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Ultrafast Optical Modulation and Ultra-Short Pulse Generation Based on Tunable Graphene-Plasmonic Hybrid Metasurfaces

Background

Generation of ultra-short pulses is in demand for a variety of applications ranging from telecommunication and optical computing to ultrafast science and high-resolution spectroscopy. In spite of the relative maturity of ultra-short pulse generation in the visible and near-infrared regions of the electromagnetic (EM) spectrum, there remains a deficiency of such sources in the mid-infrared spectral range (~2-20 μm).

Invention Description

Researchers at Arizona State University have developed a new method for ultrafast optical modulation and femtosecond/picosecond pulse generation for the infrared (e.g., mid-infrared) to terahertz spectral region. This is accomplished via ultrafast modulation of hot carriers in monolayer graphene, integrated on a plasmonic metasurface of nanoantenna arrays. In one example, the carrier concentration of graphene is derived out of equilibrium by a preceding 100-fs optical pump pulse at 1040 nm with ~11 nJ pulse energy, which results in a corresponding change in the surface conductivity of graphene, particularly in the mid-infrared (MIR) range. The interaction of incident s-polarized pump intensity with graphene is enhanced by nearly 100 times owing to the localized surface plasmon resonance (LSPR) excitation in nanoantenna arrays. As the optical properties of graphene change in time, the MIR resonance of the metasurface along the perpendicular axis blueshifts. This is associated with a transition from perfect absorption to almost complete reflection for the p-polarized continuous wave (CW) MIR probe (6-7 μm) within a few-hundred femtosecond time scale, exhibiting ultrafast modulation of the device. All-optical mid-IR modulators with a 200 μm x 200 μm device footprint and subwavelength thickness of ~600 nm have been fabricated. Experimental results suggest > 10 dB modulation depth and a response time of less than 300 femtoseconds.

Potential Applications

- Spectroscopy for materials analysis and biomedical study
- Optical frequency comb generation

- Free-space communication
- Biomedical imaging

Benefits and Advantages

- Use of graphene enables ultrafast carrier dynamics
- Design facilitates fast phonon relaxation, leading to shorter response times (a few hundred femtoseconds) than all-optical modulators based on pure graphene sheets (> 1 ps)
- Achieves modulation depth of up to 95% in the mid-infrared range

Research Homepage of Professor Yu Yao