Abstract: We numerically demonstrate frequency-tunable coherent thermal emission from graphene coated silicon carbide (SiC) grating metamaterials. Rigorous coupled-wave analysis shows emission peaks associated with magnetic polariton, whose resonance frequency can be dynamically tuned by varying graphene chemical potential. The underlying physical mechanism is elucidated, while the geometric and directional effects on the selective emission peaks are explored. The metamaterial structures coated with multiple graphene sheets are further investigated to achieve a larger tunability up to 8.5% in peak frequency.

Infrared (IR) thermal sources with tunable frequencies are highly desired for IR spectroscopy, radiative cooling and energy harvesting. Metamaterials with exotic optical and radiative properties that cannot be obtained in naturally-occurring materials have been studied for IR emitters. As a pioneering work, Greffet et al. demonstrated both temporal and spatial coherences of thermal emission by exciting surface phonon polaritons (SPhP) from SiC gratings [1]. By using materials with tunable optical constants, optical and radiative properties of micro/nanostructured metamaterials can be dynamically controlled. For example, phase transition VO₂ has been proposed to design metamaterials with switchable or tunable thermal emission peaks by thermally modulating the resonance conditions of magnetic polariton (MP) [2,3] or surface plasmon polariton (SPP) [4].

Graphene has been employed in the design of tunable metamaterials due to its variable optical properties induced by chemical doping, voltage bias, or external magnetic field [5], while most of reported work focused on tuning SPP conditions with graphene. In this work, we numerically demonstrate infrared frequency-tunable coherent thermal emission, whose spectral location can be shifted by modulating the MP resonance via varying chemical potential of graphene. Figure 1(a) schematizes the proposed tunable metamaterial structure, which is made of a graphene-coated 1D SiC grating array with period \( \Lambda = 5 \, \mu \text{m} \), width \( b = 0.5 \, \mu \text{m} \), and height \( h = 1 \, \mu \text{m} \).

![Figure 1](image_url)

Figure 1. (a) Schematic of the tunable coherent thermal emitter made of graphene-coated SiC gratings. (b) Calculated spectral normal emittance at different graphene chemical potential \( \mu \) for TM polarized waves.
Spectral-directional emittance of the graphene-coated SiC grating is obtained indirectly as $\varepsilon = 1 - R$, where $R$ is the spectral-directional reflectance of the opaque metamaterial structure within the phonon absorption band of SiC. The radiative properties were numerically calculated with the rigorous coupled-wave analysis (RCWA), whose convergence was ensured with a sufficient total of 81 diffraction orders. The thickness of monolayer graphene is considered as $t_G = 0.5$ nm in the calculation, which was verified to be sufficiently small from careful convergence check.

The spectral emittance at normal direction for transverse-magnetic (TM) polarized wave (i.e., magnetic field is along the grating groove) is plotted in Fig. 1(b) with varying graphene chemical potential $\mu$. For the bare SiC grating without graphene monolayer on top, there exists a temporally-coherent emission peak at the wavenumber $\nu_{\text{res}} = 853 \text{ cm}^{-1}$ with an peak emittance of 0.73, which is associated with the excitation of phonon-mediated MP in SiC gratings [6]. When a graphene sheet with a chemical potential $\mu = 0$ eV is coated onto the SiC grating, the emission peak location barely shifts, but peak emittance increases to 0.96. As the graphene chemical potential $\mu$ increases from 0 to 1 eV, the emission peak frequency monotonically shifts from 853 cm$^{-1}$ to 887 cm$^{-1}$, resulting in a relative tunability of 4% in peak frequency.

Electromagnetic fields at the MP resonance conditions are plotted to study the behavior of MP in graphene-covered SiC gratings. With the help of an inductor-capacitor (LC) model, which considers the graphene sheet as an additional inductor in the resonant circuit, the magnetic resonance condition is analytically predicted and in good agreement with the numerical results. The modulation of MP resonance frequency with varying graphene chemical potential can be well understood in terms of the LC model. Furthermore, the geometric and directional effects on the tunable coherent emission peaks are also studied. Moreover, by covering the SiC grating with multilayer graphene sheets, the tunable spectral range for the coherent thermal emission can be further broadened to cover most of the phonon absorption band of SiC, resulting in a large tunability of 8.5% in peak frequency with 4 layers of graphene sheets. The novel tunable metamaterial would pave the way to a new class of tunable thermal sources in the infrared region.

Acknowledgements. This work is supported by the National Science Foundation under a CAREER Award (CBET-1454698). HW would like to thank the partial support from the US-Australia Solar Energy Collaboration - Micro Urban Solar Integrated Concentrators (MUSIC) project sponsored by the Australian Renewable Energy Agency (ARENA). ASU New Faculty Startup fund and Seed Project fund are greatly acknowledged.

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