Living in a material world

From ceramic insulating bricks to exotic fullerenes, lasers play an important part in the creation and study of new materials. However, as **Michael Kenward** discovers, academics and industry are not working together as they should.

Watching academic research is a good way to find technologies that might become money spinners in the future. In the world of laser processing of materials, it seems that we can expect anything from the mundane to the mind boggling – from heat-resistant bricks to electronic components based on new forms of carbon, taking in novel photonic materials on the way. The trouble is that, as a recent study by the UK's Engineering and Physical Sciences Research Council (EPSRC) found, industry and academia do not talk to one another as much as they could, so ideas languish.

The EPSRC asked Duncan Hand of Heriot-Watt University to carry out a consultation exercise within the applied-optics community. He was also asked to look into the possibility of setting up a new EPSRC programme in applied optics.

The view within the community is that the links between academics and industry are not as good as they might be. "That is the message that was coming across," said Hand. "It is supposed to be applied research. However, it isn't getting the final connection in place. As a result, there is a lot of potential that is not being realized."


Oxford University

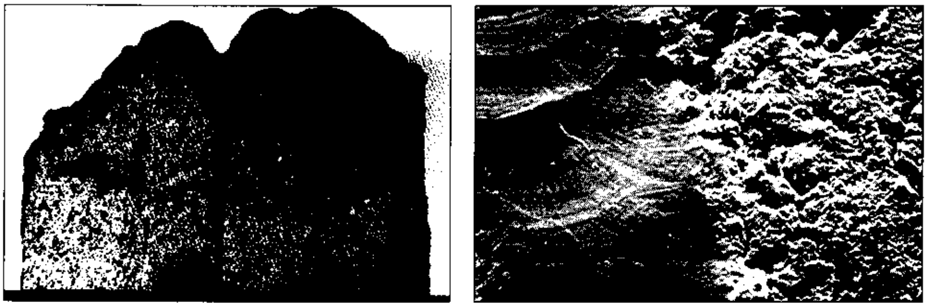
1. Interference patterns from four ultraviolet laser beams in a thick film produce a photonic crystal for the visible spectrum from photoresist. This faced-centred cubic pattern has a lattice constant of 397 nm.

Laser-treated bricks

On the positive side, some research addresses clear industrial problems and it involves companies and academics working together. The Department of Mechanical Engineering at the University of Manchester Institute of Science and Technology (UMIST), for example, is carrying out a research project on ceramic bricks, which are used in the refractory linings of furnaces and incinerators.

Working with a number of companies, including Cleanaway, ICI, Morgan Materials Technology and Plasma and Thermal Spray, Lin Li of UMIST has shown that diode lasers can melt the surface of a ceramic in a controlled way (figure 2). The net effect is a reduction in the porosity of the ceramic, which makes it more difficult for aggressive chemicals to penetrate and damage the refractory brick.

Furnace and incinerator linings take a beating from the hostile environment that they work in. This can involve high temperatures and mixtures of aggressive chemicals. A refractory-brick lining protects ▷



2. Laser treatment can make ceramic bricks for furnaces last longer: a cross-section of an area that has been treated by diode lasers (left), and the difference between a sealed and an unsealed area (right).

the outer metalwork of a furnace. These bricks are, in effect, throwaway items. Every six months or so the operator shuts down the furnace to inspect the refractory linings for damage. Linings usually need to be repaired after a year or so of use.

Replacing refractory bricks is an expensive business. Cleanaway spends around £350 000 a year on refractory materials for its Ellesmere Port plant near Chester, says Chris Ashcroft, treatment manager of Cleanaway's technical waste business. "If we could give the brick a year's extra lifetime it would be useful to us," he said.

Laser-treated bricks survived their first six months in Cleanaway's incinerator so well that the company was happy to leave them in place for a further six months.

Key to success

Earlier attempts to use lasers to seal ceramics failed because the surface flaked away from the body of the material. The key to the UMIST project was the way in which the research group deployed the laser. Just melting the surface could do as much harm as good. It can set up too steep a thermal gradient near to the surface of the brick, thus causing the outer layer to flake off as the material cools.

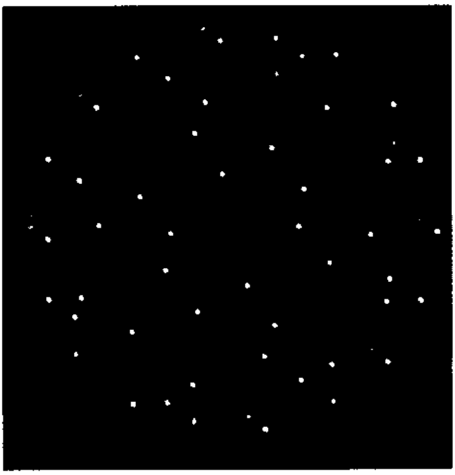
Li and his colleagues got round this by heating the surface of the brick with an arc lamp. This reduced the temperature gradient near the zone where the laser beam hits the material, making it less likely that the ceramic will crack under the stress of temperature variations.

The heat and laser treatment created a crack-free, dense, non-porous surface zone, which would normally be produced by heating the whole sample to a high temperature – an expensive process when you only want to treat the surface layer.

It is important to retain porosity in the main body of the brick because it is crucial to the material's properties as a thermal insulator. "You need a dense surface to prevent corrosion, and back porosity for insulation," said Li. The laser generates the dense surface without penetrating too deeply into the porous ceramic.

Another important innovation in the UMIST project was the use of diode lasers. These produced a better microstructure than carbon dioxide lasers – the normal choice in industry when high power is important. They also created some interesting new materials that the UMIST team hopes to study in a follow-up project.

The diode lasers in question came from medical laser maker Diomed. Diode lasers have only recently been able to deliver enough power for industrially heavyweight applications. Diodes are much smaller than carbon dioxide lasers, so their portability makes it possible to treat bricks *in situ*, or to seal cracks between bricks during installation and maintenance.



3. Sussex University uses YAG pulses to make C_{60}.

The first UMIST project was a one-year feasibility study that was funded by the EPSRC. Thanks to a further grant of nearly £350 000 the researchers are about to begin a three-year follow-on project.

In the first one-year programme, the focus was on achieving surface sealing to a depth of more than 0.5 mm without inducing cracks and without the use of a furnace. Morgan Materials Technology supplied a range of monolithic refractory materials and Cleanaway supplied different types of alumina-based refractory surface-lining bricks as test samples. The team made comparisons between a 1 kW Rofin–Sinar CO_2 laser in continuous TEM^{01} mode, a 400 W Scorpion Nd:YAG laser with optical-fibre beam delivery operating in pulsed mode, and 60 W and 120 W Diomed lasers, both of which were operating in continuous-wave mode with optical-fibre delivery. A 1000 W arc lamp was the heat source for surface sealing.

Buckyballs and nanotubes

In terms of materials research, C_{60} is about as far away from refractory bricks as you can get. Carbon may be another insulator, but this particular form of the element – where 60 atoms come together in the shape of a caged ball (figure 3) – has so far been of little more than a scientific curiosity since its discovery in 1985. Now researchers have turned their attention to developing manufacturing technologies for these fullerenes (*OLE* August 1999 p24).

Once again, lasers can play a part in making C_{60}, especially nanotubes (tiny tubes that are created out of a scaffold of carbon atoms). Nanotubes hold out the prospect of very strong composite materials, or new electronic and optical devices. For example, one option for creating flat-screen electronic displays is to replace the ▷

bulky cathode-ray tube with an array of millions of tiny guns that fire electrons at a tiny phosphor dot on a screen.

Researchers have put a lot of effort into fine tips for field-emission sources that, when subjected to the required voltage, give off electrons (p28). Carbon nanotubes might have the makings of tips for field-emission devices. The problem has been in making them. A group at Sussex University led by Harry Kroto, professor of chemistry and a winner of the Nobel Prize for Chemistry for his part in the discovery of C_{60}, produces nanotubes using lasers.

The researchers started with a silicon substrate and deposited a thin metal film on it. A YAG laser, delivering between 2 and 10 mJ per shot, etched tracks that were 50 μm wide into the metal surface. The laser also created some damage in the silicon, producing a rough surface with some metal clusters remaining in the tracks. Nanotubes of C_{60} form in these tracks through chemical-vapour deposition.

Microstructured materials

Other researchers have discovered the value of lasers in laying the foundations for novel materials. For example, at Oxford University a multidisciplinary team of chemists and physicists has devised a holographic technique for producing fine details in photonic materials.

The group employs lasers as part of its research into the production of microstructured photonic materials (MPMs). MPMs have physical-feature dimensions that are near to the wavelength of light. The material can influence the propagation of waves at wavelengths from the ultraviolet to the far-infrared.

Andrew Turberfield and Bob Denning took an ultraviolet laser beam, split it into four and recombined the beams to create an interference effect within a thick film of a material. This created intensity peaks that caused a photochemically sensitive substance to become insoluble and form photonic crystals (figure 1).

The aim of much research into MPM is to produce the photonic equivalent of the integrated circuit and combine different functions in a single device. Photonic microstructures in these materials can trap photons in an otherwise transparent material, for example. There can be a band of frequencies that have no propagation modes. Quantum effects can also enable MPM devices to act as lightguides, which can divert photons round corners.

These materials need physical features of approximately the same magnitude as the wavelength of light, so it makes sense to use light and lasers to create them. However, this is easier said than done.

Semiconductors have it easy in comparison, says Bob Denning. "You throw atoms together and they organize themselves. With MPMs you have to manipulate the dielectric blobs, which have dimensions of 0.5 μm. These blobs have to be arranged with air in the gaps between them."

The Oxford group can adjust the size and arrangement of the dielectric blobs that it produces by changing the angle at which the laser beam impinges on the light-sensitive material. The way to create photonic devices, says Denning, is to add layers of material and carry out a series of processing steps. In this way the holographic approach could, for example, lay down waveguide structures, he says.

The scientists and the university's spin-off company, Isis, are looking for a company to take the research forward. A patent is in the pipeline in several countries.

Refractory bricks, C_{60} nanotubes and photonic devices illustrate not only the versatility of lasers in materials processing but also the breadth of research in the area. However, there are problems when it comes to establishing links between academic research groups and companies that can turn their ideas into useful technologies and products. This is one conclusion from the study by EPSRC, which funded all of the research projects described here.

The panel that reviewed Duncan Hand's survey (*OLE* April p6) identified three areas, which included industrial laser material processing, that could benefit from a new research programme. The other sectors were diagnostics and support for manufacturing industries.

Hand highlights a number of specific technologies that could benefit from further research. The first one is the use of optical fibres to deliver high-power light from YAG lasers. This would be particularly useful for work on large items that might be difficult to move.

Laser direct casting

Another relatively new area of research that looks interesting, says Hand, is laser direct casting. This is effectively a weld-build process, he explains, that uses metal powders and lasers to build up components.This allows the creation of complex three-dimensional parts. As each layer forms, a heat-treatment effect occurs on underlying layers. "You end up with very strong materials," said Hand.

If EPSRC does decide to launch a new programme – the panel suggests the general title Optical Technology for Manufacturing and Industry – we may see more examples of materials, exotic and more down to earth, where lasers played a vital part in their production. ☐