Electric Field Effect on Vertical Magnetotransport in Multilayer Systems under Tilted Magnetic Fields

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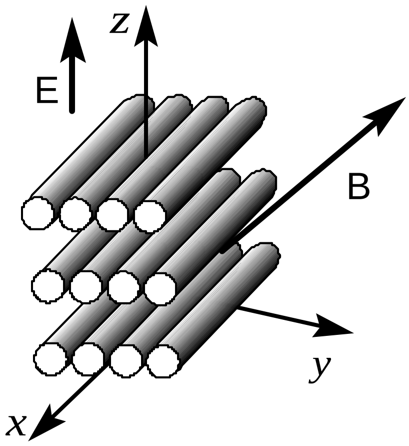
It has been known that the interlayer magnetoresistance of multilayer systems, for example, GaAs/AlGaAs superlattice or organic layered conductors, shows remarkable angular dependent behaviors when magnetic field orientation is changed. Although these angular effects essentially originate from the modulation of single tunneling probability between neighboring two layers, they have been usually explained by semiclassical orbital motion on Fermi surfaces and the Boltzmann transport theory. In the present work, we have additionally applied electric fields parallel to the stacking axis, and studied the change of the angular effects in interlayer transport both theoretically and experimentally.

Here, we discuss quasi-one-dimensional (Q1D) multilayer systems, where each layer consists of coupled conducting 1D chains (see Fig.1), since they show rich angular effects, Lebed resonance, Danner-Chaikin oscillations, and the third angular effect, depending on rotating directions of magnetic fields. Among them, the Lebed resonance is the most fundamental effect, and the others are just its amplitude modulation. The Lebed resonance is resonant increase of interlayer conduction which occurs when magnetic field becomes parallel to one of the lattice planes including the conducting 1D axis. In Q1D conductors under magnetic fields, semiclassically, an electron carries out orbital motion on a sheetlike Fermi surface. At the Lebed resonance, electron orbits become periodic on Fermi sheets, and the interlayer group velocity averaged over an orbit becomes finite causing resonant increase of interlayer conduction. When we additionally apply electric fields along the stacking axis, electron orbits are modified in the different way on two Fermi sheets: When electric field accelerates an orbital electron on one Fermi sheet, it slows down an electron on another Fermi sheet. Therefore, under electric fields, electron orbits on two Fermi sheets become periodic at different field orientations. This causes the doubly splitting of Lebed resonance. The electric field effects on other angular effects, which are amplitude modulation of Lebed resonance, can be understood from this splitting.

In order to demonstrate the above effect experimentally, we have chosen a layered organic conductor α-(BEDT-TTF)$_2$KHg(SCN)$_4$ as a Q1D multilayer system. It is known that this material has sheetlike Fermi surfaces in low temperature region as a result of Fermi surface reconstruction. This material shows a series of very sharp and clear Lebed resonances, which means the existence of sheetlike Fermi surfaces, and its interlayer resistance is so large that we can easily apply high electric fields along the stacking direction. Single crystal samples were rotated in fixed magnetic fields up to 13T. To avoid sample heating, the electric field was applied to samples as successive voltage pulses with width of 5μs and duty ratio of 1/3000. The waveforms of both voltage and current pulses were recorded in the 12bit digitizer. As shown in Fig. 2(a), when the height of voltage pulses is small enough, the interlayer current shows a series of Lebed resonance peaks as a function of the tilt angle of magnetic fields. Figure 2(b) indicates the waveform of one Lebed resonance peak (p=1) for several interlayer electric fields. We can see that the Lebed resonance peak shows doubly splitting as expected above, and this split becomes larger as the voltage pulse height is increased. Figure 2(c) shows the split width as a function of interlayer electric fields for five Lebed resonances. Since the split width depends on the resonance position, the abscissa is normalized so as to be independent from resonance position. In Fig.2(c), the splits of all resonances are proportional to the electric field and scaled on a single line. This fact strongly suggests that the observed splitting originates from the mechanism discussed above. If it is true, we can estimate the Fermi velocity from the observed splitting as v_F=8x10^{5}m/s. This value is consistent with the result of the infrared study of the other group. In this way, the split effect of Lebed resonance under electric fields would possibly give a useful experimental tool to determine the Fermi velocity of Q1D conductors.



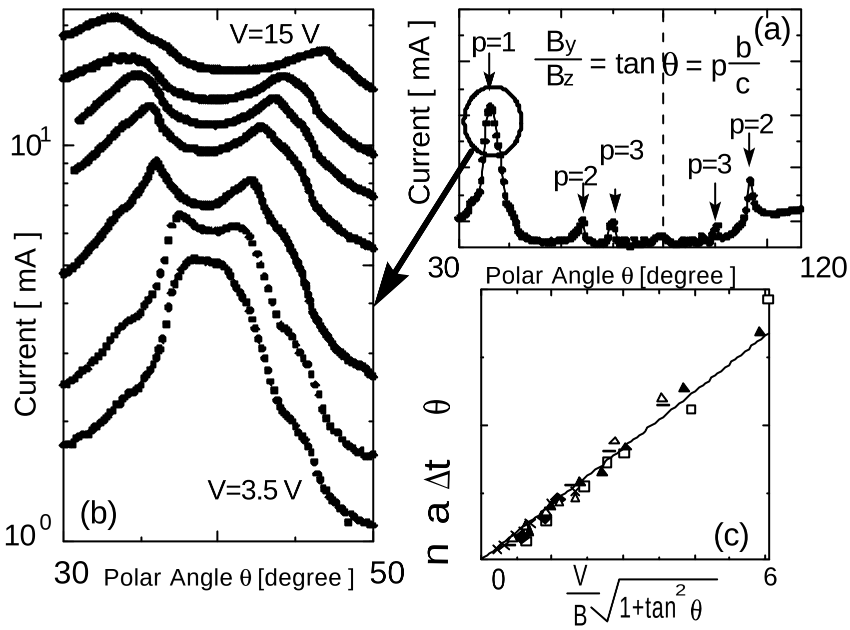


Fig. 1 Schematic structure of the Q1D multilayer system. Coupled conducting chains (//*x*-axis) form conducting layers (//*xy*-plane). Electric fields are applied parallel to the stacking axis (*z*-axis).

Fig. 2 (a) Angular dependence of interlayer conduction in an organic conductor *a*-(BEDT-TTF)$_2$KHg(SCN)$_4$ under very weak electric fields. Temperature was kept at 1.7 K and the total magnetic field was fixed to 13 T. Arrows indicate the Lebed resonances. (b) *p*=1 Lebed resonance under several interlayer electric fields. (c) Plot of split width against normalized electric field.