# Supporting Information

## Nano-Imaging of an Edge-Excited Plasmon Mode in Graphene

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## 1. Device characterization

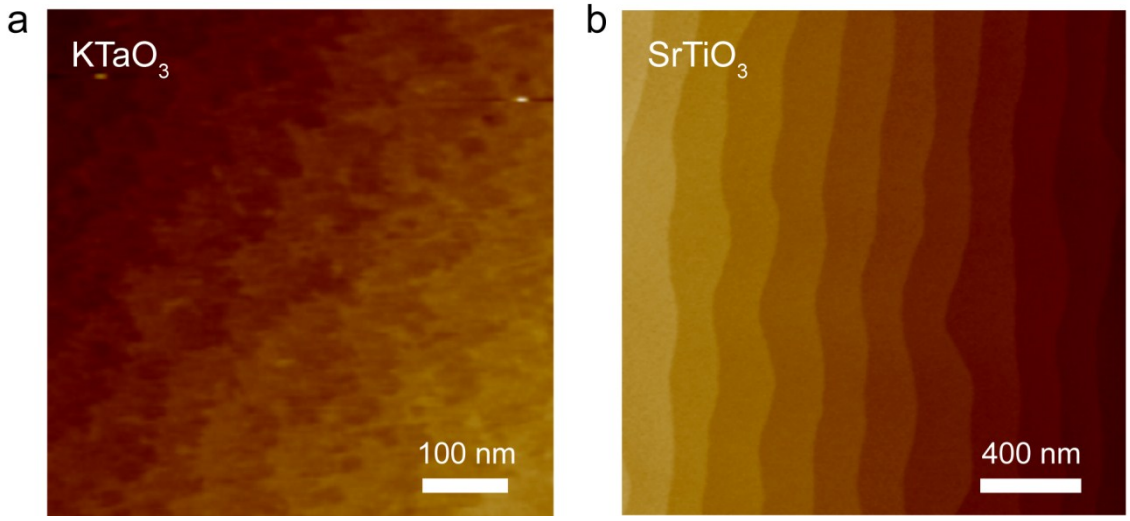


**Figure S1.** Atomic force microscopy images of the $KTaO_3$ surface (a) and $SrTiO_3$ surface (b).

The atomic force microscopic images of the $KTaO_3$ and $SrTiO_3$ surfaces after pretreatment are shown in Figure S1, both showing atomically flat terraces.

The monolayer graphene feature and carrier density can be estimated through Raman spectroscopy.[1] From the peak positions of G ( $\approx$ 1594.6 $cm^{-1}$) and 2D ( $\approx$ 2704.2 $cm^{-1}$) as well as from the full width at half maximum (FWHM) of G ( $\approx$ 12.43 $cm^{-1}$) and 2D ( $\approx$ 31.18 $cm^{-1}$), the graphene flake can be roughly estimated to be hole doping with the carrier concentration $n \approx 6 \times 10^{12}\, cm^{-2}$. Due to the exceptional linear dispersion, Fermi energy of graphene is given by $E_F = \hbar v_F \sqrt{\pi n} \approx$ 286 meV, where $\hbar$ and $v_F$ are reduced Planck constant and Fermi velocity of graphene, respectively. Note that such unintentional doping of graphene with similar doping level has also been reported on other substrates,[2-4] which is attributed to the adsorption of $H_2O$ or $O_2$ molecules in the ambient atmosphere. Such doping level keeps our frequency range of

interest away from the interband damping regime. ($|E_F| > E_P \approx 0.12\,eV$, where $E_F$ is Fermi energy and $E_P$ is plasmon energy)[5,6] Thus, it is beneficial to the excitation and detection of plasmon modes. The estimated concentration is also verified by the transport results discussed later.

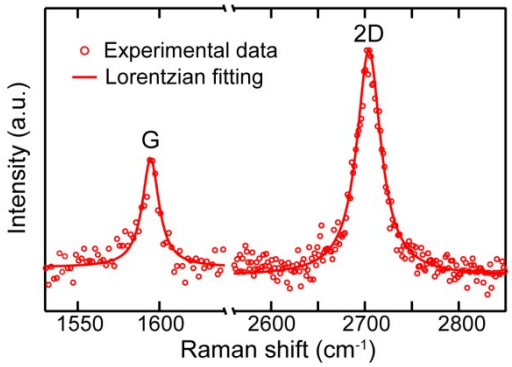


**Figure S2.** Raman spectrum of a monolayer graphene flake on the $KTaO_3$. The red circles are the experimental data, while the red lines are the Lorentzian fitted curves.

## 2. Transport measurements

To better understand the scattering strength, we also carried out an electronic measurement of graphene device on a $KTaO_3$ substrate. The graphene flake was etched into standard Hall bar geometry and contacted by Au/Ti electrodes. At 2 K, the Hall mobility can be more than 10,000 $cm^2\ V^{-1}\ s^{-1}$, as shown in Figure S3. The SNOM sample quality should be even better considering the fact that additional disorder or impurities are induced during device fabrication processes for the transport device. Such high mobility is in consistence with the long propagating length of plasmons described in the main text. Here, the back-gate voltage was applied to the device using a 0.5 mm-thick $KTaO_3$ substrate as the dielectric layer, inferring the tunable carrier densities for

future low-temperature near-field imaging experiment. At zero gate voltage, the carrier density is p-type with $n \approx 4.6 \times 10^{12}\ cm^{-2}$ close to the value estimated from the Raman results.

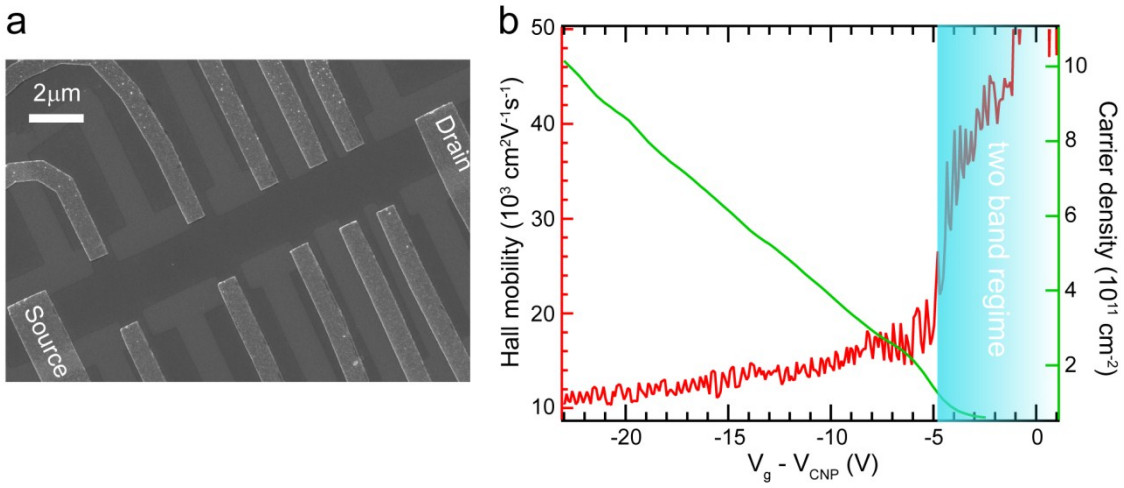


**Figure S3.** (a) Hall bar graphene device on a $KTaO_3$ substrate. (b) The mobility and carrier density extracted from Hall data at T = 2 K.

### 3. Substrate phonons

To clarify the source of plasmon modes presented in the main text, we have also checked the phonon polariton modes in crystals. We have obtained a broadband nano-infrared spectrum of the $KTaO_3$ substrate, as shown in Figure S4. Almost zero amplitude is found in the frequency range used in this work, eliminating the possible plasmon-phonon hybridizations.

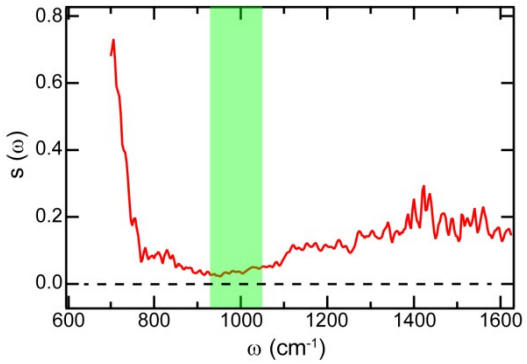


**Figure S4.** Broadband nano-infrared spectrum of the bare $KTaO_3$ substrate. Green shade indicates the frequency range used in this work.

**4. SNOM measurements of graphene on the silicon oxide**

To further clarify the role of substrate in supporting the edge-excited plasmons propagating in graphene, we have carried out control experiments on the conventional $SiO_2$ substrate. As illuminated in Figure S5 using a silicon tip, the primary fringe can hardly be distinguished, revealing a very weak edge-excited mode, different from that on $KTaO_3$ and $SrTiO_3$. Quantitatively, the ratio between the intensity of the principle oscillating peak and the intensity of inner part flake can also reflect the damping rate of graphene plasmons.[7] It is only 1.15 for graphene/$SiO_2$ in Figure S5, while the value is as high as 1.92 for graphene/$KTaO_3$ in Figure 1a and 1.71 for graphene/$SrTiO_3$ in Figure 4a, showing a stark contrast in plasmon damping rate.

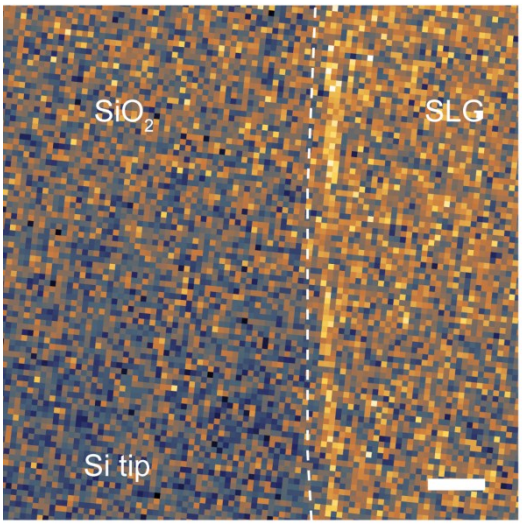


**Figure S5.** Near-field images of graphene lying on $SiO_2$ as control experiments, showing a weak and discontinuous fringe along the edge. The white dashed line marks the edge of graphene. IR frequency: $\omega$ = 946.0 $cm^{-1}$. Scale bar, 200 nm.

**References**


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