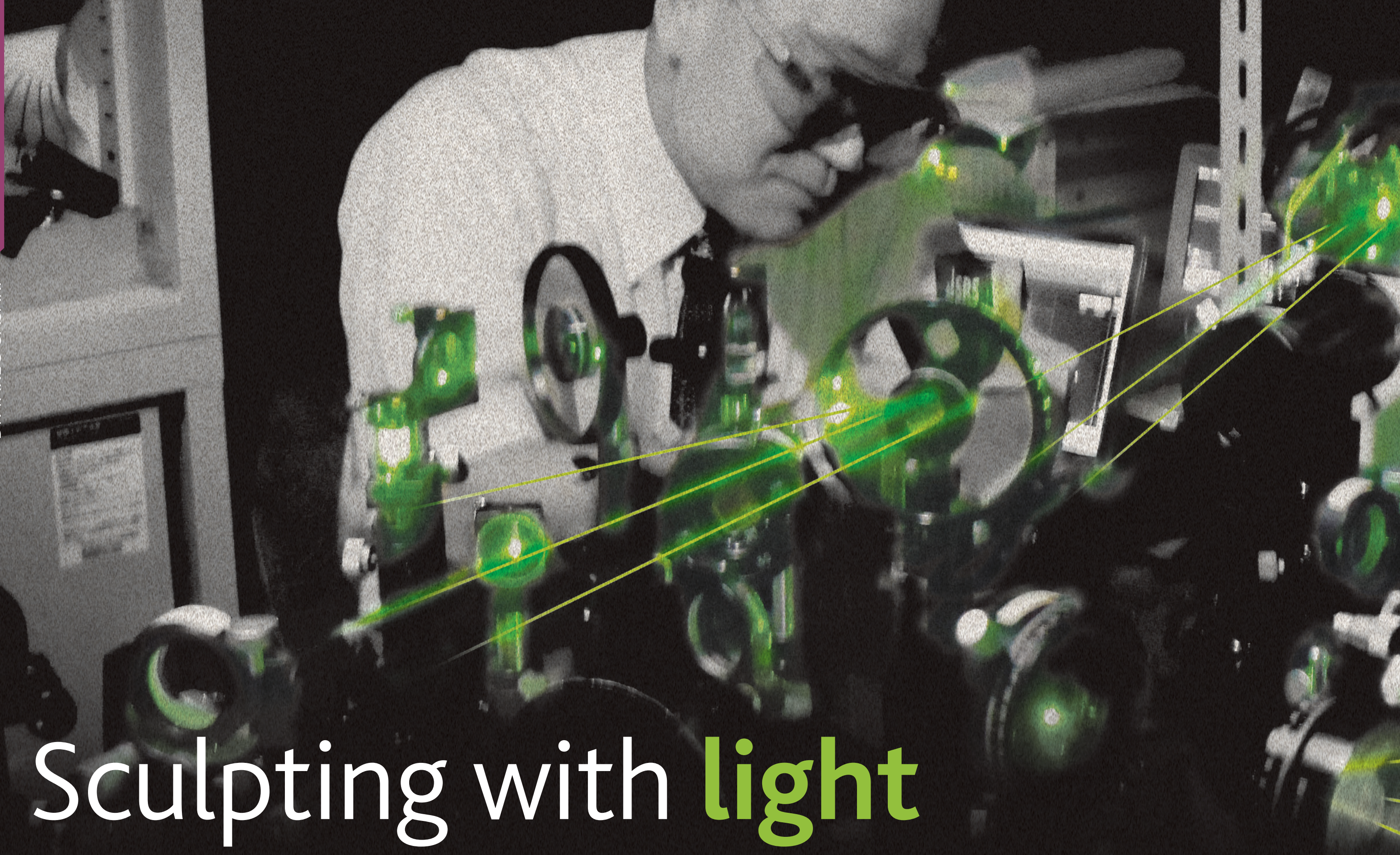

DR TAKEO SASAKI

# Sculpting with light

Optical physicist **Dr Takeo Sasaki** describes his fascination with photorefractive materials as well as shedding some light on their various applications in sensing, holography and many other practical arenas

### What areas of your field do you find most fascinating, and why?

I'm interested in organic materials that respond to light stimulation. When I was a junior high school student, I remember watching a television commercial in which UV light was shone on a polymer liquid, and the irradiated area of the liquid turned into a solid polymer film. I found it very fascinating. Even after I joined a research group in graduate school and started my studies on photo-functioning polymers and liquid crystals, the variety of responses I observed from materials exposed to light and the interactions this generated still excited me, and continue to do so today.

I began to study the photorefractive effect because this phenomenon is particularly intriguing. When you irradiate a photorefractive material with a laser, you can observe many unusual effects: the light beam incident bends upon contact to a photorefractive material; the energy transmitted is amplified by the irradiation of another beam shone through the same material; the photorefractive material then records hologram images in reverse, the list goes on. Any researcher dealing with photorefractive materials will always be interested by these diverse and often unpredictable responses.

### Why have ferroelectric liquid crystals (FLCs) been used to detect photorefractive response?

Although they are liquid, they show ferroelectric qualities – an optical response to electric fields. It has been shown that FLCs respond to applied electric fields very quickly. By the mid-1990s, the photorefractive effect of liquid crystals was already being studied by several groups. The photorefractive response of nematic liquid crystals had also been reported.

We thought that if we used FLCs for photorefractive applications, we could obtain a high-speed photorefractive material. We began our investigations and found that FLCs have many photorefractive applications. However, processing the photorefractive FLCs required sophisticated techniques, and obtaining reliable data was difficult. After our first reliable report, we were able to establish a consistent evaluation system and publish further papers.

### Have you seen much progression in your field recently?

In the development of photorefractive materials, there have been reports of high-gain or high-speed materials. However, there has been no evidence of a material that shows high photorefractivity (gain coefficient higher than 800 $cm^{-1}$) and fast response (a few milliseconds) at the same time. We have developed a photorefractive FLC material that shows a gain coefficient higher than 1,200 $cm^{-1}$ and a response time shorter than 1 ms.

### What are two-beam coupling experiments?

Two-beam coupling is used to investigate the photorefractivity of a mixture. When you cross laser beams in space, nothing happens – but when you irradiate a photorefractive material with laser beams, the laser beams interfere with each other and the intensity of one increases while the other is reduced.

**How are you applying your research to the field of photonics?**

The photorefractive effect is an optical phenomena that can help create a holographic image. The holography itself is an optical phenomenon, in fact – and I believe that it will eventually be used for photon manipulation.

**You work alongside Yumiko Naka. How does her expertise complement this project?**

Yumiko Naka joined our research group in 2010. She synthesises compounds for the preparation of photorefractive ferroelectric liquid crystals and her contribution has been crucial to this research.

**Will you be attending any events or conferences in 2014 to discuss you research?**

I will attend the coming Faraday Discussions 174 (8-10 September 2014, Strathclyde, UK). I anticipate to have active discussions on the photorefractive phenomena of FLCs with researchers from around the world.

**What do you hope to achieve next?**

I want to develop a material that shows a clear photorefractive effect – that is, a clear 3D hologram with a fast response time. That would enable us to create devices for safety, optical logic and other related applications.

# Optical revolution

Material scientists at the **Tokyo University of Science** have for many years been perfecting photorefractive mixtures that may now have applications in true holograms, sophisticated detection units and optical circuits

**IN 20TH CENTURY** future-fantasy novels, one commonly recurring theme was that of the dynamic hologram. A 3D light image projected into space, the hologram has actually been around for nearly sixty years; the accidental result of trying to refine electron microscopes. In their optical form, they can be commonly viewed today on familiar products such as credit cards, drivers' licences and even DVD cases. In essence, a hologram is simply a photograph that records not only the intensity of light, but also the interference between two distinct light sources – the object beam and the reference beam – in order to reproduce a 3D image. Creating a moving hologram, however, presents far greater difficulty.

This is where the photorefractive effect comes into play. Certain materials change their refractive qualities after exposure to light; essentially, electrons in the material become excited by light energy and leave their atoms, becoming fixed instead to ionised particles elsewhere in the material. Because they become fixed in their new positions, the pattern of light that passed through the material is effectively recorded within it – and the refractive qualities of the material are changed accordingly. When two beams interfere with each other they create a specific pattern that can be recorded within the material, allowing scientists to effectively capture a holographic image.

## BEYOND HOLOGRAMS

In time, these materials could give rise to the sustained motion holography necessary to enable holographic film and television – but that is far from being their only application. When two light beams cross within a photorefractive material, one will become amplified while the other is suppressed in a process known as beam coupling. This quality opens up the possibility of using such materials in the fabrication of sophisticated detectors for highly specific light patterns, which would recognise the exact fingerprint of a light signal; it also suggests that using photorefractive materials essentially as transistors in optical circuits might be feasible, amplifying one light signal at the expense of another.

> The ideal photorefractive material would exhibit two qualities: a minimal response time and a maximal gain coefficient

The opportunities offered by photorefractive materials are certainly exciting, but more work is required in order to select the optimal

# INTELLIGENCE

## DYNAMIC AMPLIFICATION OF LIGHT SIGNALS IN PHOTOREFRACTIVE FERROELECTRIC LIQUID CRYSTALS

### OBJECTIVES

- To develop fast and responsible photorefractive materials
- To investigate and analyse the physical properties of ferroelectric liquid crystals

### KEY COLLABORATORS

**Professor Naoto Tsutsumi**, Graduate School of Science and Technology, Macromolecular Science and Engineering, Kyoto Institute of Technology, Japan • **Dr Takafumi Sassa**, Senior Research Scientist, Advanced Device Laboratory, RIKEN, Japan

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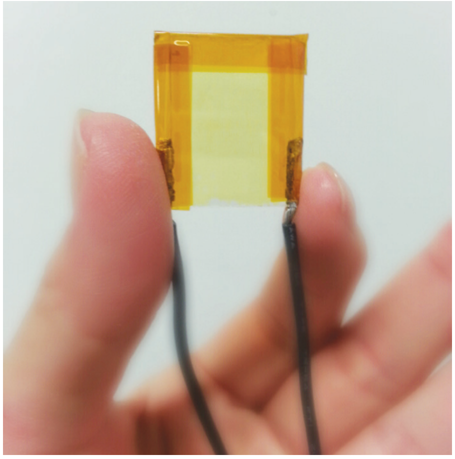
**TAKEO SASAKI** is a physical chemist with a background in synthesis of polymer materials and liquid crystals. Since he received his doctorate from the Tokyo Institute of Technology, Sasaki's research interests have been focused on the development of photo-functional materials. He has intensively studied the photorefractive effect of liquid crystalline materials and received the SPSJ Wiley Award (2004) from the Society of Polymer Science, Japan, for his efforts. Sasaki currently explores the photorefractive effect of organic materials and the synthesis of novel liquid crystalline materials.

**YUMIKO NAKA** is a graduate of the Tokyo University of Science. In 2011, she received her doctorate from the Tokyo Institute of Technology. She then joined Tokyo University of Science as a Research Associate in Professor Takeo Sasaki's laboratory. Naka received the Student Presentation Award (2009) from the Chemical Society of Japan, Rainbow Award (2010) and Encouragement Award (2012), both from Japanese Liquid Crystal Society. Her current research interests include the photorefractive effects of organic materials and the synthesis of novel functional polymers.



Photorefractive ferroelectric liquid crystal sample.

materials for use in these applications, and the most effective methods to employ when dealing with them. This is one of the goals of a group of researchers based at the Tokyo University of Science in Japan and led by Dr Takeo Sasaki. For almost 20 years, Sasaki and his colleagues have been investigating photorefractive polymers of one sort or another, and in the last 16 years this work has focused particularly on ferroelectric liquid crystals (FLCs).

### PERFECT PROPERTIES

The ideal photorefractive material would exhibit two qualities: a minimal response time and a maximal gain coefficient. The response time is the time the material takes for a refractive index grating to form within the material, and it would have to be very fast in order to enable real-time motion holography, somewhere in the order of a couple of microseconds. The gain coefficient is a measure of how much the light signal will be amplified by passing through the material in terms of wavenumber, which is measured in $cm^{-1}$. This represents the actual photorefractivity of the material, and ideally this measurement should be higher than 800 $cm^{-1}$.

In the early stages of their research, the Tokyo scientists searched for materials that could fulfill both of these qualities at once. Ultimately, their most successful experiments have been conducted with FLCs, a form of liquid crystal that is naturally electrically polarised. When an electrical field is applied to them, FLCs respond immediately in a way that changes the optical characteristics of the material. Using these convenient crystals, Sasaki and his collaborators successfully demonstrated the selective amplification of optical signals, putting forward this material as an easy and low-cost component in the fabrication of future optical devices.

### ALL IN THE MIX

Using FLCs in combination with photoconductive compounds, Sasaki's team was able to reduce photorefractive response times to 8 ms, while pushing gain efficient up to over 800 $cm^{-1}$. In a 2012 study published at the beginning of last year, they combined achiral smectic C liquid crystals with various chiral-structured terthiophene compounds, and investigated the photorefractive properties of the resulting mixtures using two-beam coupling experiments. They ascribed the high-performance results to the enhanced charge mobility enabled by the photoconductive compounds with which the liquid crystals had been doped.

The result of this experiment was rather impressive; the team succeeded in generating a true motion-hologram of a simple triangle-based pyramid rotating around a point. The image itself was generated on a computer, and then displayed on a spatial light modulator. A laser beam was then bounced off of the modulator and through the FLCs. The study found that the crystals could be 'refreshed' quickly enough to allow for the smooth motion of the shape, and no image retention or residual image was observed – in other words, this was a simple but flawless 3D motion hologram.

### GROWING RESOLUTION

Since accomplishing this impressive feat, Sasaki and his team have continued to push their FLCs further – and in a paper that is yet to be published, they will announce their most exciting result yet. With further experimentation, they have been able to cut response time to just 1 ms, and further increase the gain coefficient to over 1,200 $cm^{-1}$. This has allowed for the transmission of an animation at 30 frames per second, with response times fast enough to amplify the image in real time. With current-generation commercial screens and monitors beginning to embrace 3D technology, the motion holograms created by Sasaki and his colleagues seem to promise the optical output of the future.

As well as constituting an exciting advance and impressive technology, true holograms could also herald a number of benefits for those who interact with computers on a regular basis. Eye strain from staring at a 2D computer screen all day could be easily avoided with the advent of 3D holographic displays, which would offer the same experience as viewing an everyday object. The other applications of photorefractive materials also offer similar practical facility. "Vehicle guidance systems have recently made use of optical object detection by emitting and detecting reflected laser beams," Sasaki points out. "The intensity of the reflected beam from soft material such as clothing is weak, but in amplifying such signals, this selectively could one day prove useful."

### LIVING IN THE FUTURE

The materials being developed by Sasaki and the other researchers working alongside him therefore have a range of applications, and represent some of the most immediate and compelling uses of optical technology. Although the future of human technological advances is hard to predict, it seems sure that this Tokyo research group is lighting the way towards the innovations of tomorrow.