# Highly tunable hybrid metamaterials employing split-ring resonators strongly coupled to graphene surface plasmons.

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## Abstract

Metamaterials and plasmonics are powerful tools for unconventional manipulation and harnessing of light. Metamaterials can be engineered to possess intriguing properties lacking in natural materials, such as negative refractive index. Plasmonics offers capabilities of confining light in subwavelength dimensions and enhancing light-matter interactions. Recently, the technological potential of graphene-based plasmonics has been recognized as the latter features large tunability, higher field-confinement and lower loss compared with metal-based plasmonics. Here, we introduce hybrid structures comprising graphene plasmonic resonators coupled to conventional split-ring resonators, thus demonstrating a type of highly tunable metamaterial, where the interaction between the two resonances reaches the strong-coupling regin Such hybrid metamaterials are employed as high-speed THz modulators, exhibiting ~60% transmission modulation and operating speed in excess of 40 MHz. This device concept also provides a platform for exploring cavity-enhanced light-matter interactions and optical processes in graphene plasmonic structures for applications including sensing, photo-detection and nonlinear frequency generation.

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