at 415 nm (3.0 eV) with a peak efficiency of 84%. In Soraa's results, the efficiency of the LED operating at elevated temperature is higher than at room temperature at a wide range of bias currents, all the way up to the technologically relevant high current densities of 100 A cm^{-2} (in particular, see Fig. 2 in ref 16). We note that in Xue's results, the high-temperature measurements also show an increased efficiency all the way to similar current densities.

It is instructive to speculate on whether the voltage losses in the state-of-the-art LEDs can be substantially decreased. The peak-efficiency operating voltages in Xue's paper are still generally larger than the bandgap near room-temperature. At high temperatures the voltages are substantially reduced, which compensates for the temperature-induced reduction in the quantum efficiency. From the fundamental point of view, however, voltages exceeding the bandgap generally allow population inversion and laser operation in structures where ohmic and other electrical losses are insignificant. In the case of idealized LEDs, this implies that as soon as the bias voltage exceeds the average photon energy, the LED reaches population inversion, enabling laser operation. As the LEDs studied by Xue *et al.* do not seem to show any signs of lasing, this suggests that the electrical losses in the studied LEDs are still large.

Overall, the results of Xue *et al.* constitute the first technologically promising demonstration of thermophotonic exploitation of waste heat in a LED to enhance emission power. The work does not yet provide a quantitative explanation for the observed fourfold increase in the emitted power, and it remains to be seen whether state-of-the-art LEDs whose electrical losses (and thus heat generation) are already very low at room temperature can also benefit from the approach. In any case, the results will undoubtedly provide the industrial motivation for further research into thermophotonics. ❐

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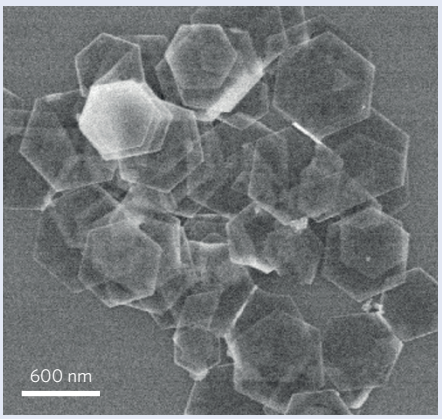
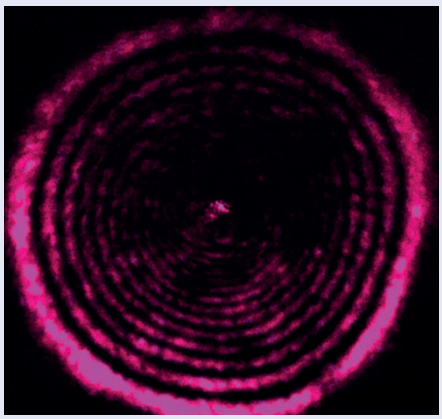
TOPOLOGICAL INSULATORS

Nonlinear opportunities

Topological insulators — fascinating materials whose bulk is insulating but whose surface can be conductive with well-defined spin textures — may turn out to be useful for creating novel nonlinear optical devices. That's the conclusion of a study into their properties, which has revealed that they can exhibit a broadband, ultrafast nonlinear effect called spatial self-phase modulation (SSPM). Bingxin Shi and co-workers from Hunan University and Shenzhen University in China observed and studied SSPM in a topological insulator made from nanosheets of bismuth telluride (Bi_2Te_3) dispersed in alcohol (*Appl. Phys. Lett.* **107,** 151101; 2015). They report that the sample exhibits broadband SSPM from the ultraviolet (400 nm) to the near-infrared (1,070 nm) due to the presence of a large, ultrafast, broadband third-order optical nonlinearity.

The scientists synthesized ultrathin Bi_2Te_3 nanosheets by a solvothermal method that involved dissolving bismuth chloride ($BiCl_3$) and sodium selenide (Na_2TeO_3) in ethylene glycol and then heating to 200 °C. The result was the creation of hexagonal-based plates of uniform size (400–600 nm across), as determined by field-emission scanning electron microscopy (pictured; left). The nanosheets were dispersed in an alcohol solution, which was then poured into a quartz cuvette for optical characterization.





Femtosecond laser light with a central wavelength of 800 nm, pulse duration of 100 fs and repetition rate of 1 kHz was focused onto the sample and the transmitted light was collected by a CCD (charge-coupled device) camera placed 5 cm behind the sample. The authors observed the generation of diffraction rings due to SSPM (pictured; right).

They report that the formation of the diffraction rings showed complex temporal behaviour; the rings rapidly appear, and then the upper half of the rings begin to collapse, finally the structure becomes stable after about half a second. The distortion in the upper part of the rings is believed to be due to thermal effects and gravity. Tiny gas bubbles moving upward were generated as a result of the absorbed laser energy, causing non-uniform density distribution of the Bi_2Te_3 nanosheets in the solvent and consequently distorting the intensity distribution of the diffraction rings. The SSPM diffraction rings were also observed for laser illumination at wavelengths of 400 nm and 1,070 nm. The study indicates that the nonlinear refractive index $n_{2,single}$ of the Bi_2Te_3 nanosheets is ~10^{-15} m^2 W^{-1}, corresponding to the third-order nonlinear susceptibility of ~10^{-9} esu.

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