Hyperbolic cooling of graphene Zener-Klein transistors

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Engineering of cooling mechanisms is a bottleneck in nanoelectronics. Whereas thermal exchanges in diffusive graphene are driven by defect-assisted supercollisions [1], the case of high-mobility graphene on hBN is radically different with a prominent contribution of remote phonons from the substrate. Here, we show that a bilayer graphene on hBN transistor can be driven in the Zener-Klein tunnelling regime where current is fully saturated (Figure 1). Using sensitive GHz noise thermometry [2], we show that ZK-tunnelling triggers a new cooling pathway due to the emission of hyperbolic phonons polaritons (HPPs) in hBN by out-of-equilibrium electron-hole pairs (Figure 2). The most striking consequence is a reversal of the doping dependence of the electronic temperature due to the Pauli blocking of ZK-tunnelling at finite doping. HPP cooling is the most efficient mechanism in graphene and promotes graphene Zener-Klein transistors as a valuable route for RF power amplification.

References

[1] A. Betz et al., Nat. Phys., 9 (2013) 109
[2] W. Yang et al., submitted (2016)

Figures

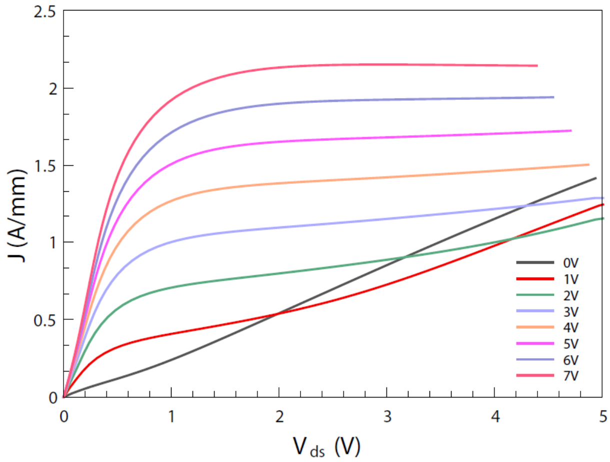

Figure 1: Current saturation in a n-doped high-mobility bilayer graphene on hBN transistor (channel length 4 µm). Large saturation currents are obtained, ultimately limited by 100 meV hBN-HPP scattering. At charge neutrality transport is dominated by Zener-Klein tunnelling.

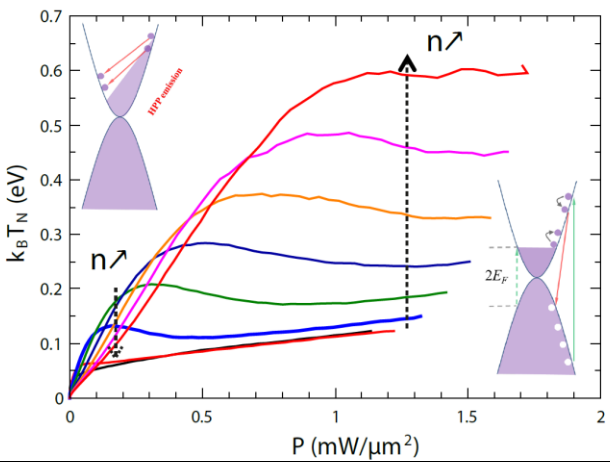

Figure 2: The noise temperature T_N, controlled by Wiedemann-Frantz heat transport at low bias, saturates in the Zener-Klein tunnelling regime where electron-hole pairs are massively created. The observed temperature plateaus result from a compensation of the Joule power P by emission of 200 meV hBN-HPPs. The most remarkable feature is the inversion of the doping dependence of T_N with a temperature minimum obtained at charge neutrality.