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# Recent Advances in Mid-Infrared Graphene Plasmonics: Metasurface for Complex Amplitude Modulation and Compact Waveguide Switch

Tunable plasmonic modes offered by graphene provide new opportunities to create electo-optically active devices with novel characteristics that have thus far been impossible to be realized by using conventional media. Here we introduce two recent theoretical research results in mid-IR graphene plasmonics: (1) Dynamic complex amplitude modulation in graphene-based metasurfaces and (2) modulated resonant transmission of graphene plasmons across a deep-subwavelength plasmonic waveguide gap.

**Electronically Tunable Graphene Metamolecules for Complete Complex Amplitude Modulation**
Metasurfaces have been shown to manipulate wavefront of light in subwavelength structures, overcoming the limitations in conventional optical systems. Although many efforts have been made to realize dynamic wavefront reconstruction in nanophotonic elements, current active metasurfaces suffer from inevitable interference between amplitude modulation and phase modulation as well as limited range in tunabilities. Here, we report dynamic complete complex amplitude modulation in metamolecules operating in the mid-infrared. The metamolecule is composed of a pair of metaatoms, and graphene plasmonic nanoresonators are utilized to incorporate electronically tunable functionalities. In the metamolecule, the two metaatoms are independently controlled to secure the two degree of freedoms required for modulating the amplitude and the phase of light, enabling 2π phase shift as well as large amplitude modulation including perfect absorption. We develop a generalized graphical model to examine the underlying requirements for complete complex amplitude modulation, offering intuitive design guidelines to maximize the tunabilities in metasurfaces. To illustrate the reconfigurable capability of our designs, we demonstrate dynamic beam steering and holographic wavefront reconstruction in a structurally identical metasurface by simply tuning the metamolecules

**Modulated Resonant Transmission of Graphene Plasmons Across a λ/50 Plasmonic Waveguide Gap**
We theoretically demonstrate the nontrivial transmission properties of a graphene-insulator-metal waveguide segment of deeply subwavelength scale. We show that, at mid-infrared frequencies, the graphene-covered segment allows for the resonant transmission through the graphene-plasmon modes as well as the nonresonant transmission through background modes, and that these two pathways can lead to a strong Fano interference effect. The Fano interference enables a strong modulation of the overall optical transmission with a very small change in graphene Fermi level. By engineering the waveguide junction, it is possible that the two transmission pathways perfectly cancel each other out, resulting in a zero transmittance. We theoretically demonstrate the transmission modulation from 0% to 25% at 7.5-μm wavelength by shifting the Fermi level of graphene by a mere 15 meV. In addition, the active region of the device is more than 50 times shorter than the free-space wavelength. Thus, the reported phenomenon is of great advantage to the development of on-chip plasmonic device.