All at the same time

A SINGLE ONE-PIECE SEMICONDUCTOR LASER CAN NOW EMIT THE THREE PRIMARY COLOURS, WRITES **S ANANTHANARAYANAN**

The defining character of the laser is that light waves emerge as a continuous train, not snatches of a wave that are not in step with each other. If we took the uniform footfall of a marching soldier as an instance of regular motion, like the rise and fall of a wave, then a laser would be like a platoon marching in step, while ordinary light is like the same soldiers, all marching but not keeping to the same drumbeat.

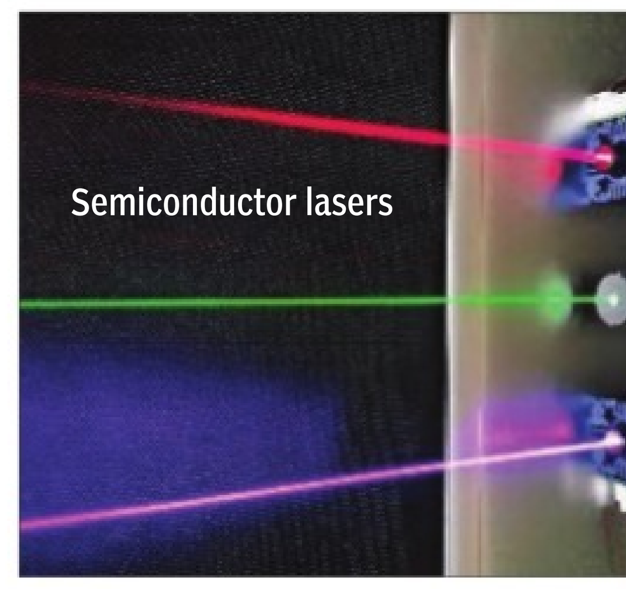
Along with this defining character, the hallmark of lasers is that the light arises from energy level transitions within atoms and they shine in a light of acutely single colour, or light that has very little spread if it is dispersed by a prism, which splits white light into the whole rainbow. And then, the way laser light is generated makes sure that the rays within a beam are nearly parallel and the beam does not spread, even over great distances.

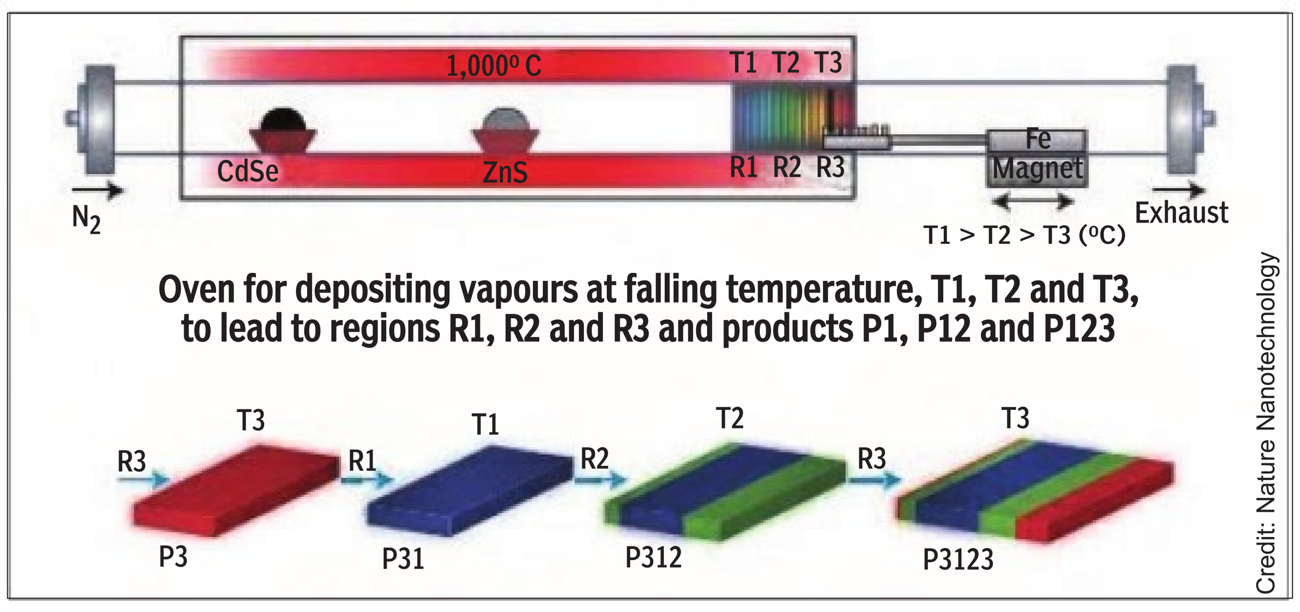
While the fact that the light waves are all in step, or *coherent*, has made lasers useful in scientific research, the fact that the beam stays narrow also has many uses. One of these is to generate a very intense beam that can be used as a welding torch, for instance, or as a beam that does not dissipate by spread, which could save power for use in communications or to light a signboard at a distance. In this last application of lighting and signage, the capability to create laser light of all colours has important commercial value. A team of researchers at Arizona State University, including a collaborator from Tsinghua University, Beijing, report in the journal *Nature Nanotechnology* a technique to build a single semiconductor crystal that can produce laser light in each of the primary colours at the same time!

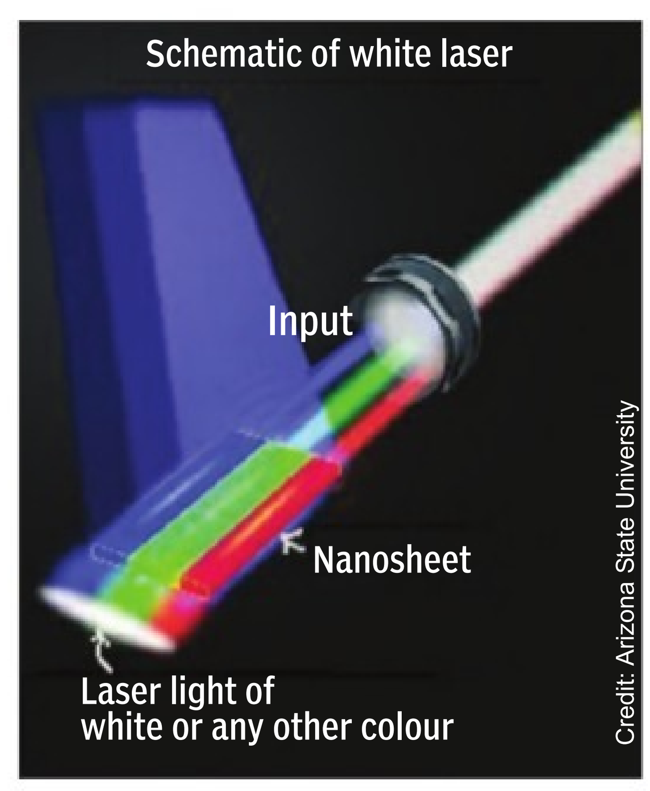
A common source of light, not necessarily a laser, is the *light emitting diode*, a device that also uses semiconductor material. The difference between semiconductors and insulators or good conductors is that the former have the capacity to release current-carrying charged particles if they are given a small nudge, unlike insulators that cannot, or conductors that need hardly any nudge. Now, semiconductors can get even more active if the atoms in a crystal have an impurity of a different kind of atom, which has either one electron — which is the current carrier — more or less that the number that the semiconductor atoms have. In such a case, the material has this extra electron, or the lack of one, called a "hole", which is free to move and conduct electricity.

Things become more interesting when we place these two kinds of semiconductor materials, with the wandering electron or the "hole", against each other. The electrons can cross over to the other side and "fill" the "holes" but there is no way "holes" can cross over to the other side. The junction of the two kinds of semiconductors then becomes a "one way gate" and the device is called a "diode", or a two-terminal device that allows current to pass only in one direction. The electrons that cross over and fill the holes, however, create a negative charge due to their presence and this prevents more electrons from coming in, and the process stops almost as soon as it starts.

But if a current is passed through the device so that electrons keep crossing over and neutralising holes, what happens is that higher energy electrons fall into lower energy holes and some of them give off a photon of light of a colour that corresponds to the energy difference. This is the principle of the *Light Emitting Diode*, or *LED*, which is the basis of many display systems, even TV screens. LEDs can now be made to emit light of many colours, including blue, green and red, the "primary colours", and panels of these lamps can be mixed to create a large number of natural colours.








Professor Cun-Zheng Ning

The laser

The basis of how early gas lasers and also the later solid state lasers work is the property of some atoms that have been excited, either by intense light or by electricity, to pause an instant before they de-excite, by emission of light. Because of this "pause", a good number of atoms can be excited so that a chance particle of light could cause a cascade of de-excitation and a flash of laser light. To keep the laser going, the arrangement has a pair of parallel mirrors that keep photons going back and forth and repeatedly cause laser cascades. In the case of LEDs also, electron-hole pairs can be gotten to "pause" before they emit that photon of light when they combine. In such a case, again, there can be an accumulation of "paused" emitting pairs waiting to be tripped by a photon of light, and there can be laser action. Crystals of semiconductor material that are arranged for this to happen are called *semiconductor lasers* and they represent an important segment of lasers in industry, communications and for lighting and illumination.

As the applications of semiconductor lasers grow, there is now an interest in creating more and more efficient arrangements to produce different shades of light, and with as compact a device as possible. The paper in *Nature Nanotechnology* by Fan Fan, Sunay Turkdogan, Zhicheng Liu, David Shelhammer and professor of electrial, computer and energy engineering, Cun-Zheng Ning says that apart from being more efficient than LEDs, a panel of four lasers, each emitting light of one colour, can be combined to create almost all the shades present in white light. The best approach to getting to such a combination has been with discrete devices, each emitting in one colour. But having four, or even three, devices for each pixel of a display, for instance, is cumbersome and increases size, complexity and cost.

Early attempts at creating a single device used non-semiconductor material and were bulky, apart from needing a separate interface with the semiconductor material of most other electronic equipment, the authors of the paper say. And building a single semiconductor structure involved growing high quality crystals of dissimilar materials, which has challenges because of the differing lattice geometry.

The more successful efforts in recent times have been with nanocrystals or nanowires of semiconductor material, but even with these there are issues of the material being opaque to some colours and in creating electrical contacts. Just over two years ago, the present authors had succeeded in creating a composite laser in the form of a nanosheet and a nanowire with a looped end made from cadmium, sulphur and selenium that emitted in the green and red. Adding the capacity for blue light was a challenge.

The ideal element to add for blue light, the authors say, was zinc sulphide (ZnS), which was known to form structures with the other three elements. But ZnS itself had limitations in not being compatible with the geometry favoured by the two-colour emitting nanosheet. The group, therefore, went into the growth mechanisms of the crystals and was able to coordinate the different stages so that they arrived at multi-segment, mixed structure nanosheets consisting of the four elements in different combinations and with the geometry required for the generation of laser light in red, green and blue, simultaneously. The problem of opacity, the authors say, was overcome by a change in the layout of segments, to lie side by side instead of one before the other.

The team has also tested separate optical exciting of each segment to tune the output, to create different shades and also white light. The description, "white laser", the authors say, may sound contradictory as lasers suggest pure colours and white is a range of colours — but "our results demonstrate that the apparently contradictory terms 'white' and 'lasing' can both be realised in a single monolithic structure", they add.

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SYMBIOTIC RELATIONSHIP

THE FLOW OF ENERGY THROUGH THE BIOSPHERE IS ACCOMPANIED BY A FLOW OF MATTER, SAYS **TAPAN KUMAR MAITRA**

Biological processes are remarkably efficient in energy conversion. *Heat losses* are, nonetheless, inevitable in every biological energy transaction. Sometimes the heat that is liberated during cellular processes is put to good use. Warm-blooded animals, for instance, use heat to maintain body temperature at some constant level, usually well above ambient. Some plants use metabolically generated heat to melt overlying snow or to attract pollinators. In general, however, the heat is simply dissipated into the environment and lost.

Even more fundamental is the *increase in entropy* that accompanies cellular activities. We will get to that in more detail shortly; here, we can simply note that every process or reaction that occurs anywhere in the universe always does so in such a way that the total entropy, or disorder, is increased. This change in entropy occurs at the expense of energy that might otherwise have been available to do useful work and is, therefore, an inevitable "sink" into which energy is lost. Just as the ultimate source of nearly all energy in the biosphere is the sun, the ultimate fate of all energy becomes randomised in the universe as increased entropy.

Energy enters the biosphere unaccompanied by matter (that is, as photons of light) and leaves the biosphere similarly unaccompanied (as heat losses and increases in entropy). While it is passing through the biosphere, however, energy exists primarily in the form of chemical bond energies of oxidisable organic molecules in cells and organisms. As a result, the flow of energy in the biosphere is coupled to a correspondingly immense flow of matter.


The Voodoo Lily (*Sauromatum guttatum*) warms certain parts of its flowers. The plant is pollinated by flies, which apparently mistake the flowers for dead meat. The flower emits odours that help attract the flies, and heating helps disperse the smelly gases.

In addition, there is an accompanying cycle of nitrogen. Phototrophs obtain nitrogen from the environment in inorganic form (often as nitrate from the soil, in some cases as N_2 from the atmosphere), convert it into ammonia and use it in the synthesis of amino acids, proteins, nucleotides and nucleic acids. Eventually, these molecules, like other components of phototrophic cells, are consumed by chemotrophs. The nitrogen is then converted back into ammonia and eventually into nitrate — by soil micro-organisms, in the latter case.

Carbon dioxide, oxygen, nitrogen and water, thus, cycle continuously between the phototrophic and chemotrophic worlds, always entering the chemotrophic sphere as energy-rich compounds and leaving again in an energy-poor form. The two great groups of organisms can, therefore, be thought of as living in a symbiotic relationship with each other, with a cyclic flow of matter and a unidirectional flow of energy as components of that symbiosis.

When we deal with the overall macroscopic flux of energy and matter through living organisms, we find cellular biology interfacing with ecology. Ecologists are very concerned with cycles of energy and nutrients, with the roles of various species in these cycles, and with environmental factors that affect the flow. At the cellular level, our ultimate concern is how the flux of energy and matter we have been considering on a macroscopic scale can be expressed and explained on a molecular scale in terms of energy transactions and the chemical processes that occur within cells. We, therefore, leave the macroscopic cycles to the ecologist and turn our attention to the reactions that occur within individual cells of bacteria, plants and animals to account for those cycles.

First, however, we must acquaint ourselves with the physical principles underlying energy transactions, and for that we turn to the topic of bioenergetics.

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Should we contact aliens?

WITH THE NEWS FROM KEPLER-452B, IT SEEMS MORE LIKELY THAN EVER THAT THERE IS EXTRA-TERRESTRIAL INTELLIGENCE. SO HOW WISE IS IT TO ADVERTISE OUR PRESENCE? **ADAM LUSHER** REPORTS

As you read this, the metal dishes of 42 radio telescopes hidden in a little-visited valley in California's Cascade Mountains are locked on to a star system hundreds of light years away. Together they will scan 10 billion radio channels, searching for signals deliberately sent by intelligent aliens or accidentally leaked from their planets. Then the dishes will turn to the next star and its satellites.

The 42 devices of the Allen Telescope Array have already taken a preliminary look at Kepler-452b, the potentially habitable, Earth-like planet whose discovery was announced last week. And "so far, any inhabitants of Kepler-452b are remaining coy", admits Seth Shostak, of the Search for Extraterrestrial Intelligence Institute, which runs the telescope. But as its director of research, he is anything but disheartened.

"Right now," he says, "there could be radio waves zipping through your body that have come from another planet. But if there are no signals, it would mean that of the trillion planets in our galaxy — roughly 10 per cent of which are amenable to life — earth is the only place with critters that have understood science and built technology based on it. So if this is the only place in the galaxy with intelligent life, then earth is some sort of miracle – and we scientists tend to think that, if you say something is a miracle, you haven't studied statistics."

It seems that hopes for discovering intelligent alien life have rarely been higher. In the same week of the Kepler-452b revelation, billionaire Russian Internet entrepreneur Yuri Milner announced he was funding Breakthrough Listen, a new, decade-long $100 million project dedicated to the quest. And the money, one of the biggest ever donations to the search for alien intelligence, led Professor Frank Drake, chairman emeritus of the Seti Institute and adviser to Breakthrough Listen, to declare, "We will have the most powerful and enduring search that's ever been launched."

Which, of course, does not alter the fact that so far we have found nothing. But, explains Dr Shostak, finding alien life was never going to be straightforward: "If aliens had been looking at earth with a radio telescope, they would have found nothing during the first four and a half billion years. Earth may have had microbes, or dinosaurs, but we only became detectable around the time of World War II, with the invention of radar."

In 2010, Professor Stephen Hawking warned against actively seeking to make contact, saying, "We only have to look at ourselves to see how intelligent life might develop into something we wouldn't want to meet." But, says Dr Shostak, it is already too late to hide. The signals that have leaked from earth are now 50-60 light years out. Every day, our TV signals wash over another star system. Which does at least mean, says Dr Shostak, that "it's too late to worry about it". Besides, if we do discover something out there, we might find our reactions are strangely… human.

THE INDEPENDENT


Looking up: the Allen Telescope Array in California.

PLUS POINTS

Mystery solved

A longstanding mystery surrounding the deaths of 3,000 soldiers from Napoleon's army found in a mass grave in Lithuania has been solved. The jumbled bones of the men who died on the French leader's ill fated attempt to march on Moscow in 1812 show signs of starvation, according to archaeologists from the University of Central Florida.

According to *Forbes*, buttons found on the site, which was first discovered in the Lithuanian capital of Vilnius in 2002, show over 40 different regiments were represented from Napoleon's army as they made their desperate dash back across Europe. Around 500,000 in the Emperor's army began their long march to Moscow in June 1812,


"The soldiers" bones were found in 2002.

but by the time they were stumbling back to Vilnius in retreat six months later only 40,000 had survived. Around 20,000 men were believed to have died of hypothermia, starvation and typhus in Vilnius alone.

This failure was seen as the beginning of Napoleon's downfall from power in France, which led to his temporary exile in 1814 before his imprisonment by Britain following the Battle of Waterloo in 1815.

CAROLINE MORTIMER/THE INDEPENDENT

Arrested translation

Interruption of the protein translation machinery as it reads a messenger RNA (mRNA) transcript is rare but problematic. A new study in *Science Advances* on 24 July reveals that one cause for such arrest is the mRNA sequence itself — specifically, strings of multiple adenosine (A) nucleotides. Although such translation stalling on poly(A) stretches had been observed previously, it was thought that the encoded amino acids were to blame. The finding that in fact the nucleotides are responsible could have important implications for gene mutations previously considered silent, or synonymous.


Ribosome translating mRNA.

"That it's really the RNA sequence and not the protein sequence which is important — that was a serendipitous finding, and what's beautiful… is that they followed it up," said cell and molecular geneticist Jonathan Dinman of the University of Maryland, who was not involved in the work. "They were looking for one thing… but found the unexpected."

Ribosomes, the proteins that read the codon sequences of mRNA transcripts and translate them into amino acid chains, occasionally stall. And when they do, the general result is degradation of both the mRNA and the unfinished protein. However, Rachel Green at Johns Hopkins University School of Medicine and her colleagues made a strange discovery. They found that bacterial ribosomes were more prone to pausing on strings of lysines if they were encoded by AAA codons than by AAG codons. "That was really puzzling and… to be honest, it was a surprise for us," said Sergej Djuranovic, who was previously a postdoc in Green's lab and is now an assistant professor of cell biology and physiology at Washington University in St Louis. "Nobody had really looked at the differences between mRNA sequences, or codons, for the basic amino acids," he said.

The results also suggested that apparently silent mutations in stretches of poly-lysines — those that alter codon sequences but not amino acids — might not be so silent after all. Indeed, Djuranovic's team showed that in poly-lysine stretches of actual human genes, mutating AAG codons to AAA codons consistently decreased protein expression and mRNA stability, while mutating AAA codons to AAG had the reverse effect.

RUTH WILLIAMS/THE SCIENTIST