Energy-Efficient Strain-Programmable Probabilistic Bits

Technology ID

BDP 8520

Category

Hardware/Quantum Information

Selection of Available Technologies

Authors

Xiaodong Xu

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The manipulation of quantum properties of electrons to store information has been used for decades, and its continued study is key to the development of new fields such as spintronics and quantum computing. The discovery of strain-induced properties of stacked CrSBr layers promises advances in both unparalleled control of key material properties, as well as energy efficiency, in the development of new information storage components.

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What is the Problem?

Magnetic tunnel junctions (MTJs) are one of the most important computer components that rely on the quantum properties of electrons. They are made up of two magnetic materials, separated by an insulator through which electrons tunnel between. The magnetization of the materials can either be parallel (P) or anti-parallel (AP), which acts as a switch to control the flow of electrons passing through. MTJs are not only used in today's computers as magnetic random-access memory but are a crucial technology in spintronics, a key field in the development of quantum computing.

Switching between P and AP states (1 and 0 states, as a conventional bit) requires input energy equal to the energy difference between the states. A large energy difference as seen in thick MTJs results in a conventional bit; the stored state is stable and will not change unless actively switched by a new input. A small energy difference however, as seen in thin MTJs, results in a system varying between P and AP states. This "probabilistic" bit (p-bit) is of great interest in developing fields such as neuromorphic computing.

Conventionally, this energy difference is fixed by the thickness of the materials. In addition, this transition from P to AP states requires the application of large currents or magnetic fields. There is still an unmet need for energy efficient MTJs beyond these standard mechanics, as well as MTJs that can act as either a conventional or probabilistic bit.

What is the Solution?

The technology applies strain to stacked layers of CrSBr on a flexible substrate to change the magnetization state without applied current or magnetic field. Without any strain. the CrSBr layers exhibit an AP state, disallowing electron flow. However, when strained, this AP state transitions to a parallel P state, functioning as a conventional bit by controlling only strain. This lack of magnetic field or current application makes this bit much more energy efficient to use.

Applied strain can also be used to set the MTJ to work as either a conventional bit or a probabilistic bit. At an intermediate level of strain, the energy difference between the P and AP states is pulled closer together so that the states swap randomly back and forth, functioning as a probabilistic bit. This technology realizes a truly programmable bit, whose operation can be made to be conventional or probabilistic, all while relying only on applied strain.

What is the Competitive Advantage?

The two major advantages of this technology are its energy efficiency, and the unprecedented level of control over the magnetic states. The energy efficiency comes from the fact that little to no current is needed to apply the strain. At the same time, the piezoelectric system that applies the strain is capable of incredible levels of precision resulting in fine control over the resulting states. This opens the door to operation of the MTJ as either a conventional or probabilistic bit, with the capability of being extended to creating quantum bits by attaching superconducting leads. The material itself also offers useful properties, such as being able to operate at relatively high temperatures up to 150 K and remain stable when exposed to air.

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