Tunable Spin Filter Based on III/V Antimonide Materials.

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We offer a simple design of quantum-point-contact spin filter. Such a device should allow for local control of the spin polarization in a semiconductor, and for direct electrical detection of the induced spin polarization. The basic device structure is shown in Fig. 1 and consists of: a lower set of split gates that are used to define the quantum point contact; a thin insulating layer, and; a continuous metal gate. In basic operation, the lower gates are configured to set the quantum point contact close to its threshold for conduction. A current is then driven through the upper gate, inducing a local magnetic field ***B***. The magnetic field induces a Zeeman splitting of the electron energy, and so gives rise to different transmission probabilities for the two spin species:

$$T_{\pm} = T(E_0 \pm {}^1/_2 g^* \mu_B B).$$

Here, E_o is the electron energy in the absence of a magnetic field, g^* is the effective g-factor relevant to the heterojunction system under study, and μ_B is the Bohr magneton.

In Figs. 2(a) & 2(b), we plot the variation of the spin-dependent transmission probabilities, T_+ and T_-, as a function of energy and magnetic field for a GaAs/AlGaAs point contact that is biased close to pinch off.

In Fig. 2(c), the bright region indicates the range of parameter space where the transmission of one spin species is high while that of the other is low.

In Fig. 3, we show the variation of the conductance, and the spin polarization, with magnetic field, at a fixed energy of 16.7 meV. (The conductance of the barrier $G = (e^2/h)(T_+ + T_-)$, while the polarization is defined as $P = (T_+ - T_-)/(T_+ + T_-)$). At zero magnetic field, the conductance is initially $2e^2/h$ at this energy, since the lowest sub-band is spin degenerate and is fully transmitted at zero field. As the magnetic field is increased, however, the conductance smoothly decreases to e^2/h, signaling the development of full spin polarization ($P = 1$).

In Fig. 4, we show the results of calculations of the spin-filter characteristics for a device realized in Si ($g^* = 2$, $m^* = 1.1m_o$), InAs ($g^* = -15$, $m^* = 0.023m_o$), and InSb ($g^* = -51$, $m^* = 0.014m_o$). In the case of Si, the relatively small value for the g-factor results in the need to generate magnetic fields as large as 1 T, in order to achieve satisfactory polarization. In InAs this field is reduced to of order a few tens of mT, while in the case of InSb it is expected that effective filtering should be achieved in a field of only mT. Such weak magnetic fields could easily be achieved by using a ferromagnetic gate, through which short current pulses could be driven to magnetize and demagnetize the gate material. This approach obviates the need for a continuous drive current in the upper gate, and so should help in reducing power dissipation.

In Fig. 5, we show the effect of temperature on the spin-filter characteristics of GaAs and InSb devices. In the GaAs device, the filtration effect is rapidly lost with temperature, and can no longer be clearly resolved at 4.2 K. In InSb, the very much larger g-factor yields correspondingly increased energy splittings, and so results in the persistence of spin-filter action to higher temperatures.
Because of InSb lattice parameter problem we used at first the InAs QW based heterostructures for tunable spin filter elaboration. The undoped and Te δ-doped structures were grown by MBE on p-–GaSb (100) substrates.

Currently, we are in the process of making transport measurements and devices.

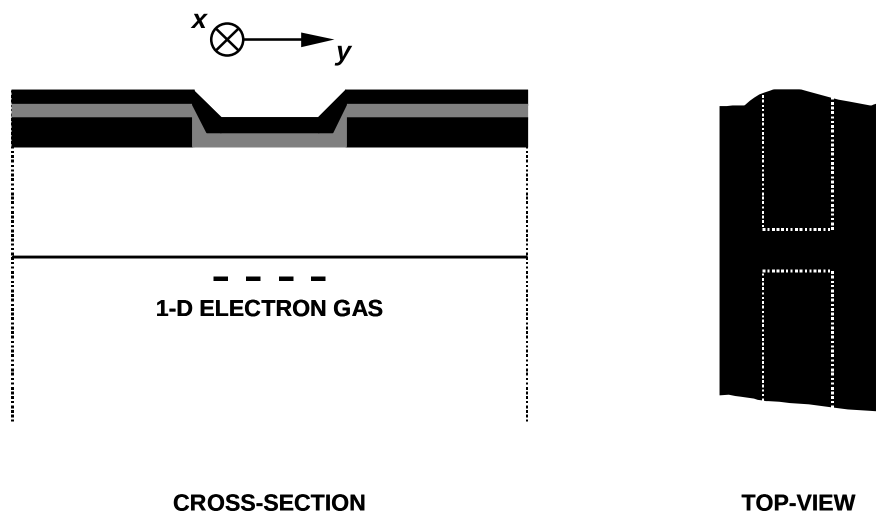

Fig. 1: Schematic illustration of the quantum-point-contact spin filter. Black regions correspond to metallic gates, while the gray shading denotes a thin insulating layer. The coordinate system is also indicated for reference.

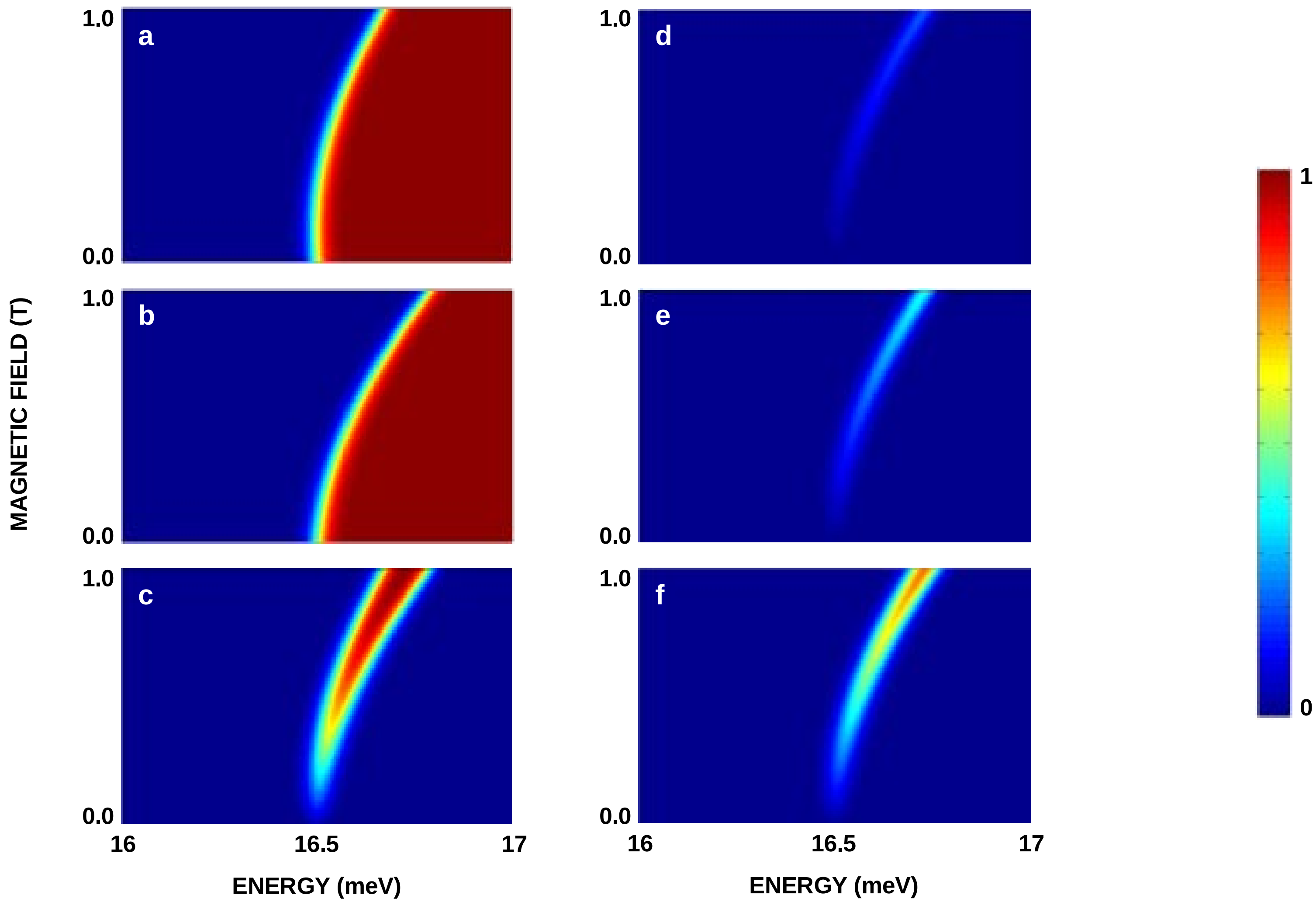

Fig. 2: (a) T_+ ;(b) T_-; (c) (T_+ - T_-) versus energy and magnetic field for GaAs.: $g^* = 2.0$, $m^* = 0.067m_o$. (d) – (f): (T_+ - T_-) calculations for $g^* = 0.2$, 0.4, and 1.0

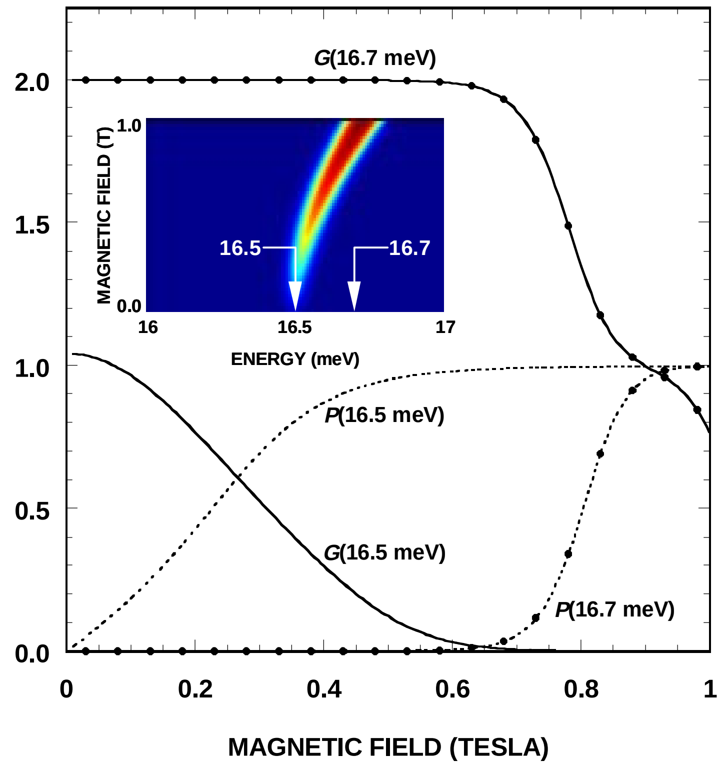

Fig. 3: The variation of the conductance (solid line, in units of e^2/h) and the spin polarization (dotted line) of the transmitted carriers as a function of magnetic field, for two different energies. The filter parameters here are: $m^* = 0.067m_o$, $g^* = 2$, $V_o = 15$ meV, $\hbar\omega_y = 3$ meV and $\hbar\omega_x = 0.1$ meV.

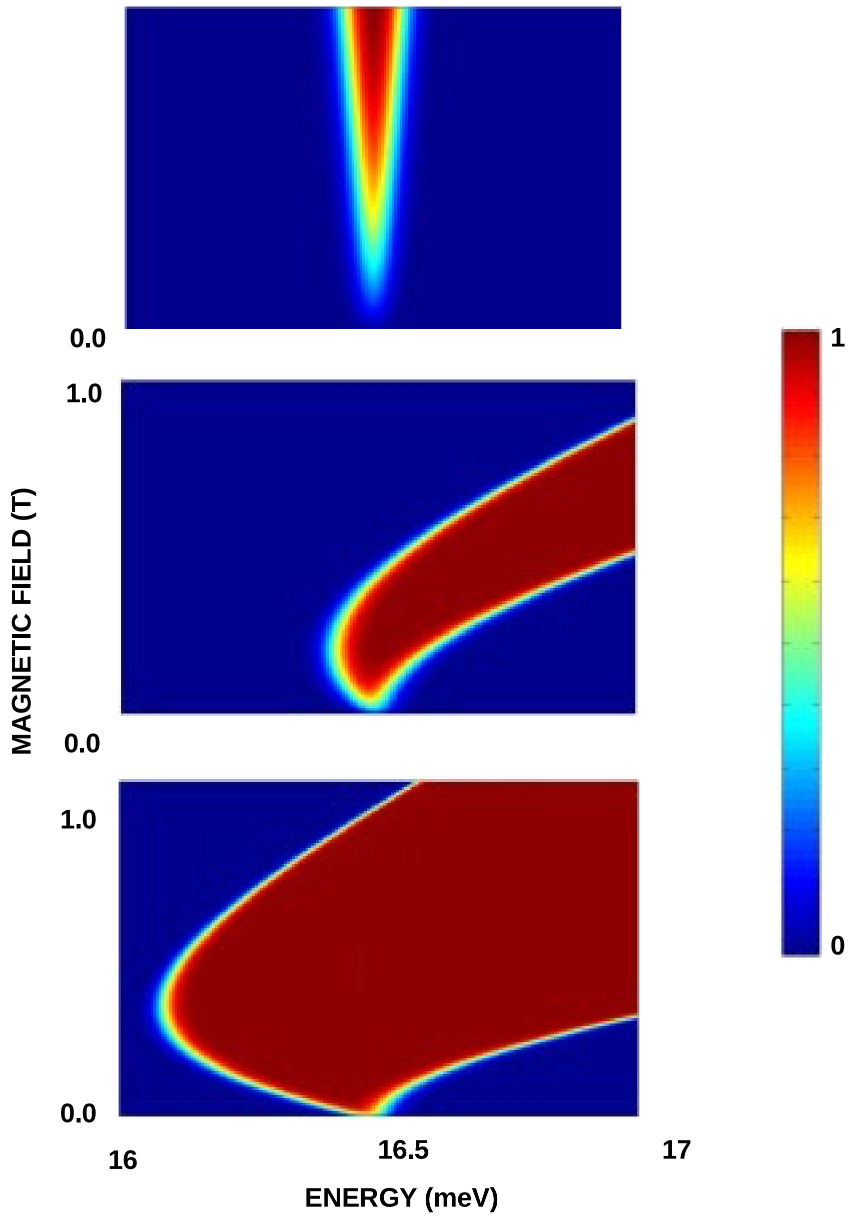

Fig. 4: Differential transmission (T_+ - T_-) versus energy and magnetic field. Top panel: Si. Center panel: InAs. Bottom panel: InSb.

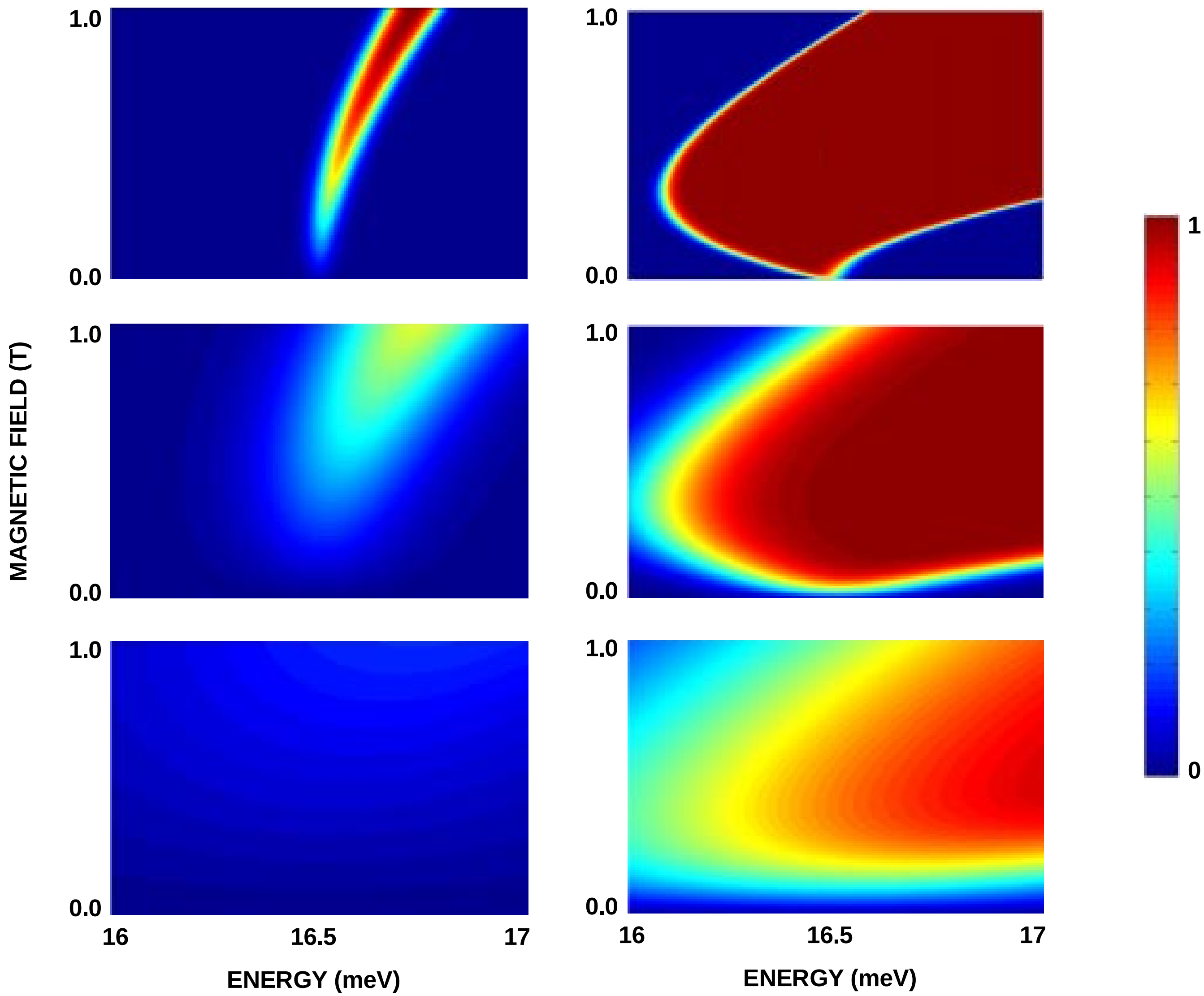

Fig. 5: Temperature dependence of the spin-filter action in two different material systems: GaAs and InSb. The temperature is 0 K for the top panels, 1 K for the center panels, and 4.2 K for the bottom panels.