Shedding light on lasers

By Abram Katz, Register Science Editor

When the first working laser was developed in 1960, physicists were intrigued, but none could see much practical use for the light-emitting device.

Now, lasers are virtually everywhere: in surgical tools, computer optical drives, grocery store scanners, compact disc players, carpentry levels, range finders for golfers, police equipment and in "smart" bombs.

While scientists know how lasers work, until recently they could not calculate the output, or gain, of a laser without an actual test. This hasn't hampered mass adoption by industry, but it just didn't sit right with A. Douglas Stone, Yale University professor of applied physics, and his colleagues.

Although Stone is in applied physics, he is a theorist and he collaborated with Yale graduate students and scientists in Zurich, Switzerland, to mathematically quantify the intensity of a laser over time, as well as understand a new breed of "diffuse random lasers" unlike anything in your computer, mouse or pointer.

Stone succeeded by solving fearsomely complex nonlinear equations that had been neglected for four decades.

We tend to take lasers for granted. However, their working principles are hardly easy to grasp.

Conventional lasers all trace back to early work by Albert Einstein.

Einstein, who is best known for his theories of relativity, won the 1921 Nobel Prize in physics for his explanation of the photo-electric effect, in addition positing the existence of discrete units of energy, which he called quanta. This ultimately led to quantum mechanics, which Einstein spent decades trying, unsuccessfully, to disprove.

The photo-electric work also led Einstein to the idea of "stimulated emission," Stone said. Laser, in fact, is an acronym for light amplification by stimulated emission of radiation.

To understand what this means, consider that atoms's electrons can zap into higher orbits when they absorb a certain amount of energy. The electron then drops down to the original orbit, dumping the energy in the form of a photon. Photons all "want to be alike," Stone said, so when the photon passes another atom, it causes a similar photon to pop out. This is stimulated emission.

Many substances can be made to "lase." Semiconductor crystals containing rare earth elements comprise most current solid state lasers. There are also gas lasers and chemical lasers.

The medium is placed in a tube with mirrors at both ends. Mirrors are necessary to raise the number of stimulated emissions.

Some form of energy, such as light or electricity, is used to "pump" the atoms in the gain material. The liberated photons bounced back and forth in the mirrored chamber, developing greater and greater intensity.

Generally, one of the mirrors is half-silvered, so that when the beam reaches a certain strength is can penetrate and emerge as light of one color, with all of the waves lined up in orderly fashion.

All of the waves form coherent light based on the length of the tube, Stone said. Light resonates at certain frequencies, like a guitar string. The tube length determines the frequency of the laser light.

That's pretty much how all everyday lasers work. It's good for mechanisms down to a few fractions of an inch. But, as physicists attempt to fabricate nano-machines, gizmos with mirrors are too complicated to fashion.

Enter the diffusive random laser, an unconventional substance that appeared in 1999.

In essence, a random laser is a puddle or clump of nano particles. When excited, the randomly scattered atoms shoot laser beams of different frequencies in several directions.

"It was hard to understand why it 'lased.' What explains the frequencies?" Stone asked.

The atoms might be acting as their own resonators, taking the place of mirrors, but what could account for the different colors of laser light?

Stone and colleagues concluded that the explanation for diffusive random laser would requires a more general, fundamental laser theory. The goal was to calculate, given the composition of the material and the intensity of the "pumping" light, what frequency laser beams would emerge.

Moreover, Stone sought an ab initio theory - that is, an explanation based on first principles.

"Shouldn't we be able, if we know the resonator and gain molecules, to tell you what will come out?" Stone said.

Solving the problem required working through extremely complex nonlinear equations that no one had solved in more than 40 years, he said.

The ultimate equation involves integrals, differentials and a dozen variables. And it works.

The string of squiggles can predict the intensity and frequency of laser beams emitted by a random laser, and it also works for conventional lasers.

Diffuse lasers are appealing to engineers because they can literally be painted on surfaces. This will allow fabrication of new kinds of devices, Stone said.

One of the random laser's first uses might be to identify tiny components. By applying the right gain material, the laser will emit certain wavelengths.

Shining a light on the laser will immediately reveal whether it has the right colors or not.

And just like the laser of 1960, the future of diffuse random lasers is impossible to predict.
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