# Ultra-long wavelength Dirac plasmons in graphene capacitors

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Graphene is a recognized 2D platform for plasmonics in the THz and mid-infrared domains. These high-energy plasmons couple to the dielectric surface modes giving rise to hybrid plasmon-polariton excitations. The ultra-long wavelength GHz range addresses the low energy end of the spectrum, where Dirac plasmons are damped by ohmic losses but essentially decoupled from the environment. Using hexagonal boron-nitride encapsulated graphene [1] we demonstrate a plasma resonance capacitor [2] showing a quarter-wave plasmon mode, at 35GHz, with a quality factor Q=2. At low doping, or high temperature, ohmic losses take over giving rise to an evanescent wave response [3]. The resolution of the resonant technique yields precise determinations of the electronic compressibility, kinetic inductance, and electronic mean free-path, in good agreement with graphene plasmon theory. The 100 µm long wavelength allows engineering doping-modulated devices where plasmons are controlled by Klein tunneling. Down scaling for room temperature operation opens perspectives in microwave detection for wireless communication and sensing [4].

## References

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## Figures

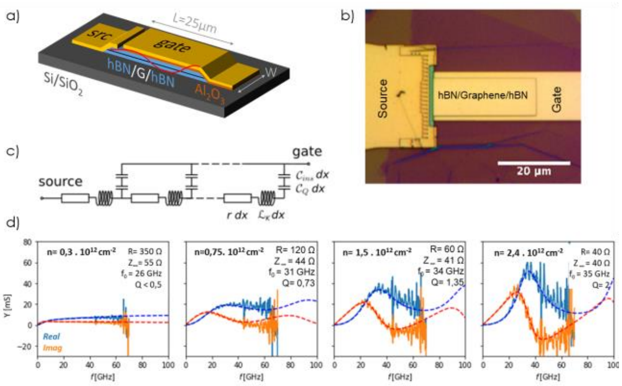


**Figure 1: (a)** Sketch of a plasma resonance capacitor (PRC) made of encapsulated graphene in hBN. **(b)** Optical image of a typical T-shape encapsulated PRC sample (dimensions L × W = 24 × 8 µm). **(c)** Distributed line model of the graphene resonator. **(d)** Complex admittance of PRC measured at T = 30 K at increasing electron density. Theoretical fits with equation (dashed lines) are shown in an extended frequency range exceeding the 70 GHz bandwith of our measuring probe station. The carrier density and fitted values of the resonant frequency $f_0$, quality factor Q, and characteristic impedances $Z_\infty$ are specified in the figures. The plasmon resonance is overdamped (low Q) at low density due to increased ohmic losses. It is well developed at $n = 2.4 \times 10^{12}$ $cm^{-2}$ with Q = 2 at $f_0$ = 35 GHz.