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Fizeau Drag In Graphene Plasmonics

Dragging of light by moving media was predicted by Fresnel and verified by Fizeau's celebrated experiments with flowing water. This momentous discovery is among the experimental cornerstones of Einstein's special relativity theory and is well understood in the context of relativistic kinematics. By contrast, experiments on dragging photons by an electron flow in solids are riddled with inconsistencies and have so far eluded agreement with the theory. Here we report on the electron flow dragging surface plasmon polaritons (SPPs): hybrid quasiparticles of infrared photons and electrons in graphene. The drag is visualized directly through infrared nano-imaging of propagating plasmonic waves in the presence of a high-density current. The polaritons in graphene shorten their wavelength when propagating against the drifting carriers. Unlike the Fizeau effect for light, the SPP drag by electrical currents defies explanation by simple kinematics and is linked to the nonlinear electrodynamics of Dirac electrons in graphene. The observed plasmonic Fizeau drag enables breaking of time-reversal symmetry and reciprocity at infrared frequencies without resorting to magnetic fields or chiral optical pumping. The Fizeau drag also provides a tool with which to study interactions and nonequilibrium effects in electron liquids.

References

- [1] Y. Dong et. al., Nature, 594 (2021),513-516.
- [2] W. Zhao et. al., Nature,594 (2021) 517–521.

Figures

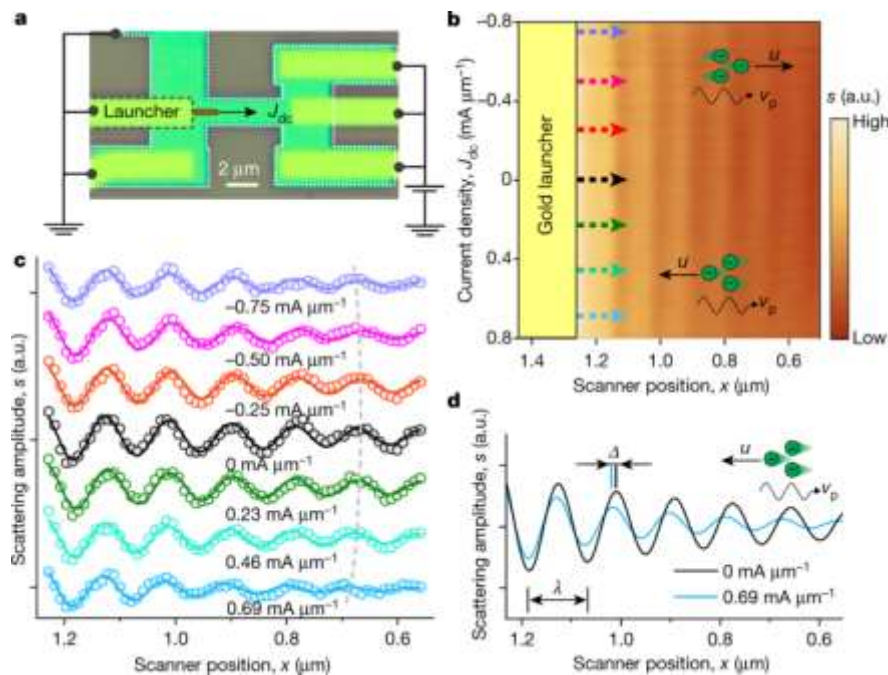


Figure 1: **a**, An optical image of a representative device. **b**, Near-field image, at $V_g = 47$ V and $T = 170$ K, acquired by scanning along the same line while varying the current density between ± 0.8 mA/ μm . **c**, Averaged (± 25 $\mu\text{A}/\mu\text{m}$) SPP line profiles at different current densities. The circles are raw data; the solid lines are fitting results. The line profiles are shifted vertically for clarity. **d**, Fitted SPP line profiles without d.c. current (black) and with $J_{dc} = 0.69$ mA/ μm (blue), illustrating a reduction of the SPP wavelength.