Abstract

Search for Advanced Class of Magnetic Tunnel Spin-Injectors for Spintronic Device Applications

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The control and manipulation of the electron spin in semiconductors is central to spintronics, which aims to represent digital information using spin orientation rather than electron charge. Such spin-based technologies may have a profound impact on nano-electronics, data storage, and logic and computer architectures. In silicon spintronics, the unique qualities of ferromagnetic materials are combined with those of silicon, aiming at creating an alternative, energy-efficient information technology. In order to obtain a balanced assessment of the potential and the merits of a spin-based information technology, the devices and circuits need to be realized, their characteristics and limitations need to be determined and their performance based parameters must be quantified.

The central aim of the thesis is to develop the three cornerstones of silicon spintronics devices, namely the creation, detection and manipulation of spin in silicon utilizing three-terminal (3-T) Hanle device. In particular, various kind of ferromagnetic materials (FM), such as half-metallic Heusler alloy (Co_2MnSi), half-metallic inverse Heusler alloy (Mn_2CoSi), magnetic oxide ($Ni_{0.65}Zn_{0.35}Fe_2O_4$), zero spin-gap half-metal (V_2NiAl), spin gapless semiconductor (Ti_2CoSi) have been used as ferromagnetic tunnel contact to silicon for efficient injection and detection of spin polarization in semiconductor (SC) at room temperature. For that purpose, an ultra-thin (~ 2 nm) oxide layer (such as, SiO_2) sandwiched between the FM and SC, has been utilized that acts as a tunnel barrier. Electron beam physical vapour deposition (EBPVD) system has been employed in order to deposit the metal films whereas the oxide film has been grown by pulsed laser deposition (PLD) system. Several characterization techniques, such as high resolution X-ray diffraction (HRXRD) for structural characterization, X-ray photoelectron spectroscopy (XPS) for chemical analysis, atomic force microscopy (AFM) for surface morphology, cross-sectional transmission electron microscopy (HRTEM) for interfacial study, vibrating sample magnetometry (VSM) for magnetic property study, have been utilized for the fabricated FM/SC heterostructures.

The electronic- and magneto- transport characteristics (current-voltage, resistivity, magnetoresistance etc.) of the heterojunctions have been investigated in detail. The efficient electrical injection of spin-polarized carriers into silicon from each of the above mentioned magnetic tunnel contacts, spin accumulation in the semiconductor channel, and electrical detection of induced spin-polarized carriers at room temperature with the help of a three-terminal Hanle device have been explored and the corresponding spin-parameters such as spin life time, spin diffusion length, spin-polarization have been extracted. Finally, a high quality exchange biased trilayer magnetic tunnel junction (MTJ) has been fabricated utilizing magnetron sputtering system. The micro-fabricated MTJ composed of a spin gapless semiconductor (SGS) Ti_2CoSi (TCS) inverse Heusler alloy (used as a lower electrode), a thin MgO layer (used as a tunnel barrier), and a half-metallic ferromagnet (HMF) Co_2MnSi (CMS) Heusler alloy (used as an upper electrode), exhibits extremely large tunnel magnetoresistance (TMR) ratios of 892 % at 5 K. Spin dependent transport properties reveal that the MTJ can act as a reconfigurable magnetic tunnel diode. All these exceptional features can undoubtedly nominate CMS/MgO/TCS MTJs as a promising candidate to serve as memory or logic elements in next generation ultra-high density magnetoresistive random access memories together with contemporary spin based electronic devices.

Keywords: Spintronics, Three-terminal Hanle device, Spin injection, Heusler alloy, Inverse Heusler alloy, Zero spin-gap half-metal, Spin gapless semiconductor, Magnetic tunnel junction, Tunnel magnetoresistance.

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