Although similar DFG excitation of THz GPPs in monolayer graphene has been reported before[5], the work of Yao and co-workers was performed in a chip-scale architecture that allows for versatile GPP tunability. Indeed, apart from evidencing the on-chip excitation of deeply subwavelength THz GPPs, the researchers managed to actively control the GPPs charge distribution and frequency. The design of the dual-layer graphene heterostructure (fabricated in six steps[4]) allowed for the independent electrostatic gating (at the single-volt level) of either the top or bottom graphene layers. By varying the applied gate potentials, the researchers were able to change the corresponding Fermi levels of the layers and, consequently, the concentration of either electrons or holes, depending on the sign of the potentials. Since the GPP dispersion is precisely dictated by the Fermi level, the researchers demonstrated control over the frequency of the excited GPPs in each of the layers over a notably wide interval an octave (4.7 9.4 THz) limited exclusively by the optical bandwidth of the pump amplifier. Furthermore, when one of the layers was electrostatically tuned to the Dirac point, the excitation of GPPs in this layer was impeded due to the lack of charge carriers.

A special situation took place when the Fermi levels of both graphene layers became comparable as did the frequencies of the plasmons in each of the layers. In this case, due to the small separation between the layers (by 30 nm of Al_2O_3 insulator), plasmons in each of the layers could talk to each other. More precisely, due to the overlap of the electromagnetic fields, the original GPPs in the dual-layer graphene hybridized into symmetric higher-frequency and antisymmetric lower-frequency modes. In the symmetric mode (also called optical plasmon mode), the charges oscillate along the graphene plane, and are thus collinear with the propagation of GPPs. In contrast, in the antisymmetric (acoustic plasmon) mode, the charges oscillate perpendicular to the graphene plane and thus to the propagation of GPPs. In the measurements of Yao et al., the optical mode was observed while the acoustic mode was strongly suppressed due to Landau damping. Interestingly, a previous experiment[6] revealed instead acoustic (screened) THz GPPs in a graphene layer placed above an Au pad. The experimental confirmation of the coexistence of both optical and acoustic THz GPPs within the same device seems to remain a challenge.

With the help of electrical gates, Yao and colleagues demonstrate control of the THz GPPs in terms of frequency, the possibility to selectively switch them on and off in either of the graphene layers, and even to manipulate the symmetry of their charge distribution by creating hybridized GPP modes. With these capabilities for the manipulation of GPPs, there is strong potential for the developed THz GPP-based chip technology to be used in miniaturized hybrid telecom THz circuits including, for instance, modulators and plasmon interferometers for data processing.

To fully explore the capabilities of the graphene-integrated optical chip, it would be necessary to improve the efficiency of excitation of THz GPPs. At present, the reported optimal efficiency is rather modest, approaching the value of 10 ^{4}. Roughly speaking, 10^4 infrared photons are needed to produce one THz GPP. The low conversion efficiency is a general problem in nonlinear processes, especially for moderate laser powers (in the work of Yao et al., the power density was approximately 2.5×10^{10} W cm ^{2} for 2 ps pulses). However, there is plenty of room for improvement, such as cladding with a nonlinear bulk material (to increase the volume where the DFG takes place), or combining the structure with resonant optical antennas (to enhance and confine the electromagnetic fields). In the future, it would also be interesting to study the possibility of on-chip integration of other atomically thick van der Waals materials that support polaritons[7,8]. Nonlinear wave-mixing in such waveguide-integrated heterostructures may open new paths for atomic-scale optoelectronics. ☐

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TERAHERTZ EMITTERS

Lasing from dressed dots

A theoretical analysis of asymmetric dressed quantum dots in a photonic crystal cavity suggests that the system could form a new type of solid-state terahertz laser. However, an experimental realization will likely require advances in fabrication technology.

Simone De Liberato

The direct generation of coherent terahertz radiation from solid-state devices is a notoriously challenging endeavour. On one side, electronics struggles with the high frequencies involved. On the other side, standard laser approaches are hindered by the lack of materials with naturally occurring terahertz dipole transitions and the problem of competing fast non-radiative relaxation processes for excited states. While terahertz quantum cascade lasers that exploit transitions between engineered sub-bands in semiconductor heterostructures are a longstanding topic of active technological development[1], their tunability and efficiency remain limited, and many efforts are exploring alternative solutions[2 4]. Now, another option has been brought to the table. Writing in ACS Photonics, Igor Chestnov and co-workers theoretically investigate the possibility of using dressed asymmetric quantum dot ensembles in a resonator to realize a terahertz laser[5].

To understand the principle of the proposed device, one needs to first review the concepts of electromagnetically dressed states and strong light matter coupling. When a quantum emitter is resonantly excited by a coherent pump, its energy levels