Imaging of electron transport in metals and in a standard Hall bar

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Abstract

We describe a rather new technique to image ballistic current transport. This allows to understand the microscopic composition of macroscopic (thermo-) electric transport phenomena. The patterns can give plenty of information about macroscopic (interfaces, surface structure and confining potential)and microscopic properties (Fermi surface, band structure) of the investigated sample.

Keywords: Ballistic transport, electron focusing, vortex state, quantum Hall regime

1. Introduction

If very pure and nearly perfect crystals are cooled down to very low temperatures, the mean free path l^* in these samples can reach values in the range of several hundreds μm. If the macroscopic scale of the experiment is in the range of l^* (ballistic regime), the carrier transport is entirely determined by the Fermi surface of the investigated material. An imaging of the carrier transport then allows to obtain information about the electronic properties of the crystal. Carriers of different type and different location on the Fermi surface can be distinguished by their reaction upon the application of a magnetic field. The technique presented here uses a small light spot to excite carriers either thermoelectrically (for metallic crystals) or due to the photoelectric effect (in semiconductors).

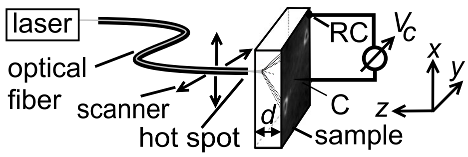

Fig. 1. Scheme of the experimental setup. A laser beam is coupled into an optical fibre, the end of which is brought close to the sample surface. An area with ~5μ m in diameter is illuminated with some mW and carriers are excited thermoelectrically. To detect a pattern the fibre is scanned over the surface and the voltage V_C between the collector contact C and the reference contact RC on the sample edge is detected as a function of the fibre position.

The resulting carrier distribution can be detected by small (point) contacts at the sample surface (see Fig. 1). The detected imaging of the electronic carrier transport can be very anisotropic and is a kind of fingerprint of the Fermi surface. It also reflects the potential distribution in the

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chosen sample and contact geometry.

2. Results

In Fig. 2 examples for these so-called electron-focusing patterns in the transition metal tungsten (a)-(c) [1], in the semimetal bismuth (d)-(f) and in the noble metal silver (g) are shown [2]. Figs. 2(a)-(c) illustrate how the highly anisotropic patterns depend on the crystal orientation. Figs. 2(e)-(f) are examples for the deformation of the pattern with a transverse magnetic field B_t (e) and a longitudinal magnetic field B_l (f) [3]. In these cases the carrier trajectories are bent by the field. In Fig. 2(i) the carriers are detected on the surface of excitation after a couple of specula reflection processes on the sample surface. This geometry (LITEF) allows the investigation of surface and interface properties. The dependence of the signal on the magnetic field B shows two kinds of oscillations: (A) So-called Light-Induced Sondheimer Oscillations (LISO) periodic in Bl (Fig. 2(j)) and (B) so-called Light-Induced Magneto-Oscillations (LIMO) periodic in 1/B (Fig. 2(k)(I)) [2],[3]. Their frequencies give additional (quantitative) information about the structure of the Fermi surface. In the vortex state of a type 2 superconductor the propagation of heat and Cooper pairs in a transition state can be imaged. This can help to better understand the properties of this complex state. An example for the detected ring-structures in niobium is shown in Fig. 2(h). When this method is applied on semiconductors, two-dimensional electron systems in AlGaAs hetero-structures are of main interest due to still unknown mechanisms in the integer and fractional quantum Hall regime. An example of the defining potential distribution in a small orifice of ~20μm width is shown in Fig. 2(i): The flux channels of current flowing in opposite directions are visualised [4]. The signal shows so-called Light-induced Shudnikov-de Haas Oscillations (LISHO) in dependency of the magnetic field (Fig. 2(k)(II)). From their frequency the variation of the local electron density can be deduced. Alternatively carriers can be excited by an electron beam in a standard scanning electron microscope [5]. This allows higher resolution but is restricted to very low magnetic fields. The heating effect (as for light excitation) can also be used to excite phonons and to image their dispersion in the crystal (Fig. 2(e)) [5].

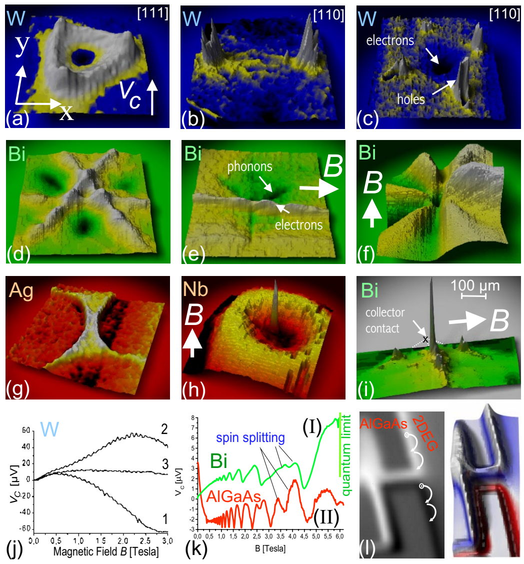

Fig. 2. Patterns of ballistic carrier transport. The perspective representation of (b) corresponds to the grey scale pattern of Fig. 1. The scale for all patterns is approximately as indicated in (i). (a)-(c) W in the indicated directions; (d)-(f) Bi under presence of a magnetic field B as indicated. (g) Ag; (h) Nb in the Vortex State. (i) So-called LITEF (Light-Induced Transverse Electron Focusing) experiment. The carriers are reflected on the surface and detected at the same surface, where the fibre is scanned. (j) LISOs at three different positions. Due to microscopic thermo-electric effects the background is not proportional to B2. (k)(I) LIMOs, (II) LISHOs in a two-dimensional electron gas (2DEG). (l) Imaging of electronic flux channels in an orifice structure of a 2DEG: grey scale image and in perspective representation.

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