Nonlinearity and Current Heating in Point Contacts on Two-dimensional Systems

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A key ingredient enabling electronic circuits is nonlinearity in current-voltage characteristics, since in the absence of nonlinearity circuits reduce to an equivalent resistor. We experimentally study nonlinearity in the current-voltage characteristics of point contacts (PCs) in mesoscopic structures on a high-mobility GaAs/AlGaAs 2D electron system (2DES), with a mean-free path of 86 μm at 4.1 K. At low bias currents the structures are initially in the ballistic regime at low temperature [1, 2, 3]. Nonlinearity in mesoscopic structures can have multiple origins [4]. We study bias-current heating as the cause of nonlinearity due to scattering effects across the ballistic-hydrodynamic regime transition, as the effective injected electron temperature is increased. We compare the results with variable-temperature measurements. The measurements are paralleled by simulations providing maps of current streamlines and potentials using the Boltzmann equation. As example, Fig. 1(a) shows differential resistance, current-voltage and static resistance characteristics under DC current bias of a side-gated (variable width) PC, with pronounced nonlinearity especially for the narrowest widths. As shown in Fig. 1(c), transverse magnetic focusing experiments are used to obtain the pivotal link between electron temperature and current bias [2]. Recent ultraclean materials such as graphene and GaAs/AlGaAs 2DESs [1, 2, 3, 5] achieve low momentum dissipation, allowing the ballistic and hydrodynamic transport regimes. Both these non-Ohmic regimes offer new functionalities and low power consumption. Here we show their inherent nonlinearities traced to electron-electron interactions, and discuss the relation to the Gurzhi hydrodynamic effect [6].

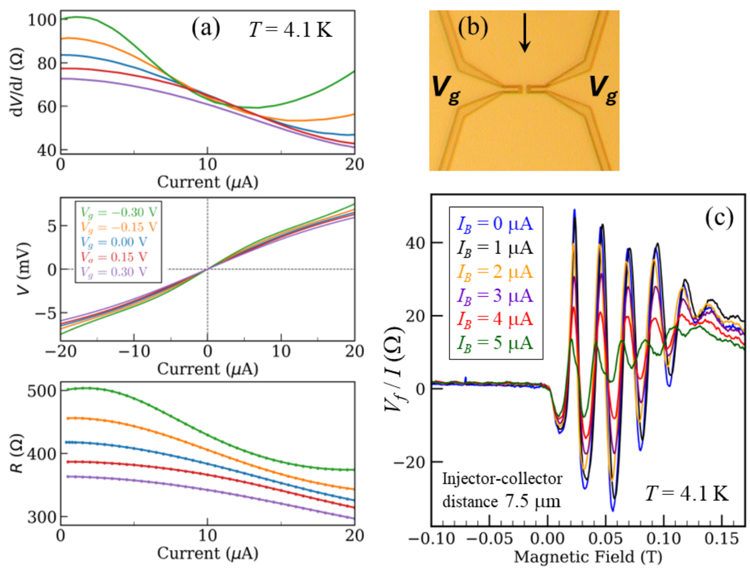

Fig. 1. (a) Differential resistance, current-voltage characteristic, and static resistance of a side-gated PC with tunable width $\sim 1\,\mu$m, parameterized in indicated gate voltage, vs DC bias current. (b) Side-gated PC. (c) Transverse magnetic focusing traces of collector voltage over injector current vs magnetic field, parameterized in indicated DC bias current into the injector PC.

References

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