing disease worldwide, and the cause of many foot amputations. Bone infections are also seen in patients with peripheral vascular disease, and those with poor dental hygiene.

While antibiotics are the usual protocol to treat these infections, bacteria are becoming increasingly resistant to these drugs. To combat these infections, many scientists are looking to silver.

A team led by Shahnaz Qadri, Ph.D., College of Science and Engineering, Hamad Bin Khalifa University, Doha, Qatar, explored the potential of using particles composed of silver, copper and boron. This mix can produce silver and copper ions for long durations and has shown effective antimicrobial properties in bone cells, according to experiments. A single dose of the antimicrobial nanoparticles killed 90 percent of bacteria-causing infection in bone cells. The group previously had studied the use of copper alone but found that it formed a copper oxide layer that lowered particles' antimicrobial activity.

Experiments in mice showed that the nanoparticles had no negative effects on the infected animals, who were able to tolerate doses up to 20 times higher than the researchers had anticipated. "Our in-vivo studies showed that our nanoparticles do not induce adverse effects on mice that have induced infection. All mice survived when they were injected with Ag-Cu-B nanoparticles for three months and six post nanoparticles administration," the researchers wrote in their article *Metallic nanoparticles to eradicate bacterial bone infection*, which appeared in the journal Nanomedicine: Nanotechnology, Biology and Medicine.

The researchers continued: "We believe it is the first study that demonstrated a new route of nanomedicine therapy for internal bone infection. Many of the approved antibiotics do not kill the intracellular infection. The overall impacts of our study are that it demonstrated the creation of novel inorganic nano-based composites to fight against bacterial infections particularly those requiring long-term antibiotic or surgical treatment."

Silver Imbedded Towels Big Hit on Kickstarter

A Kickstarter campaign aiming to raise US$20,000 for silver-imbedded towels raised US$282,596 with more than 2,000 backers.

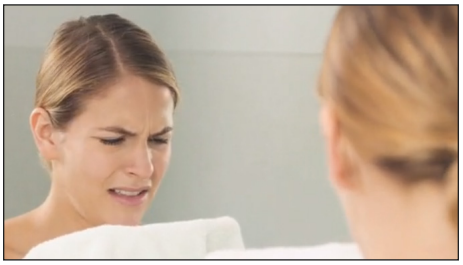
The towels, produced by Silvon, are expected to ship in February and will sell for US$69.00 per set. The company last year had received over US$1 million for a Kickstarter campaign to produce silver-imbedded bed linens, which are being shipped to 13,000 contributors worldwide.

Company officials say the towels have been tested by a third-party lab and the silver ions killed 99 percent of bacteria exposed to them. They also note that regular towels harbor bacteria – causing a musty odor – and that the silver-imbedded towels might be beneficial to people with acne who are trying to keep their faces free from bacteria.

The towels are produced by weaving silver fibers with 100 percent organic cotton. The silver fibers are manufactured in the United States and shipped to a weaving and finishing facility in India that company officials say has advanced technology and expertise in production of their specialized products.

The towels should be washed in cold water on a gentle cycle and tumble dried. Towels should be laundered every two weeks, company officials suggest.

Towel products may be bought individually, but a set which includes two bath towels, two hand towels, two face towels and a bath mat will retail for US$230.



Click the image to watch a video about Silvon towels

Demand for Silver in Key Sectors Growing, Conference Attendees Told

Silver industrial demand was the theme at the Silver Industrial Conference in Washington, DC, in October, hosted by the Silver Institute, with presenters and panelists offering their views on various industrial sectors poised to contribute to silver industrial demand in the future.

Brian VanderWilp, Americas Business Director, CRI Catalysts, noted that the total silver required to satisfy current demand for Ethylene Oxide (EO) – whose production requires silver catalysts – is about 151,000,000 troy ounces. With a forecast market growth rate of 5% for EO, an additional 7,550,000 troy ounces of silver would be needed annually.

He added that EO has many uses, including the production of water-based paint coatings, window cleaners, brake fluids, inks, adhesives and laminates for circuit boards. The largest application is in the manufacturing of monoethylene glycol, a key ingredient in antifreeze, polyester fibers and plastics.

Larry Wang, Global Product Manager, R&D Director, Heraeus Photovoltaic, told attendees that the average 1-watt solar power output uses about 20 mg silver, and while the amount of silver paste is expected to drop per cell, the number of solar cells being produced will more than make up for the difference in silver demand. Current global photovoltaic installations produce about 84 gigawatts of power with forecasts of 154 gigawatt installations by 2022.

On the automotive side, Steve Gehring, Vice President, Vehicle Safety & Connected Automation at Global Automakers, a group that represents automakers, noted that silver demand is pegged to safety upgrades in vehicles. Silver is used in rear cameras, lane departure warnings, rear window defrosters and other devices. The electrification of automobiles, coupled with the growth of hybrids, are also factors in projected increased silver use in vehicles.

Along with demand, the price of silver may see an increase, according to Bart Melek, Global Head of Commodity Strategy at TD Securities. He said that an ounce of silver could reach $US18.25 by the end of 2018. “TD Securities remain relatively positive on gold and silver longer-term, as it is unlikely the Fed will tighten policy as aggressively as they implied. Furthermore, U.S. political drama and geopolitical tensions with North Korea continue to see precious metals attract investor interest as an uncertainty hedge.”

Another area of demand discussed at the conference was healthcare. Trevor Keel of Agility Health Tech (also a consultant to the Silver Institute) said that silver is used in many products both for consumers and health care professionals. He discussed Corning’s Gorilla Glass, a product family of screens used in smartphones and tablets which have germ-fighting silver imbedded into the glass. He also talked about silver being used in water filters to fight the build-up of germs.

The attendees included miners, industrial fabricators, refiners, bullion bankers, government officials and journalists.

Sweat Battery Uses Silver to Power Wearables

What if you could turn your sweaty exercise clothes into batteries that power your electronic "wearables"?

A research team at Binghamton University, State University of New York, has developed a textile-based, bacteria-powered bio-battery that could be integrated into wearable electronics. The batteries are powered by bacteria in sweat and rely on silver-oxide as one of its components.

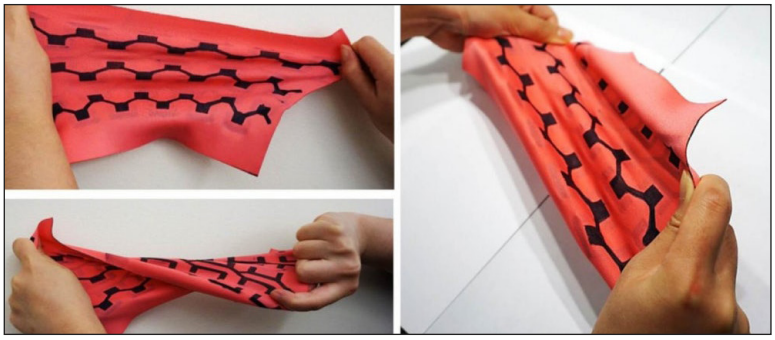
According to team leader Professor Seokheun Choi, the human body contains more bacterial cells than human cells, so looking to bacteria for power is conceivable for wearable electronics such as those that measure temperature, heart rate, blood pressure and other biometrics.

"There is a clear and pressing need for flexible and stretchable electronics that can be easily integrated with a wide range of surroundings to collect real-time information," Choi said in a prepared statement. "Those electronics must perform reliably even while intimately used on substrates with complex and curvilinear shapes, like moving body parts or organs. We considered a flexible, stretchable, miniaturized bio-battery as a truly useful energy technology because of their sustainable, renewable and eco-friendly capabilities."

The textile-based battery uses the bacterium *Pseudomonas aeruginosa* as a catalyst and it works even if the fabric is twisted or stretched. (Healthy people should have little concern about *Pseudomonas aeruginosa*, which is found naturally in perspiration. For people with compromised immune systems or other diseases, the bacteria can be deadly if it enters the body.)

The battery's structure consists of an anode and cathode (positive and negative poles respectively) placed together in a single chamber. The anodic chamber is designed to attract electricity from bacterial cells in liquid, while the cathode uses silver oxide as a reduction-oxidation medium to actually produce small amounts of electricity.

Choi noted that the single-chamber approach makes battery production simpler than a typical battery design that uses membranes. He and his team were able to simultaneously construct 35 separate devices, which augers well for mass production.



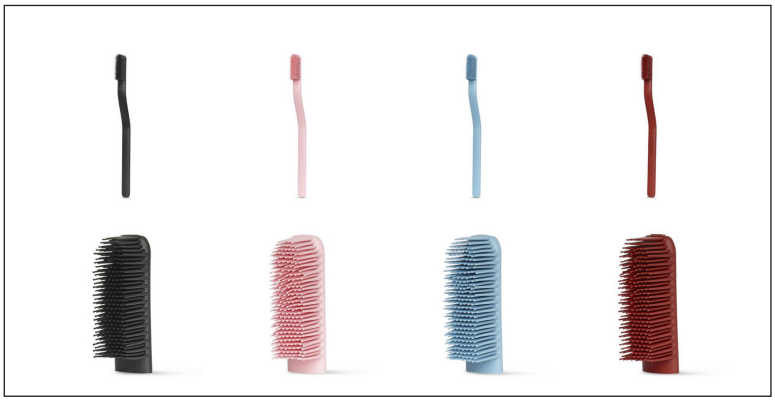
NANOSCALE

This textile bio-battery is powered by sweat and relies on silver-oxide to produce electricity.

Toothbrush Offers Recyclable Bristle Head With Imbedded Silver

A uniquely-designed toothbrush has a head composed of a rubber-like material -- thermoplastic elastomer (TPE) -- imbedded with silver particles. TPE combines the properties of rubber with the benefits of thermoplastic, which makes the bristle head flexible and recyclable, according to company officials. They add that the heads last twice as long as regular nylon bristles while offering the antibacterial properties of silver.

The bristle heads of the Boie Brush are replaceable, but you keep the handle. This means less waste in landfills. The heads are recyclable locally, but the company also runs an in-house return and recycle program if your area does not recycle. A toothbrush costs US$12.00 while a replacement head is priced at US$5.00.



BOIE USA

The Boie Brush is a uniquely-designed toothbrush with head composed of a rubber-like material imbedded with silver particles. (Click the image)

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