The road to silicon spintronics.

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Semiconductor electronics has been the cornerstone of information technology for many decades. It is based on the manipulation, control, and storage of electrical charge in circuits used for logic and memory applications, with the transistor as the central element. Semiconductor materials prevail because they allow power amplification, with silicon being by far the dominant material. However, as concerns are raised about the further advancements of semiconductor devices in future chip generations, alternative technologies are actively being explored. The field of spintronics aims to improve the performance and enhance the functionality of electronic circuits and systems by making use of the spin of electrons. While significant progress has been made in recent years in combining spin with III-V (GaAs) based semiconductor materials, silicon-based spintronics is still at its infancy.

While it is clear that implementing spin-functionality into silicon is potentially highly rewarding, it has turned out to be a major challenge. Amongst the key advances to be made are to develop robust and efficient ways to inject electron spins into Si, and to develop suitable (optical, electrical) methods to detect and manipulate the spin-polarization in the Si. However, perhaps the most challenging aspect is to design fully electrical silicon-based spin-devices with useful functionality and large spin-signals in a simple and preferably two-terminal geometry. With respect to the latter, efforts have so far been focussed on devices such as the spin-MOSFET, a transistor with a Si channel and a ferromagnetic (FM) source and drain. It is particularly clear that this demands careful consideration of the requirements for the FM injector and detector contacts [1,2,3], going beyond the obvious need for a high spin polarization of the contacts. For example, it is found that Schottky barrier formation on Si can be detrimental to the magnetoresistance of such a device [3]. This is partly because of the resulting large resistance area (RA) product of the contacts and partly because of the potential energy landscape, which affects spin flow across the interface [4].

As a solution, novel approaches are developed [3] to control the Schottky barrier height and resistance-area (RA) product of spin tunnel contacts to Si, e.g., using low work function materials. These include ferromagnets as well as non-magnetic materials, inserted as ultrathin (sub-nm) interfacial layers into FM/Si spin-MOSFETs or spin tunnel contacts on either side of the tunnel barrier. In this way, the RA product of FM/Si contacts can be tuned over 8 orders of magnitude (see fig. 1). Equally important, the resultant tunnel magnetoresistance data (fig. 2) show that a reasonable tunnel spin-polarization is simultaneously maintained. Interestingly, the Schottky barrier can even be inverted, in which case an interfacial accumulation layer (i.e., a 2-dimensional electron gas) can be established, creating new device options. Such engineered spin-tunnel contacts with low work function materials therefore not only qualify as conductivity-matched source and drain electrodes for silicon spintrons, but also open up new avenues to design spin devices based on Si quantum structures for application in silicon spintronics.