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Spintronic Devices: From Spin-Valves and Spin Lasers to Fault-Tolerant Quantum Computing

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Impressive success of spintronic applications in metal-based structures utilize magnetoresistive effects for substantial improvements in the performance of magnetic sensors, computer hard drives, and magnetic random access memory (MRAM) [1, 2, 3]. However, this may only be the tip of the iceberg. A versatile control of spin and magnetism in a wide class of materials and their nanostructures, could also have a much broader impact leading to the new generation of multifunctional devices for spin logic and spin communication. A spin valve in which two ferromagnetic electrodes are separated by a non-magnetic region is ubiquitous in computer hard drives and MRAM which rely on magnetoresistance: the difference in resistance between a spin valve's antiparallel and parallel magnetization configuration. A variation of this spin valve in graphene-based heterostructures has enabled room temperature spin logic [4]. Its future realization may use tunable magnetic proximity effects [5] where a gate-controlled reversal of spin polarization eliminates the need for an applied magnetic field and magnetization reversal. With the change of the carrier spin polarization it is also possible to enhance the operation of semiconductor lasers [6] enabling ultra-high frequency operation and superior optical communications [7, 8].

Commercially available spin valves could be the building block in engineering elusive topological states using tunable magnetic textures generated by the fringing fields. An interesting example is the formation of non-Abelian Majorana bounds states (MBS) through proximity-induced superconductivity in a two-dimensional electron gas (2DEG) [9, 10], illustrated in Fig. 1. Magnetic textures generate synthetic spin-orbit coupling to support p-wave superconductivity in 2DEG and provide confinement to localize and manipulate MBS. Adiabatic changes of the magnetic texture allow exchanging MBS to realize robust topological qubits and gate operations for a fault-tolerant quantum computing [11].

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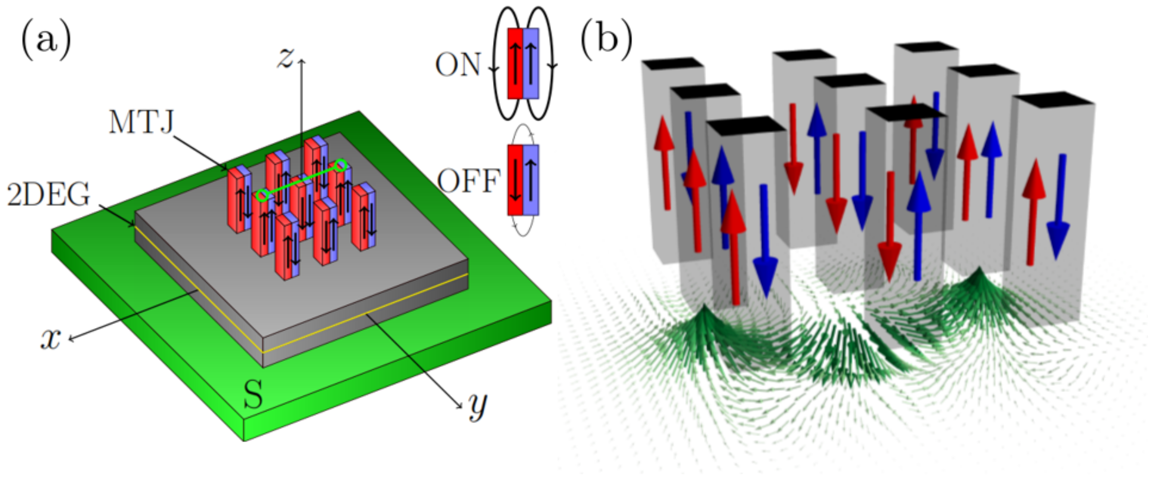

Figure 1: (a) Schematic of the setup. A two-dimensional electron gas (2DEG) is formed in a semiconductor quantum well grown on the surface of an s-wave superconductor (S). An array of spin valves realized as magnetic tunnel junctions (MTJs) produces a magnetic texture, tunable by switching individual MTJs to the parallel (ON) or antiparallel (OFF) configuration. For the depicted array configuration, two Majorana bound states form at the ends of the middle row (the green line). (b) Magnetic texture produced by the fringing fields generated by the MTJ array.

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