A LEADING LIGHT FOR SMART MANUFACTURING

High-tech spatial light modulators can manipulate laser beams with incredible precision and are REVOLUTIONIZING MATERIALS PROCESSING, thanks to a collaboration between industry and academia.

Since their invention in 1958, lasers have become a vital tool for manufacturing products as diverse as cars, musical instruments and computer chips. Lasers not only offer precise drilling, cutting and welding, they can texture surfaces, strip paint and etch tiny identification codes on to devices.

However, controlling lasers is not easy. Different applications demand lasers with different strengths, pulse lengths and polarizations, over a range of visible and non-visible wavelengths, and often at scales smaller than thousandths of a millimetre.

Traditionally, beams have been trained on their targets using motors and servos that minutely shift lenses, mirrors, gratings or the target itself. While these have been very useful, their precision is limited, and they need regular inspection and maintenance as parts wear down.

Optical engineer, Haruyoshi Toyoda, director of the central research laboratory at Hamamatsu Photonics in Hamamatsu, Japan, has been working on laser control since he joined the company in 1986. Alongside academic partners, including Toyoda's long-time friend, Yoshio Hayasaki, vice director of the Centre for Optical Research and Education at Utsunomiya University, Hamamatsu is at the forefront of developing components called Spatial Light Modulators (SLMs).

'MAGIC MIRRORS'

As well as offering extremely precise control of laser beams without the need for mechanical parts, SLMs can monitor their work and automatically correct deviations. They hold the promise of faster, cheaper, high-quality manufacturing, as well as sophisticated 3D printing and holographic imaging.

"In the 1980s, when I started working at Hamamatsu, there was a boom in interest in optical computing, when we realized that using photons to transmit information could enable faster, more powerful processors," says Toyoda. As a result, researchers at the Massachusetts Institute of Technology in Boston, US, led by electrical engineer, Cardinal Warde, then proposed SLMs as a way to control the laser beams, and started joint research to develop an electron tube type SLM with Hamamatsu, Toyoda adds.

The SLMs developed in recent years at Hamamatsu, under a Japanese government cross-ministerial Strategic Innovation Promotion Program (SIP) called 'Photonics and Quantum Technology for Society 5.0', make use of the unique properties of liquid crystals.

This familiar technology has been used in digital displays for decades, but can now be controlled almost on a single-molecule basis. The crystal molecules, which essentially act as miniature mirrors and lenses, are arranged in pixels just 12 micrometres across, connected to tiny electrodes. By applying a voltage to a pixel, the tilt of the molecules is changed so that they interact with incoming light in different ways.

"Our SLM looks like an ordinary mirror, but it is more like a magic mirror," says Toyoda. "The tilt of the molecules in each pixel changes depending on the voltage applied. This means we can control the shape of the laser wavefront with micrometre accuracy."

"WITH OUR IMPROVED THROUGHOUT OF LASER PROCESSING, THERE IS NO LIMIT TO WHAT WE COULD DO."

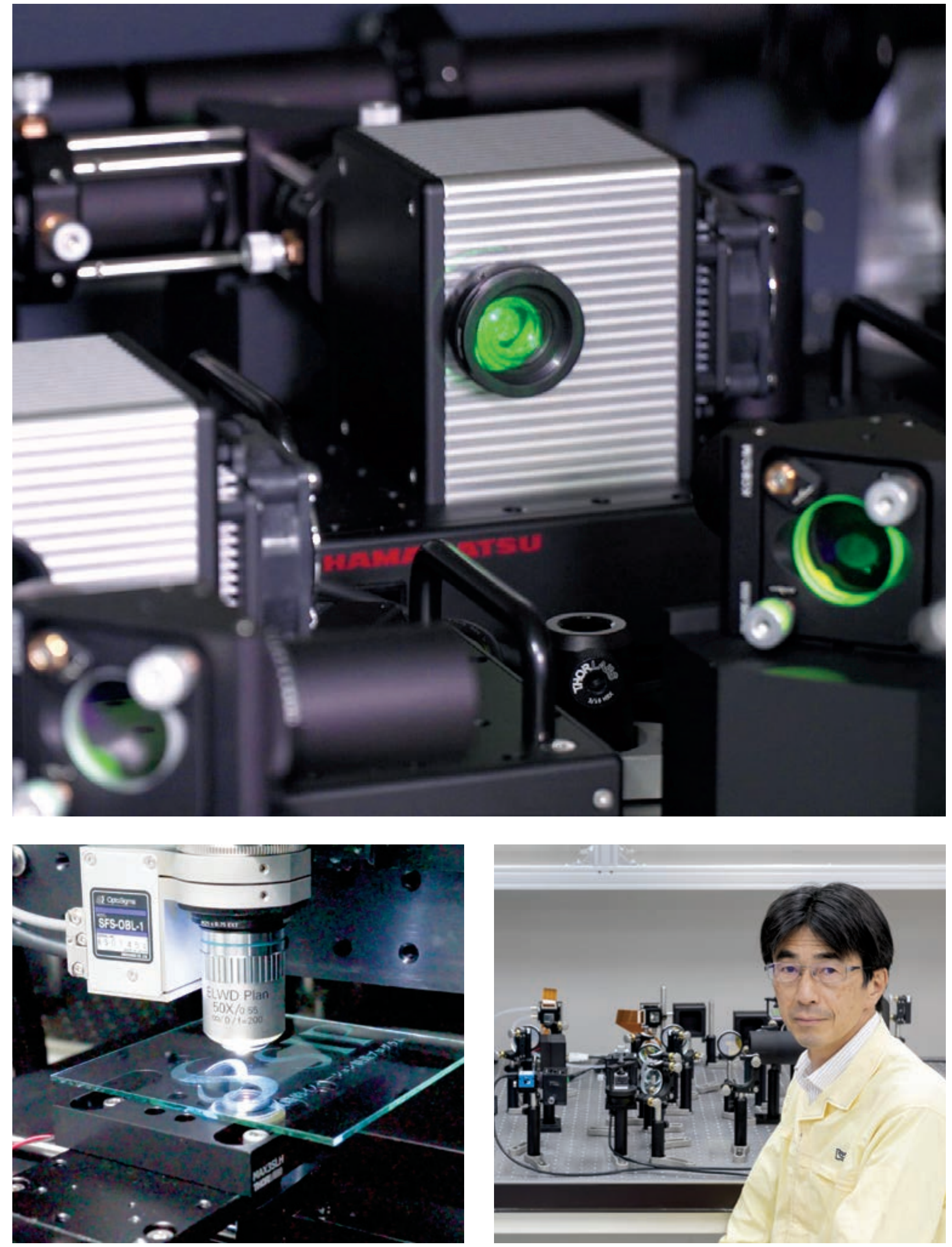
STABILITY AND FLEXIBILITY

SLMs have many advantages over mechanical systems. They are more stable against temperature and humidity changes, provide better positional accuracy, maintain better beam intensity and provide flexible 3D control, so that the lasers can do things such as drill and cut simultaneously.

"SLMs can be used for thermal laser processing, where the beam continuously supplies energy to melt a target," says Hayasaki. "However, they can provide even more precise machining through non-thermal processing — applying extremely short laser pulses so that heat cannot conduct to the wider area around the focus. This will be extremely useful for machining materials that are vulnerable to heat, such as glass and semiconductors."

According to Toyoda, "the SIP project has allowed us to develop large-area SLMs that achieve 100% light utilization efficiency, and to improve the handling of high-power lasers with ultra-short pulses." But even SLMs can be affected by environmental factors — for example, the thickness of grooves cut in glass can vary randomly with temperature, humidity, or external vibrations. For this reason, the researchers are enabling SLMs to monitor their own work as they go, and automatically adjust their configuration if they spot any errors.

"We use two types of digital feedback to maintain optimal conditions in our laser processing," says Toyoda. "We have cameras to observe the intensity of light reflected from the SLM, and to monitor the modification of the target materials. This information is fed back to the controlling computer, which calculates the best way to re-optimize the light pattern — for example by moving the focal spot, adjusting its size or adding extra focal spots."



▲ **Hamamatsu's experimental optics set-up (top). An example of laser processing in action on Utsunomiya University's system (left). Haruyoshi Toyoda in front of Hamamatsu's laser processing system (right).**

EXTENDING APPLICATIONS

By providing such unprecedented control, SLMs enable many new achievements in manufacturing. For example, Hamamatsu and Utsunomiya have used ultra-short-pulsed lasers to drill holes as small as 40 micrometres for printed circuit boards and to form patterns in solder mask structures for circuits and components in semiconductor devices.

Another impressive technology is laser annealing, whereby a laser can instantaneously heat a substance, such as amorphous silicon, and cause it to crystallize in a desired shape and position. Lasers can even be used to peel off ultrathin semiconductor chips that have been grown on a substrate, in a process known as 'debonding'. These methods will greatly benefit the development of high-power logic circuits, sensors and computer memory.

SLMs are finding uses in high-resolution microscopy, adaptive optics, optical micropatterning, holographic and three-dimensional displays, and optical tweezing to control the states of micro- and nano-particles, molecules, and atoms. Toyoda and Hayasaki are hopeful that their devices will also play a big part in the development of commercial optical and quantum computers.

"With our improved throughput of laser processing with beam splitting and beam shaping, there is no limit to what we could do," says Toyoda. ■

LOOKING FORWARD

In the future, the machines combining Hamamatsu's device and Utsunomiya University's holographic control might perform their digital feedback corrections by using the internet to find the best laser processing conditions, or 'recipes' for manufacturing through cloud developed by the University of Tokyo. This could involve distributed cloud servers that host machine learning algorithms with artificial intelligence to explore many different combinations of parameters, such as beam intensity, diameter, and shape. This so-called Cyber-Physical System (CPS) in combination with SLMs would shorten the search for the best combination.

"In the past, laser processing relied on the experience and intuition of specialists, and the process of finding the optimum laser processing conditions is generally so tough," says Yoshio Hayasaki of Utsunomiya. "The search for optimal processing conditions in the CPS can be carried out more heuristically and efficiently by combining SLMs to allow variable and continuous controls of the beam shape."

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