High-Tech Materials Alert (TechVision)

ITO Replacement Materials for Consumer Electronics

April 8, 2016
D737-TV
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Materials Used as Alternatives to ITO (Indium Tin Oxide) in Consumer Electronics
Nano–Random Access Memory (NRAM)® Using CNT

Unmet Needs

1. Dynamic Random Access Memory (DRAM) has a minimum size to which it can be built.

2. Conventional semiconductors consume energy, even in standby mode.

3. Other types of random access memory (RAM) require multiple processing steps thus result in higher manufacturing cost.

Innovation Attributes

- Very minimal power consumption when in standby mode
- NRAM is 100 times faster than NAND type flash memory
- High durability and extremely resistant to environmental forces (heat, cold, radiation, vibration, and magnetism)
- Limited process steps that result in low manufacturing cost and compatibility with both in Multi Level Cell (MLC) operation and 3D multilayer architecture

Technology Profile

Who

Nantero is a worldwide leader in advancement of carbon nanotube technology for the electronics industry.

Where

The company has its headquarters in Massachusetts, United States.

What

- A film of CNTs is deposited onto a regular silicon substrate that incorporate an underlying cell select device and array lines (normally transistors or diodes) acting as an NRAM switch.
- The resistive state of the CNT fabric depends on the number of NRAM placed in resistive modes.
- NRAM also functions as a resistive non-volatile random access memory (NVRAM).

Funding

For the development of the CNT, Nantero has raised over $42 million from several investors such as Draper Fisher Jurvetson and Harris & Harris Group.

Applications

- Wearable electronics
- Smart devices
- Flexible electronics
- Semiconductors

Commercialization Strategy

Over 170 US patents have been issued to Nantero. The company licenses its IP to major chip manufacturers and electronics companies across the globe and aim to increase visibility across the globe.

Analyst Perspective

Nantero’s NRAM technology enables manufacturers to quickly and cost-effectively shift towards a new generation of memory, which has become a critical requirement as flash and DRAM technology as these reach maturity.
The use of Innlay™ AgNW Inks in high-end electronic devices could offer considerable benefits for the major electronic device manufacturers. 

Innlay™ Silver Nanowire Inks

Silver nanowires (AgNW) are being increasingly researched as a possible ITO replacement material due to its exceptional electrical, thermal, and optical properties.

Who

This electronic materials company is supplying the consumer electronics market with touch screen and display applications.

Technology Profile

Innolink Dynamics was founded and is located in San Francisco, California, US.

What

Inks are composed of silver nanowires which is directly embedded onto the surface of the substrate, which serves as the host polymer. The ink is specifically engineered without the use of binders.

Innovation Attributes

- Innolink AgNW inks provide the best in-class optical performance as compared to other ITO replacement materials.
- The transparent conductive electrodes (TCE) can be printed invisibly without having to use photolithography.
- The inks are physically flexible where ITO films lack.

Applications

- Touch screen technology
- Smartphones
- Tablets
- Wearable electronics
- Displays
- Liquid crystal display (LCD)

Funding

Innolink Dynamics received funds from several investors such as BASF ventures, Rho Capital Partners, and MentorTech Ventures. Support from government is mainly from the National Science Foundation, US Department of Defense: Army and US Department of Defense: Navy.

Partnership

Several partnerships have supported the development of this technology. Partners include Morrison & Foerster, Foley & Lardner LLP, City National Bank, and Alexandria Real Estate Equities, Inc.

Analyst Perspective

The use of Innlay™ AgNW Inks in high-end electronic devices could offer considerable benefits for the major electronic device manufacturers.
The innovation of this technology could help satisfy the increasing demand for energy storage systems in portable electronics and electric cars. Due to the combination of its unique properties, it makes graphene the perfect material to replace ITO.

### Technology Readiness Level

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The technology is in the development stage and further research is needed before commercialization.

### Technology Background

Lithium metal is being deposited at the unstacked graphene anode at an ultralow local current density. By doing so, the local current density is decreased heavily thus inhibiting the growth of dendrite efficiently.

### Year of Impact

2020

### Unmet Needs

- Performance of existing lithium metal batteries is hindered by the growth of dendrites at the surface of the lithium metal.
- The lithium dendrites may cause internal short circuits, causing it to briskly overheat and in some cases, catch fire.

### Innovation Attributes

- Inhibit dendrite growth by inducing an ultralow local current density on the surface of graphene anode
- Provide a great stable cycling capacity of 4.0 mAh/mg, which is 10 times more than normal graphite anode in lithium-ion batteries
- Leads to stable charging or discharging performance, low interface impedance, and high cycling efficiencies

### Potential Applications

- Laptops
- Smartphones
- Electric cars
- Electronic devices

### Funding

This study has been funded by the Ministry of Education in China, National Basic Research, and Natural Science Foundation.

### Future Plans

Results of this study could help advance the work of researchers who are investigating the diffusion behaviour of Li-ions and electrons in the process of lithium depositing and stripping to improve the commercial applications of lithium metal anodes.
Copper Nanowires for Flexible Electronics

Unmet Needs

• Silver nanowires is one of the few ITO replacement materials, but like Indium, it is becoming an expensive element.

• ITO’s properties are brittle and crack easily. Hence, it is not suited for wearable and bendable electronic devices.

Innovation Attributes

Production cost is low as copper is around 100 times less expensive than silver and ITO.

The flexibility of copper nanowires has made it possible to be used in various applications such as bendable electronics and portable solar cells.

As the manufacturing process is water-based, it can be coated from solution to a transparent substrate by a standard roll-to-roll process.

Analyst Perspective

Copper nanowire can be expected to find adoption in cost effective touch screen and flexible electronic devices over the next few years.

Technology Profile

A copper nanowire ink is composed by arranging copper atoms in water to form a thin, long, and non-clumped nanowire, which afterwards transforms into a transparent conductive film and is coated onto glass or plastic.

Funding

$45,000

North Carolina has funded $45 thousand for commercializing this technology.

Who

The research has been conducted by a research team from Duke University.

Where

The technology has been developed by the Department of Chemistry at Duke University, North Carolina, United States.

Potential Applications

- Smartphones
- Flexible electronics
- Photovoltaic cells
- Touch screen technology

Commercialization Strategy

The lead researcher, Benjamin Wiley, has founded NanoForge Corporation with Steven Warwick for manufacturing of CuNW for commercial applications.
Strategic Insights

Competitive Landscape

- North America and Asia, especially Southeast Asia, are the regions with an immense amount of research activities focusing on ITO replacement materials.
- In North America, the focus is mainly on the alternative materials, while in Asia, focus is more on fabrication of the materials.
- Major key stakeholders include Cambrios (US), C3Nano (US), Fujitsu (Japan), Toagosei (Japan), Cambridge Display Technology (CDT) (UK), Directa Plus (Italy), Samsung Electronics (Korea), Heraeus (Germany), and Canatu (Finland).

Number of patents granted for different ITO replacement materials, Global, 2014-2015

- From 2014 until the end of 2015, silver annowires, copper nanowires, CNT and graphene are the top ITO replacement materials.
- Silver nanowires tops the granted patents as silver offers high conductivity, transmittance, and flexibility, despite it being more expensive than copper. Nevertheless, it is still much cheaper than indium.
- On the other hand, only 38 patents have been granted for graphene as the method for producing graphene is quite expensive at a high conductivity level. Also, it is still in the research stage.
- Major key patent holders include Liquid X Printed Metals Inc. (US), Fujifilm Corp. (US), Tianjin University (China), and Samsung Display Co. Ltd. (Korea).

Source: Frost & Sullivan
## Strategic Insights

<table>
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<th>Drivers</th>
<th>Restraints</th>
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<tr>
<td>✓ Materials are cost effective as compared to ITO identified.</td>
<td>✓ Some major R&amp;D is still ongoing to improve ITO performance.</td>
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<td>✓ High performance characteristics are equivalent and some are better than ITO.</td>
<td>✓ ITO is a well-proven technology and alternative materials for ITO are mostly in research stages.</td>
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<tr>
<td>✓ Most of ITO replacement materials are flexible and ductile, thus have empowered the growth of transparent conductive film (TCF) for the electronics industry.</td>
<td>✓ Many alternative materials for ITO have not yet achieved large-scale production methods, and this could influence the material’s potential to meet demand.</td>
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### Funding & Market Potential

- Funding is widely available for development of ITO replacement materials.
- For instance, in China, the government has provided funding for Xiamen University to develop flexible copper nanowire TCF.
- Indium is a rare earth metal, so there has always been a question of its future availability. Hence, alternatives for ITO could potentially satisfy the electronics market in the future.

### R&D Focus Areas

- Most research focuses on improving the properties of the materials to exceed ITO’s properties.
- Stakeholders who are heavily invested in the development of ITO replacement materials work together with stakeholders in the R&D for improving deposition methods of ITO-alternative materials on the required substrates.
- In term of end-user experience, major electronic device manufacturers are constantly looking toward large-scale production of cheaper and higher quality products that meet the industry needs.

### The 2020 Scenario

- As of now, only silver and copper nanowires meet most of the current industry demands, but it is anticipated that by 2020, graphene could appear in touch screen technology and be widely adopted by 2025.
- When mass production methods are available, the cost barrier should no longer be an issue.
## Key Patents

<table>
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<tr>
<th>No.</th>
<th>Patent No.</th>
<th>Publication Date</th>
<th>Title</th>
<th>Assignee</th>
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Provided herein are methods comprising (i) depositing an ink on a surface, (ii) producing a conductive metal film by, for example, heating or irradiating or other treatment of said ink, and (iii) wherein the metal film is in the form of a repetitively patterned structure forming a grid-like network of vertex-shared polygons and polygon-like structures with a varying number of vertices. Transparent, conductive structures can be formed and serve as, for example, ITO-replacement materials and structures.


The present invention relates to a process for the preparation of a composition which comprises a solvent A, silver nanowires and a conductive polymer, comprising the process steps: (i) the reduction of silver salts by means of a polyol serving as a solvent and reducing agent in the presence of a non-conductive polymer and subsequent precipitation of the silver nanowires thereby formed to obtain silver nanowires, on the surface of which at least some of the non-conductive polymer is adsorbed; (ii) the at least partial removal of the non-conductive polymer adsorbed on the surface of the silver nanowires to obtain purified silver nanowires; (iii) the bringing into contact of the purified silver nanowires with a solvent A and a conductive polymer. The present invention also relates to the compositions obtainable by this process, a composition which comprises a solvent, silver nanowires and a conductive polymer, a process for the production of an electrically conductive layer, the electrically conductive layer obtainable by this and the use of the compositions according to the invention.
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<tr>
<th>No.</th>
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<th>Publication Date</th>
<th>Title</th>
<th>Assignee</th>
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<tr>
<td>3</td>
<td>US 8610125 B2</td>
<td>Dec 17, 2013</td>
<td>Nanotube Array Light Emitting Diodes</td>
<td>Nano Electronic And Photonic Devices And Circuits Llc</td>
</tr>
<tr>
<td></td>
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<td>Carbon nanotube (CNT)-based devices and technology for their fabrication are disclosed. The planar, multiple layer deposition technique and simple methods of change of the nanotube conductivity type during the device processing are utilized to provide a simple and cost effective technology for large scale circuit integration. Such devices as p-n diode, CMOS-like circuit, bipolar transistor, light emitting diode and laser are disclosed, all of them are expected to have superior performance then their semiconductor-based counterparts due to excellent CNT electrical and optical properties. When fabricated on semiconductor wafers, the CNT-based devices can be combined with the conventional semiconductor circuit elements, thus producing hybrid devices and circuits.</td>
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<td>4</td>
<td>KR 20130007833 A</td>
<td>Jan 21, 2013</td>
<td>Transparent Electrode Comprising Graphene And Ito</td>
<td>Doosan Corp</td>
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<td></td>
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<td>PURPOSE: A transparent electrode containing graphene and ITO is provided to obtain low plane resistance while maintaining permeability. CONSTITUTION: A transparent electrode contains graphene and ITO. The graphene and ITO exist in the form of a nanocomposite. The peak level of the In2O3 in the nanocomposite is 1.5-1.8 times bigger the peak level of single ITO particle. The surface resistance of the transparent electrode is 300-3000 ohm.</td>
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<td>5</td>
<td>WO2014137541 A1</td>
<td>Sep 12, 2014</td>
<td>Stabilization agents for silver nanowire based transparent conductive films</td>
<td>Carestream Health, Inc.</td>
</tr>
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<td>Certain compounds comprising at least one carboxyl group have been found to provide anti-corrosion properties when incorporated into silver nanowire containing films. Such compounds may be incorporated into one or more silver nanowire containing layers or in one or more layers disposed adjacent to the silver nanowire containing layers.</td>
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