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$Mn_5Ge_3C_x$ Contacts for Spin Injection into Ge

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Electronic devices based on transport of spin-polarized electrons are currently under experimental investigation as possible alternatives to CMOS transistor logic. Many spintronic device concepts require the injection of spin-polarized electrons into the semiconductor body of the device. The conductivity mismatch problem usually precludes the injection of spin-polarized electrons from low resistance metal-semiconductor contacts: on the one hand the specific contact resistivity is required to exceed a certain lower bound in order for spin injection to be successful, and experimental demonstrations of spin injection into Si and Ge have been achieved for tunnel or Schottky contacts. On the other hand, a high specific contact resistivity can be an obstacle to low-power operation of spintronic devices.

Mn_5Ge_3 is a ferromagnet with a Curie temperature of 297 K [1], which can be further enhanced to > 400 K by carbon doping [2]. With a resistivity of > 100 µΩ·cm at 300 K, $Mn_5Ge_3C_x$ is a candidate for spin injection into highly doped semiconductor channels from low resistance ohmic contacts. Several deposition methods are available for the material: $Mn_5Ge_3C_x$ can be deposited either by sputtering or by molecular beam epitaxy (MBE). Mn_5Ge_3 can also be formed by a germanidation process of Mn on Ge. Mn_5Ge_3 has been shown to form an epitaxial thin film with a sharp interface on Ge(111) [3].

We report on the successful integration of $Mn_5Ge_3C_x$ into device fabrication processes (a Schottky diode is shown in Fig. 1) and a systematic investigation of its contact properties on Ge. We compare samples prepared by different deposition methods (MBE and simultaneous magnetron sputtering from elemental targets of Mn, Ge, and C under argon atmosphere) and of different carbon content as well as of different wafer orientations (111) and (100) and dopants (B and Sb) for the Ge channel material. For the evaluation of contact properties, all $Mn_5Ge_3C_x$ contacts are deposited on degenerately doped MBE-grown Ge channels ($N_{D/A} \geq 1 \cdot 10^{20}$ cm^{-3}) with a thickness of 40-100 nm and capped with Al to prevent oxidation prior to contact structuring.

A comparison of specific contact resistivities of sputtered $Mn_5Ge_3C_{0.8}$ on degenerately doped Ge channels with different surface orientations and dopants is shown in Fig. 2. From measurements of metal-oxide-semiconductor capacitances we determine the work function $\Phi_M = 4.27$ V of sputtered $Mn_5Ge_3C_{0.8}$. It is generally difficult to obtain low resistive ohmic contacts to n-Ge because of strong Fermi-level pinning, which has been shown to lead to a Schottky barrier height of ~0.6 eV for a wide range of metal work functions. In accordance with this, we find that the specific contact resistivity of sputtered $Mn_5Ge_3C_{0.8}$ is lower on p-Ge than on n-Ge. Our results also show that even for sputtered contacts, the wafer orientation has a significant influence on the contact properties.

We discuss means to further reduce the specific contact resistance of $Mn_5Ge_3C_x$ on Ge such as inserting ultrathin dielectric films at the interface or fabricating Mn_5Ge_3 contacts by means of a germanidation process after depositing Mn directly on highly doped n-Ge or p-Ge. Furthermore, we discuss how favorable conditions for spin injection can be achieved.

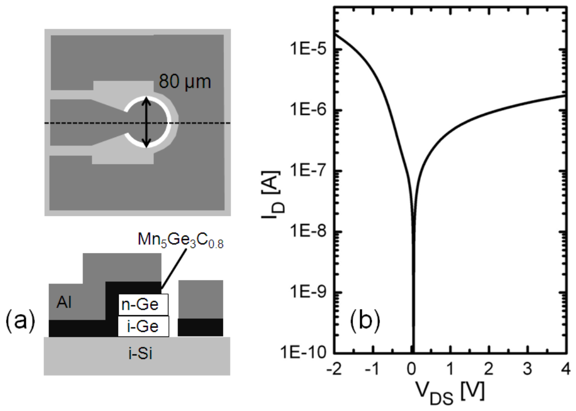

Fig. 1: (a) Schematic drawing of a Schottky diode fabricated with sputtered $Mn_5Ge_3C_{0.8}$/Al contacts. (b) *I-V* characteristics of the device.

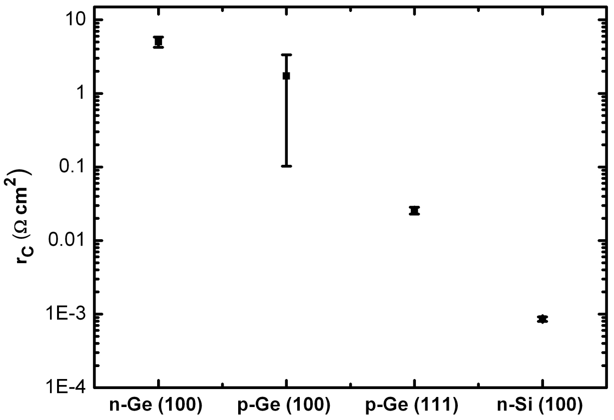

Fig. 2: Comparison of specific contact resistivities of sputtered $Mn_5Ge_3C_{0.8}$ on degenerately doped Ge channels with different surface orientations and dopants. The specific contact resistivity on n-Si (100) is shown for reference.

References

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