Ambipolar QDs in undoped Si CMOS fin field-effect-transistors

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Quantum information can be encoded in the spin state of a single electron or hole confined to a semiconductor quantum dot (QD) [1]. Several material systems have been explored in the search of a highly coherent spin qubit. Silicon (Si) is a particularly promising materials platform for scalable spin-based quantum computing because of its fully developed, industrial manufacturing processes, which enable reliable and reproducible fabrication at the nanometer scale. Furthermore, natural Si consists of 95 % non-magnetic nuclei and a nearly nuclear-spin-free environment, which prevents hyperfine-induced decoherence, can be engineered by means of isotopic purification. Electron spins in Si are also subject to a weak spin-orbit interaction (SOI) and can thus be almost completely isolated from environmental noise. As a result, an outstanding dephasing time T_2^* of 120 μs has been demonstrated for the electron spin qubit in isotopically enriched Si [2]. The hole spin represents an attractive alternative to its electron counterpart [3]. While the electron Bloch function has s-wave symmetry, the hole has p-wave symmetry. Consequently, hole spins experience a weaker hyperfine, yet stronger SOI, which enables fast, all-electrical spin manipulation [4]. Si QDs are mostly designed for unipolar operation, confining either electrons or holes. By integrating both *n*- and *p*-type ohmic contacts ambipolar behavior, i.e. operation in the electron as well as hole regime, was demonstrated for planar Si metal-oxide-semiconductor (MOS) QD structures [5,6].

We present here a new generation of ambipolar Si QDs integrated in today's industry standard, non-planar fin field-effect-transistors (FinFETs) [7]. Conventional impurity-doped source and drain electrodes are replaced in an overlapping-gate structure by a metallic, mid-gap nickel silicide, allowing for ambipolar operation in a simple and highly compact design, which is fully compatible with complementary metal-oxide-semiconductor (CMOS) technology. We demonstrate dual-mode operation of such devices, either as a classical field-effect or single-electron transistor, down to temperatures of 1.5 K: (i) a classical CMOS inverter is realized by tuning two interconnected transistors into opposite polarity. (ii) In the quantum regime, stable QD operation in the few charge carrier Coulomb blockade regime is shown for both electrons and holes.

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