ORGANIC ELECTRONICS

Laser-induced electrode fabrication

A cost-effective and convenient means of fabricating electrically conductive tracks on polymer substrates is required for the development of flexible electronics and optoelectronics.

Although researchers have suggested several metallic nanoparticle ink-based fabrication processes that rely on ink-jet printing and laser curing, these techniques can be expensive due to the high cost of nanoparticle ink — 5 nm silver nanoparticle ink costs around US$30,000 kg^{-1}. There are also several other limitations, including low processing rates, low resolution, non-uniform profiles and low surface quality compared with vacuum-deposited electrodes.

Bongchul Kang, Seunghwan Ko, Jongsu Kim and Minyang Yang at the Korea Advanced Institute of Science and Technology in Daejeon, South Korea, now report a microelectrode fabrication technique that uses organometallic ink costing only US$300 kg^{-1} while yielding higher-quality tracks than those of previously studied inks (*Opt. Express* **19**, 2573–2579; 2011).

Organometallic ink is transparent and does not contain metallic nanoparticles in its raw form. This makes it incompatible with laser curing, in which incident laser energy is absorbed and melts metallic nanoparticles to form continuous features. The researchers get around this problem by spin-coating the ink onto a substrate such as glass and then baking below the ink's sintering temperature. Precisely controlling the short pre-baking process induces incomplete thermal decomposition and the generation of 2–3 nm silver nanoparticles.

The presence of the nanoparticles in the baked ink enables laser curing and the subsequent formation of high-quality tracks. The team scanned a focused laser beam from a 1,070 nm Yb-doped fibre laser across the sample to induce agglomeration and fusion of the separate silver nanoparticles into continuous features. They then washed away regions untouched by the laser to leave the desired electrode structure. The researchers claim that the surface roughness and pattern profile are as good as that of vacuum-deposition techniques and superior to normal metal ink approaches.

A resolution of 25 μm was achieved with a laser power of 200 mW and a curing rate of 25 mm s^{-1} — around 25 times faster than conventional laser-curing approaches. A better resolution of 10 μm was achieved with 40 mW of laser power, but at a slower curing rate of 10 mm s^{-1}. Although such results are already better than conventional printing, which has a resolution of around 30 μm, the team report that resolutions of 2–5 μm are possible thanks to the low thermal diffusion of the organometallic inks. It is worth noting that the fabricated structures are particularly robust, surviving 100 iterations of the 'Scotch tape peel test'.

KAIST

Minyang Yang explained to *Nature Photonics* that irradiation wavelengths close to the nanoparticle resonance are not necessarily the best for effective laser curing. For example, the use of 532 nm green light caused explosive evaporation of organic complexes and pattern delamination problems. It turns out that the mildly absorbing wavelength of 1,070 nm is well-suited for successful process development.

"We are currently trying to apply our method to real electrical devices such as flexible organic LEDs and flexible solar cells," commented Yang.

DAVID PILE

PHYSICAL OPTICS

Backwards Doppler shifts

Researchers have observed the inverse Doppler effect at optical frequencies for the first time, using a technique that combines a moving negative-index photonic crystal and heterodyne interferometry.

Evan J. Reed

In 1843, Christian Doppler described how the waves emitted from a moving source are shifted in frequency relative to that of a stationary source, in what is arguably among the most recognizable phenomena in physics. The Doppler effect plays a central role in astronomy, medicine, meteorology and a myriad of other applications. In 1968, Victor Veselago explained how radiation emitted from a moving source in a material that has both negative dielectric permittivity and negative magnetic permeability would be endowed with an inverse Doppler shift; that is, the sign of the frequency shift would be opposite to that of the usual Doppler shift[1]. In such a case, an ambulance's siren would, contrary to our everyday experience, reduce in frequency as it approaches the listener, and then increase in frequency as it passes by.

The inverse Doppler phenomenon relies on the material having a negative effective refractive index, which causes the phase and group velocities to propagate in opposite directions. Veselago's prediction was well ahead of the experimental capabilities of its time, with the first few experiments performed only in recent years. The phenomenon was first demonstrated in the radiofrequency regime (~1 GHz) in 2003[2], and then in the audible acoustic regime in 2006[3]. Inverse Doppler effects have also been observed more recently from dipolar spin waves in the gigahertz frequency range[4,5]. Relativistic inverse Doppler effects have been observed in a cyclotron resonance maser