NEWS & VIEWS

APPLIED PHYSICS

A cascade laser's random walk

A random array of holes etched in a semiconductor structure, consisting of a periodic series of thin layers, has been demonstrated that emits mid-infrared laser radiation. The device could have sensing and imaging applications.

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Fifty-three years after their initial demonstration by Theodore Maiman[1], lasers are now ubiquitous in our daily lives. We use them at the checkout counters of supermarkets, to read or write to DVDs, or just to surf the Internet (through fibre-optic communication systems). Lasers are also widely used in industrial settings and hospitals. Over the years, scientists and engineers have developed many types of laser using various materials for diverse applications. But despite such tremendous advances in laser technology, it is still a pleasant surprise to learn of developments that may pave the way for further cutting-edge applications. One example of this is a special class of laser — a random laser — operating in the mid-infrared that Liang *et al.* report[2] in *Advanced Materials*.

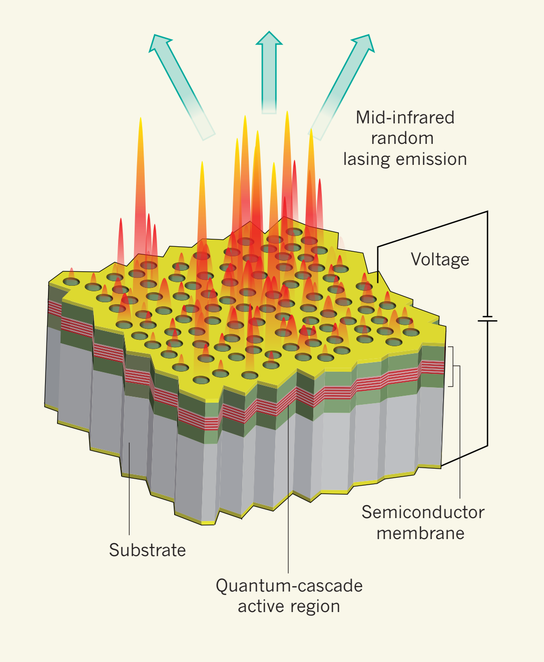

Figure 1 | An electrically pumped mid-infrared random laser. Liang *et al.*[2] fabricated a random array of holes open to the air in a semiconductor membrane on a substrate. When an external electrical voltage is applied between two gold electrodes, electrons are injected from the top electrode to the quantum-cascade active region in the membrane, which subsequently emits and amplifies light. That light is scattered by the air holes, bouncing from one hole to another before escaping vertically or laterally. The multiple scattering and interference of light traps it temporarily inside the active region, enhancing light amplification. When light leakage and absorption are balanced by this amplification, lasing occurs.

A laser has two basic components: a gain medium, which is a material that emits and amplifies light; and an optical cavity, a structure that traps light temporarily to make amplification efficient. The simplest laser optical cavity is made up of two mirrors facing each other, one highly reflective and the other partially transmitting, with a gain medium between them. Light is reflected back and forth between the mirrors, and each time it passes through the gain medium it is amplified, until it leaves through the partially transmitting mirror. A lasing threshold, beyond which laser light is emitted, is reached when the amplification of light caused by the gain medium compensates for the loss of light from the mirrors.

Unlike a conventional laser, a random laser uses a highly disordered structure to trap the light[3,4]. Although they might seem incompatible with lasers, disordered materials are common in our daily lives: milk, toothpaste, paper and clouds are just a few examples. They all consist of small particles or droplets that scatter light. When a light wave hits a particle, its direction of travel is changed randomly, and that particle is called a scattering centre. After propagating farther, the light wave will hit another scattering centre and change direction again. In a system that consists of thousands of scattering centres, a light wave will be scattered many times and undergo a 'random walk'. Multiple scattering in this manner increases the path length of the light, in turn increasing its dwell time in a disordered structure. If a gain medium consisting of dye molecules is incorporated between scattering centres, light amplification is enhanced by multiple scattering, and lasing can occur.

Since the pioneering work of Nicolay Basov[5] and Vladilen Letokhov[6] in the 1960s, extensive studies[3,4] have shown that random lasing is a phenomenon that applies to numerous systems, including powders, colloids, polymers, fibres and even biological tissues. Lasing frequencies range from the near-ultraviolet to the near-infrared. A major obstacle to the practical application of random lasers is the expensive source that is required to pump energy into the gain medium so that it can amplify the light. There are two pumping schemes: one is optical, involving absorption of light from another source (usually a laser at a different frequency); the other is electrical, such as injection of current from a battery. The second scheme is much cheaper and more convenient for many applications. However, most random lasers are optically pumped.

Liang and colleagues' work represents a major advance in random-laser technology. The authors pushed the lasing frequency to the mid-infrared, and achieved electrical pumping. To do this, they etched a random array of air holes into a semiconductor membrane (Fig. 1). Light propagating in the membrane is scattered from one hole to another, randomly changing direction at each one — rather like a drunk person wandering in a forest and changing direction whenever he encounters a tree, to use a common random-walk analogy. Because this structure is fabricated by lithography and chemical etching, the diameter, position and density of the holes can be accurately determined, allowing precise control of the scattering strength. When the scattering is sufficiently strong, random lasing occurs. The lasing threshold decreases with increasing air-hole density, because more holes help to trap light more effectively.

To push their lasing wavelength down to 10 micrometres, Liang *et al.* used a quantum cascade laser, which is an intrinsically electrically pumped device that provides strong amplification of light in the mid-infrared[7]. The membrane comprises a periodic series of thin layers of compound semiconductors. When an external voltage is applied, a representation of the energy levels of electrons in these layers would look like a staircase. Once an electron is at the top of the staircase, it begins to cascade down and emits a photon with every step that it descends. The quantum cascade laser's emission frequency is determined by the energy drop at each step, which can be adjusted by changing the layer thickness.

Liang and co-workers' quantum cascade random laser raises hopes of new imaging applications. Many biochemical molecules have spectral 'fingerprints' in the mid-infrared range, a property that can be used for sensing and imaging applications — for example, in trace-gas sensing for pollution control and environmental monitoring; combustion diagnostics; and medical diagnostics (such as breath analysis). A crucial characteristic of random lasers is that the spatial coherence of their laser emission can be easily tuned[8]. Spatial coherence describes the correlation between waves at different points in space: sunlight shining through a cloud has low spatial coherence, whereas stars in the night sky have high spatial coherence. Low spatial coherence is desirable for parallel imaging, because light illuminating different spatial positions is uncorrelated, and so coherence artefacts such as crosstalk and speckle (random granular patterns) are avoided[9].

To produce emission that has low spatial coherence, a random laser must have many modes (oscillating waves) lasing simultaneously[8]. Liang and colleagues' laser supports only a limited number of random-lasing modes, so its spatial coherence could still be high, although this has not been measured. A further increase in the laser's scattering strength would probably cause more modes to lase, thereby reducing the spatial coherence of the emission. However, because random-laser emission is non-directional, in this case a clever scheme would need to be developed for the efficient collection of total emission.

Looking to the future, this method of making mid-infrared random lasers could be extended to terahertz (10^{12} Hz) frequencies. In fact, lasers known as quasi-periodic, distributed-feedback quantum cascade lasers operating in the terahertz regime were constructed only three years ago[10]. Common packaging materials such as cardboard and plastics are transparent to terahertz radiation, making it useful for package inspection, quality control and non-destructive testing[7]. A combination of low spatial coherence and high radiance would also make a terahertz random laser suitable for applications such as high-speed parallel inspection. ■

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BIOCHEMISTRY

Metal ghosts in the splicing machine

Chemical analysis of the spliceosome's active site reveals that it is the RNA components of this enzyme complex that coordinate the catalytic metal ions responsible for production of a spliced messenger RNA. **SEE ARTICLE P.229**

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Genes are transcribed as pre-messenger RNA molecules in which the coding exon segments are typically interrupted with non-coding sequences, or introns. To create a functional mRNA, the introns must be removed and the exons joined together in a process known as pre-mRNA splicing. The two phosphoryl-transfer reactions of splicing are catalysed by the spliceosome, a metalloenzyme complex comprising five small nuclear RNAs (snRNAs) and dozens of core proteins[1]. The spliceosome uses magnesium ions at its active site as catalytic cofactors, and researchers have long been captivated by the question of whether the ligands for these metal ions are provided by the snRNAs or by the proteins, as this speaks to the evolutionary roots of the splicing process. On page 229 of this issue, Fica *et al.*[2] report that a specific constellation of phosphate oxygens in the U6 snRNA supplies the ligands that coordinate the catalytic metal cofactors in the active site. This finding establishes the concept that pre-mRNA splicing is fundamentally an RNA-catalysed reaction.

Fica and colleagues used an approach known as a metal-specificity switch to establish how the catalytic metal ions are bound within the spliceosome. They systematically introduced single atoms of sulphur in place of phosphate oxygens in the U6 snRNA of the spliceosome. Of the 20 positions tested, they found five substitutions that impaired splicing in the presence of magnesium ions (Mg^{2+}), a metal that binds efficiently to oxygen but not to sulphur. The splicing activity of these impaired spliceosomes could be rescued by the addition of manganese (Mn^{2+}) or cadmium (Cd^{2+})

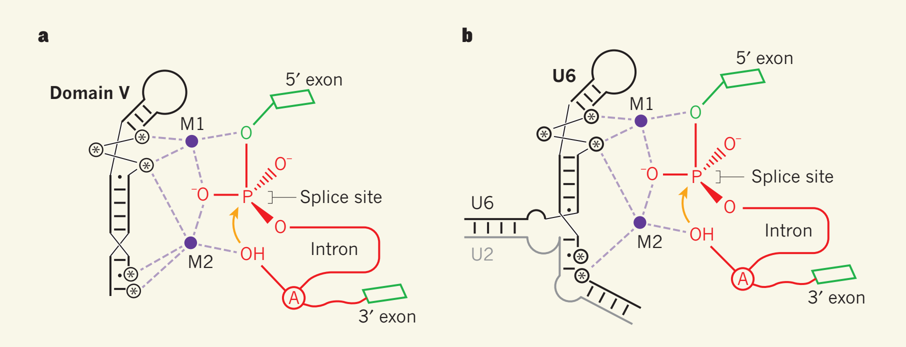

Figure 1 | Active sites of group II introns and the spliceosome. **a**, Group II introns are RNA elements that self-catalyse splicing — the removal of introns (red) and the joining of adjacent exon regions (green). They contain a hairpin structure called domain V; the phosphoryl-transfer reactions of splicing (the first of which is shown with an orange arrow) are catalysed by two divalent metal ions (M1 and M2) that are coordinated (dashed purple lines) to phosphate-group oxygen atoms of nucleotides (asterisks) in this region[5], to a non-bridging oxygen at the splice site and to an OH group from an adenosine nucleotide (A) in the intron. **b**, Fica *et al.*[2] now show that RNA also catalyses these reactions during pre-mRNA splicing by the spliceosome — a metalloenzyme complex composed of small nuclear RNAs (snRNAs) and proteins. They show that the U6 snRNA of the spliceosome (which forms a hairpin structure similar to that of domain V) provides the phosphate oxygens that bind to two catalytic metal ions at the enzyme's active site, in a similar manner to the metal-ion coordination of group II introns. The adjoining U2 snRNA of the spliceosome is also shown.