The flexibility to engineer thermal profiles that produce free-form index of refraction variations is a key advantage of the technique by Berto and colleagues. Free-form optics is a term generally used to describe optical elements without translational or rotational symmetry. Nevertheless, there are still limitations to the refractive index profiles that are possible to generate following Berto and colleagues' work, in part due to the constraints imposed by the heat distributions and possible wiring width and topologies. It is worth emphasizing that while non-symmetric optics can be implemented in LC SLMs or deformable mirrors, the former are typically pixelated and polarization-dependent while the latter have a limited number of degrees of freedom.

Among the implementations presented as a proof of concept by Berto and colleagues, tunable lens arrays, as shown in Fig. 1, and axicons to generate Bessel-like beams as well as an astigmatic lens demonstrate the flexibility of the process. Furthermore, the authors show that the lenses present low dispersion, similar to that of traditional glass lenses. Therefore, this research provides an attractive avenue to tunable, versatile, polarization-independent and spectrally broadband devices. Future work should provide a path to investigate the extent to which the process can be scaled up. Such devices would be appealing for applications such as microscopy, adaptive optics or machine vision. ❐

Rafael Piestun

Department of Electrical, Computer and Energy Engineering and the Department of Physics, University of Colorado Boulder, Boulder, CO, USA.
e-mail: piestun@colorado.edu

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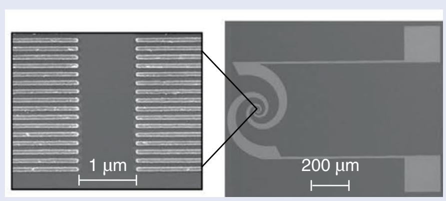
PHOTODETECTORS

Room-temperature terahertz detector

In space, faint terahertz (THz) waves in the frequency range of 0.1–10.0 THz are the dominant type of electromagnetic waves and provide crucial information about astronomical phenomena such as galaxy formation. The question is how to detect such radiation? So far, near-quantum-limited heterodyne THz detectors based on cryogenically cooled superconducting mixers have been used to detect weak THz waves, but device bandwidths on the order of 100 GHz are not sufficient to obtain meaningful spectra.

Now, Ning Wang and co-workers from the University of California, Los Angeles and the California Institute of Technology in the USA have developed a plasmonic photomixer (pictured) that operates over a much broader bandwidth of 0.1–5.0 THz at room temperature (*Nat. Astron*. https://doi.org/10.1038/s41550-019-0828-6; 2019).

The plasmonic photomixer consists of a conventional photomixer and two nanoscale Ti/Au gratings that cover an $8 \times 8\,\mu m^2$ active area with a tip-to-tip gap of 1 μm. The photomixer is integrated with a logarithmic spiral antenna on a low-temperature-grown GaAs substrate. During operation, it is pumped by two



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wavelength-tunable lasers with central wavelengths of 780 nm and 785 nm to provide a tunable optical beat frequency ω_{beat} in the THz region from 0.1 THz to 5.0 THz.

The Ti/Au gratings are designed to locally enhance the optical pump intensity through the excitation of surface plasmon waves. The drift photocurrent induced by THz waves and the pump beam has three frequency components at ω_{THz}, $\omega_{beat} + \omega_{THz}$ and $|\omega_{beat} - \omega_{THz}|$, here the last component is referred to as the intermediate frequency (IF). By tuning ω_{beat} and recording the IF output power, the received THz spectrum is extracted over a broad frequency range determined by the logarithmic spiral antenna bandwidth.

The spectral resolution of the THz detectors based on the plasmonic photomixer is determined by the bandwidth of the bandpass filter and the linewidth of the optical pump beam. The down-converted IF spectrum from 0.55 THz to 1 GHz exhibits a linewidth of 1 kHz full-width at half-maximum.

The IF output and noise powers of the plasmonic photomixer have a quadratic and a linear dependence on the optical pump power, respectively. By controlling the photomixer's signal-to-noise ratio through the optical pump power level, THz detection with quantum-level sensitivities without cryogenic cooling was achieved.

The plasmonic photomixer can also be integrated with polarization-sensitive antennas to determine small anisotropies in the interstellar radiation polarization, which are crucial for understanding shock processes in the interstellar medium originating from supernova explosions and stellar winds. ❐

Noriaki Horiuchi

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