OPTICS

Interfering With Atoms to Clear a Path for Lasers

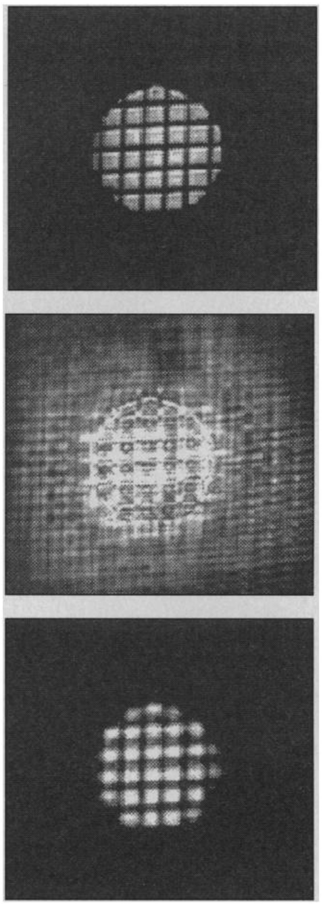
Sometimes, trying harder just makes things worse. That's the case for laser beams passing through a transparent medium such as air. Weak lasers slip through without difficulty, but more intense beams run into trouble. Their very intensity can change the optical properties of the medium, turning it, in essence, into a lens that either focuses the beam more intensely, until it splinters into filaments and hot spots, or defocuses and weakens it. Over the years, laser physicists have found self-focusing and -defocusing to be "an enormous problem," says Daniel Grischkowsky of Oklahoma State University, especially with very high-power lasers of the kind developed for laser fusion or Star Wars. And they have spent "an enormous amount of effort trying to get rid of it."

Now they have finally made some headway. Stanford University electrical engineer Steve Harris and his colleagues Maneesh Jain, Andrew Merriam, Athos Kassapi, and Guang-Yu Yin have found that they can shepherd an intense ultraviolet laser through a lead vapor without any loss of intensity when they add a second, blue beam, which alters the optical behavior of the medium. Laser physicists say the research, which was reported in the 11 December *Physical Review Letters*, is the first clear demonstration of a way to eliminate self-focusing in laser beams. "Harris has demonstrated a method of clarifying and purifying the laser beam as it travels through matter," says the University of Toronto's Boris Stoicheff, a pioneer in laser physics.

It isn't clear yet whether the method can be made to work outside the laboratory, which makes it hard to forecast practical applications, says Harris. But if nothing else, Stoicheff says that Harris's strategy, which uses the second laser beam to put a kind of electromagnetic lock on the atoms of the medium so that their optical properties can't change, "should make for a much, much clearer understanding of what's happening in the interaction of light with matter."

The work on self-focusing springs from research Harris began 5 years ago on a phenomenon known as electromagnetically induced transparency. The effect, which allows a laser beam to pass undimmed through an otherwise opaque medium, is a close cousin of one that other researchers have used to eliminate absorption within a laser itself (*Science*, 3 November 1995, p. 737). Harris explains that each atom has an electron that oscillates from its ground state to a higher energy state, known as the resonant energy, when it feels the laser's oscillating electric field. "If you could take a picture of the atom," he says, "you would see one electron moving back and forth in space periodically at the frequency of the light." In an opaque medium, these electrons oscillate out of phase with the light, and the beam quickly loses energy and is absorbed.

But if a second laser is sent into the medium, says Harris, the electrons feel two conflicting forces. In a quantum mechanical sense, the lasers freeze the electrons by setting up two possible routes of excitation to the higher energy state. One laser excites the atoms from the ground state to the excited state, while the other takes them from a slightly higher "metastable state" to the resonant energy. The two excitation paths interfere with each other, preventing the electrons from absorbing the light. "The electron," says Harris, "sees equal and opposite forces and does not move."



PHOTOS BY HARRIS *ET AL.*

A sharper image. As the intensity of a laser in a gas is increased, distortion sets in *(top and middle)*, but a second laser restores the clarity *(bottom)*.

After learning the trick of making opaque substances transparent, Harris and his colleagues went after the other obstacle to the pristine transmission of a laser beam. This, says Harris, is variation in the refractive index of the gas through which the laser is traveling. "If the refractive index is perfectly uniform," he says, "you can put a laser beam right through it. But just as soon as there's turbulence or density change, the refractive index changes and destroys the laser beam." And even if a material is optically uniform to start, an intense laser beam will create its own variations. The reason: Even the highest quality laser beam will be more intense in the middle and less on the sides. This nonuniformity causes the beam to change the refractive index as it passes through, resulting in self-focusing or -defocusing.

Think of those moving electrons, says Harris. When a laser beam moves through a transparent medium, the electrons oscillate in phase with the light's electric field. The oscillating electrons in turn generate their own electric fields, which interfere with that of the light. The interference slows the light down, which is another way of saying it increases the refractive index. In a sufficiently intense laser beam, this effect will be strong enough that any intensity variations within the beam will result in a nonuniform refractive index, tearing the beam apart.

Just as stopping the out-of-phase oscillation of the electrons in an opaque medium blocks absorption, Harris has shown that blocking the in-phase oscillation can block the changes in the refractive index. In this case, says Harris, he and his colleagues choose the frequencies of the two lasers in such a way that they will excite electrons from the metastable state and the ground state to an energy that is arbitrarily different from the resonant energy. The resulting quantum interference prevents the electrons from oscillating in phase with the light and increasing the refractive index. Self-focusing and -defocusing of the laser beam, says Harris, are "completely eliminated."

In a demonstration of this idea, the group passed an ultraviolet beam through a grid, then into a chamber filled with lead vapor. When the beam was weak, an image of the grid registered clearly on a detector at the far side of the chamber. But when the beam's intensity was increased, self-focusing set in, and the image became seriously distorted. The group then repeated the experiment, turning on the blue laser before the ultraviolet. This time the image of the grid returned to clarity.

Harris and his colleagues will soon test the strategy in gases other than lead vapor, but success isn't assured. If it works, though, the technique might ease the passage of high-powered lasers through turbulent airflows, an ability that might be valuable for imaging objects in wind tunnels. It could also be put to work in the field of nonlinear optics, where physicists like to propagate powerful laser pulses in highly refractive media.

But for the moment Harris and colleagues are savoring their ability to wipe out an effect that had seemed like a fact of life in laser physics. "It seems kind of like magic," he says.

–Gary Taubes