Chaos Is Useful: Tailored Incoherent Light Emission Improves Rainbow Refractometry

by Dr. Wolfgang Elsäßer, Darmstadt University of Technology, Germany

A novel semiconductor laser source uses resonant feedback to provide tunable coherence, avoiding speckle phenomena and enabling applications in a wide metrology field.

Chaos ist nützlich: Angepasste inkohärente Lichtemission verbessert die Regenbogen-Refraktometrie
Eine neuartige Halbleiterlaser-Lichtquelle nutzt resonante Rückkopplung, um durchstimmbare Kohärenz zu erzeugen — was Speckle-Phänomene vermeidet und Anwendungen in einem weiten Feld der Messtechnik ermöglicht.

Le chaos est utile: l'émission adaptée de lumière incohérente améliore la réfractométrie arc-en-ciel
Une source originale de laser à semi-conducteur utilise un correcteur résonnant pour fournir une cohérence accordable, évitant les phénomènes de speckle et permettant des applications dans un domaine de métrologie étendu.

Il caos puo' essere utile: l'emissione controllata di luce incoerente migliora la rifrattometria "ad arcobaleno"
Una nuova sorgente laser a semiconduttore sfrutta un meccanismo di feedback risonante per offrire un grado di coerenza modificabile, evitando in tal modo i fenomeni di granulosita' dell'immagine e permettendo vaste applicazioni in metrologia.

Optical metrology techniques are widely used to investigate and control various processes in science and technology. In particular, semiconductor lasers are bright, low-noise sources with good beam characteristics that are popular because of their attractive emission properties, small dimensions and high wall-plug efficiency (conversion of electrical to optical power). In some applications, however, interference effects of coherent light limit the resolution of the measurement. For example, coherence tomography and fibre optic gyroscopes require incoherent sources, which has led to a growing interest in appropriate bright incoherent light sources that have good beam properties and are practical, compact and cost-effective.

In recent years, nonlinear and, particularly, chaotic dynamics have demonstrated practical advantages. One example is secure chaos communications, in which broadband chaotic (unpredictable) carrier signals encrypt and transmit messages. Recently, the Institute of Applied Physics at Darmstadt University and Sacher Lasertechnik GmbH, both in Germany, collaborated to build an incoherent semiconductor laser source using nonlinear emission properties induced by tailored optical feedback (Figure 1).

Usually, optical feedback on semiconductor lasers leads to instabilities such as coherence collapse, but we have demonstrated substantial enhancement of spectral bandwidth in a Fabry-Perot semiconductor laser by resonant feedback, in which the ratio between fundamental frequencies of the laser cavity and the external cavity equals 2.5. This resonance condition facilitates strong coupling of many longitudinal laser modes, drastically enhancing the optical bandwidth of the laser source. Furthermore, the optical feedback phase continuously controls the coherence length in the range from 8 m to 120 µm. The temporally incoherent emission avoids the speckle phenomena of coherent light sources, enabling applications in the broad metrology field.

One such application is rainbow refractometry, and Cameron Tropea from the fluid mechanics and aero-

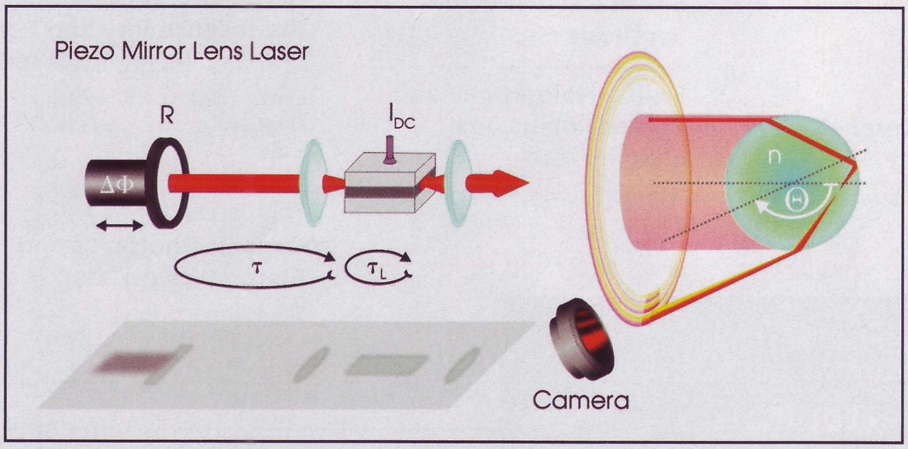

Figure 1. This incoherent semiconductor laser source uses the well-controlled feedback properties of an external cavity configuration with a piezo translator-mounted mirror (R) for rainbow refractometry on a liquid droplet.

dynamics department at the university has jointly applied the new source to this noninvasive optical measurement technique. It has applications in agriculture and in technological and industrial equipment and processes such as internal combustion engines, spray cooling and medicine.

It also is used to determine the temperature or size of droplets. When a droplet is illuminated, the scattered light forms an interference pattern, and the angular intensity distribution of the primary rainbow depends on the refractive index of the liquid, which, in turn, is dependent on the temperature.

The desired information is obtained by analysing the location of the intensity maxima in the angular intensity distribution of this interference pattern; however, with coherent illumination, interference effects between the reflected and the refracted light beams complicate the estimation of the intensity maxima. This can be avoided when the coherence length is shorter than the diameter of the droplet, so that only the pure supernumerary arcs of the primary rainbow prevail, producing a smooth interference pattern that allows for simple and accurate determination of the droplet size.

In their experiment, the scientists illuminated a water droplet with collimated light from the semiconductor laser source. For adjusted feedback phase, the source delivered an optimized spectrally broadband emission with an output power of 110 mW and a coherence length of 120 μm. The water droplet was trapped by an acoustic levitator, which suspended spherical droplets with diameters of between 400 μm and 1 mm. Direct camera images of the scattered light distribution show the difference between the simple fringe pattern obtained from incoherent illumination and the unwanted interference ripple structures produced by coherent illumination (Figure 2). Intensity plots across the images show smooth curves for the rainbow refractometry angular intensity distribution produced by the incoherent source, and jagged curves for the coherent case.

These results confirm that the semiconductor laser source is a functional incoherent light source that can be applied to modern metrology techniques. Because the coherence length of the light source is only on the order of 100 μm, the laser already is a cost-efficient alternative for applied rainbow refractometry, which commonly handles droplet diameters between 50 μm and 1 mm. And the prototype of an incoherent light source has the potential to further reduce the achievable coherence length.

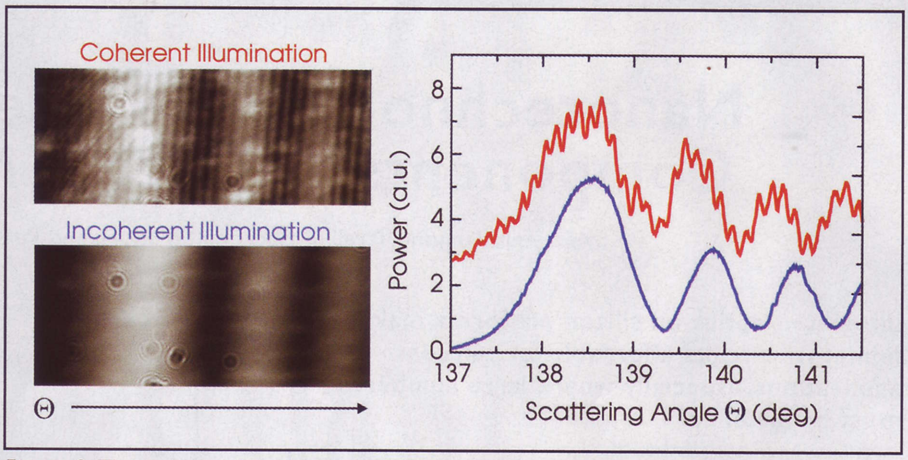

Figure 2. The camera pictures on the left contrast the smooth intensity distribution for coherent illumination (coherence length 8 m) with that for incoherent illumination (coherence length 120 μm), and the graphs confirm these differences.

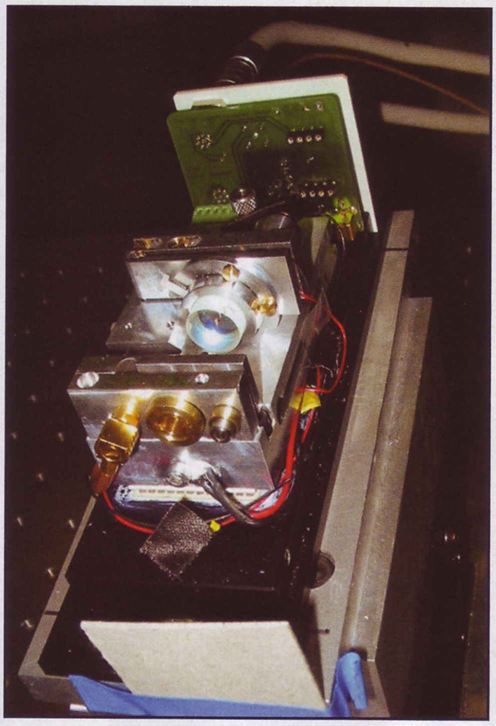

Figure 3. This photograph shows the experimental setup for investigating the potential of the incoherent light source.

One major advantage of the semiconductor laser is its simple functional principle, which is transferable to other sources. This suggests possibilities for optical measurement techniques, enabling development of incoherent semiconductor laser sources in a broad spectral range between the ultraviolet and the mid-infrared, which is being investigated in the department of physics at Darmstadt.

Ongoing research also aims to improve the performance of the light sources by the application of modern semiconductor laser structures such as quantum dot devices. With this approach, it may be possible to build integrated incoherent laser sources in which both the semiconductor laser and the external cavity are grown on a wafer.

This work originated from a project supported by the German Ministry of Education and Research. ☐

Contact: Wolfgang Elsäßer, Institute of Applied Physics, Darmstadt University of Technology; fax: +49 6151 16 3022; e-mail: elsaesser@physik.tu-darmstadt.de.