Numerical analysis of Waveguide coupled graphene thermal emitter

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Introduction: Silicon photonics platform possesses potential of realizing low cost and high-speed information processing. But one issue is lack of on-chip source. Recently graphene thermal emitters capable for near-IR emission are proposed with fast on-off modulation and potential for chip integration [1, 2]. In previous work, carbon nano-tube thermal emitter coupled to a Si waveguide was experimentally proposed [3]. However, till now the waveguide integration for graphene thermal emitter has not been examined yet. In this work, we have numerically analyzed a waveguide-coupled graphene thermal emitter.

Simulation method: In case of close distance between graphene and waveguide, we considered local density of state (LDOS) for near field thermal radiation:

$$P(\omega, T, r) = \frac{\hbar\omega}{1 - \exp(\frac{\hbar\omega}{k_B T})} \rho_{LDOS}(\omega, r)$$

Although it's not feasible to calculate analytically for arbitrary environment, we can evaluate local density of states by exploiting dipole excitation [4]. By this method we can also directly compute coupling efficiency of dipole to waveguide. To simulate planar graphene thermal radiation, we employed incoherent dipole source array with random orientations combined different Si waveguide structures as shown in Fig. 1.

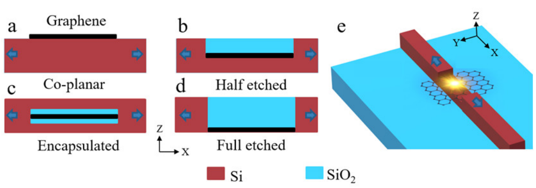

Fig. 1 (a)-(d) cross section of waveguide coupling configurations for incoherent dipole array. (e) 3-D schematic of half-etched (0.11μm) waveguide (height:0.22μm; width:1μm) coupler for graphene

In simulation, we calculate averaged coupling efficiency of optical energy into waveguide and LDOS with 49 point evenly spread in coupling area. Coupled power according to free space graphene at the same temperature can be calculated by multiply LDOS to coupling efficiency. For each position, an in-plane orthogonal dipole pair is settled. 98 simulations are run for each dipole for incoherence. We also converted optical field into different waveguide modes for mode and polarization analysis.

Result and Discussion: In Fig. 2a, we show the averaged coupled power into the Si waveguide. Fig. 2b shows the mode expansion analysis of the coupled power in the Si waveguide. It is found in Fig. 2a that the encapsulated structure possesses the highest coupled power over 0.3. The half-etched waveguide, which is more practical for fabrication, also exhibits the coupled power over 0.25.

Aside from the coupling efficiency, polarization coupled into the Si waveguide also strongly depends on the structure. In the half-etched and encapsulated structures, TE modes experience higher overlap with dipoles, leading to higher composition in the TE modes. Similarly, for normal waveguide coupling, the fundamental TM mode becomes dominant in the coupled power. This unique property can be utilized to match the polarization requirement posed by specific applications. To further enhance the performance, the cavity integration can dramatically modify the LDOS then tailor luminance behavior of waveguide-coupled graphene thermal emitter.

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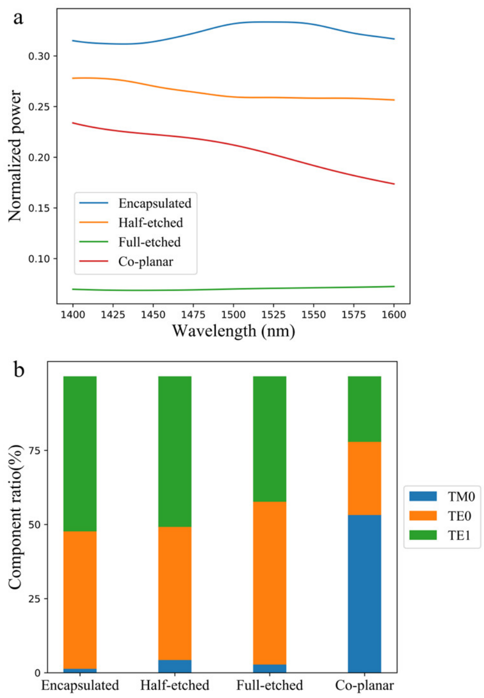

Fig. 2 (a) Optical power coupled into waveguide. (b) Mode analysis with different configurations.