Electrical Control of Silicon Photonic Crystal Cavity by Graphene

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Supplementary Material:

Theoretical estimation of broadening of cavity linewidth due to graphene absorption: The total optical energy E_T stored in a cavity is given by $E_T=\varepsilon_o\ \varepsilon_r\ |E|^2\ V_m$, where E is the electric field of the light, V_m is the mode volume of the cavity, ε_o and ε_r are respectively, the vacuum permittivity and the relative permittivity of the material inside the cavity. The electric field inside the cavity (with resonance frequency ω_o and quality factor Q) decreases with time as $E(t)=E(0)\exp(-\omega_o t/2Q)$. If the bare cavity has a linewidth of $\Delta\omega_o= \omega_o/Q$ and the cavity with graphene on top has a linewidth of $\Delta\omega$, then the energy lost due to graphene over an infinitesimally small time-duration T is given by $\varepsilon_o\ \varepsilon_r\ |E(0)|^2\ V_m\ (\exp(-\Delta\omega_o\ T)- \exp(-\Delta\omega\ T))$. This corresponds to the energy that is absorbed by graphene. The optical power absorbed in graphene (with conductivity σ) is given by $\sigma\ |E|^2\ A_m$ where, E is the electric field sensed by graphene, and A_m is the area where cavity field overlaps with graphene. Assuming graphene covers the whole cavity, we can approximate $A_m=V_m / d$, d being the thickness of the photonic crystal membrane. As the graphene is on top of the cavity, it senses the cavity field that evanescently coupled out of the top surface. Assuming an exponential fall off of the electric field along the cavity membrane from the center of the cavity the electric field sensed by graphene will be E=E(0)exp(-nd/2λ), where λ is the cavity resonance wavelength, and n is the refractive index of the cavity material. Hence equating the two expressions of total energy lost at an infinitesimally small time duration T, we can write

$$\varepsilon_o\, \varepsilon_r\, |E(0)|^2\, V_m\big(\exp(-\Delta\omega_o\, T) - \exp(-\Delta\omega\, T)\big) = \frac{\sigma\, |E(0)|^2\, V_m T}{d} \exp\left(-\frac{nd}{\lambda}\right)$$

Expanding the exponential to the first order in T, we find that

$$\Delta\omega - \Delta\omega_o = \frac{\sigma}{d\varepsilon_o\, \varepsilon_r} \exp\left(-\frac{nd}{\lambda}\right)$$

with $\sigma = q^2/4\hbar$ for graphene, where q is the charge of an electron. In our device, d=250nm, the material used is silicon ($\varepsilon_r = 11.68$), and the center wavelength is ~1500nm. Hence theoretically estimated change in the cavity linewidth just due to the graphene absorption is ~1.6 nm.

Effect of ion-gel: The cavity resonance red shifts by 40-50 nm due to ion-gel, but the resonance linewidth does not change significantly (the quality factor of the cavity with ion-gel is slightly higher than without ion-gel). Figure S1 shows the normalized cavity reflectivity with and without ion-gel. However, no change in cavity resonance is observed as a function of the electric field.

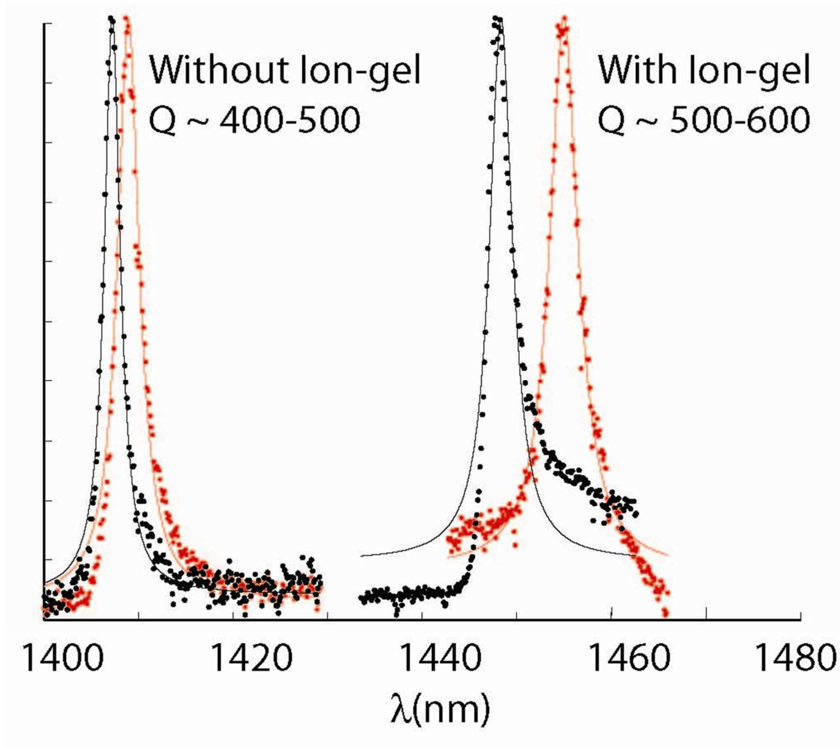

Figure S1: The normalized cavity reflectivity with and without ion-gel.