Theory Applies to All Lasers

NEW HAVEN, Conn., May 29, 2008 -- Unlike standard lasers, nanofabricated diffusive random lasers (DRLs) don't contain mirrors to trap light, making it hard for physicists to apply conventional laser theory and predict the wavelength and intensity of light they will emit. But now a new unifying theory is allowing scientists to better understand and predict the properties of all lasers.

“The lasers that most people are familiar with emit a narrow beam of light in a fixed direction that has a well-defined wavelength and a predictable power output -- like those in laser pointers, bar-code readers, surgical instruments and CD players,” said A. Douglas Stone, the Carl A. Morse Professor of Applied Physics at Yale University, one of the researchers who formed the theory with colleagues at the Institute of Quantum Electronics at ETH Zurich, the Swiss Federal Institute of Technology.

But DRLs, part of a new breed of lasers made possible by modern nanofabrication techniques, consist of a simple aggregate of nanoparticles and have no mirrors to trap light. These lasers were pioneered by Hui Cao, now a professor of applied physics at Yale University, and have been proposed for applications in environmental lighting (“laser paint”), medical imaging and displays. Until now, there has been no simple way for scientists to predict the wavelengths and intensities of the light emitted by DRLs.

Although, superficially, conventional lasers and DRLs appear to operate very differently, experimental results indicated many basic similarities, and scientists have searched for a unifying description that would apply to all lasers.

The properties of a laser are determined by measuring the lasing modes, including the pattern of light intensity within the laser, and the wavelengths of light it puts out. With conventional lasers, these modes can easily be obtained through simulations.

“For random lasers, time-dependent simulations are difficult to do, hard to interpret, and don't answer the question: ‘What is the nature of the lasing modes in a random laser?’” Stone said. “Researchers really wanted a description similar to that for conventional lasers, but no one knew how to develop such a description.”
To create their unifying theory, the researchers derived a wholly new set of nonlinear equations that fit both conventional and nonconventional lasers such as the DRL or other nanostructured lasers. Based on these equations Stone, his former PhD student Hakan Tureci, now at ETH Zurich, and two other members of Stone’s research group, Li Ge and Stefan Rotter, created a detailed computer code that can predict all the important properties of any kind of laser from simple inputs. A paper on their work was published May 2 in Science; Stone is senior author.

“The state of laser theory after 40 years was an embarrassment; it was essentially qualitative, but not predictive or quantitative,” Stone said. “We went back to the basics -- and we think we have now solved that problem.”

“By developing a new theory in which the main properties of a laser can be physically understood...they have provided a substantially broader perspective of laser physics that unifies the physical description of many possible laser structures,” a “Perspective” review of the theory in the same issue of Science stated.

“Ultimately, we hope that our code can be used as a design tool for new classes of micro- and nanolasers with important applications,” said Stone, who also believes that eventually their theory will become part of the answer to the question: How does a laser work?

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