Silicon-based nanoelectromechanical information devices

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Over the past few decades, the performance of VLSI circuits has steadily been improved by scaling down CMOS device dimensions. The ITRS 2005 shows that the 'Nano Era' for the CMOS devices has started in 1999 with the gate length being shorter than 100 nm (see Fig. 1) The roadmap also predicts that this miniaturization trend will be pursued further, and the gate length will reach below 10 nm in 2016. Along with such an aggressive miniaturization trend of the Si VLSI devices, various microelectromechanical systems (MEMSs) have recently been developed by making their characteristic length (such as the resonator length) shorter in an attempt to increase their operation frequency. For example, the oscillation frequency of over 1 GHz has recently been demonstrated for the 1-μm-scale SiC based resonator. As shown in Fig.1 the present MEMS structures are still more than one order of magnitude larger than those for electronic devices, but the gap is certainly getting smaller.

In this paper we discuss a possibility of silicon-based nanoelectromechanical systems (NEMSs) as a functional component integrated into conventional electronic device structures for building novel nano information devices. First we present a new nonvolatile memory concept based on bistable operation of the sub-μm-long NEMS structure combined with the nc-Si quantum dots (Fig. 2). It features a suspended SiO_2 beam, which incorporates the nanocrystalline (nc-) Si dots as single-electron storage. The beam may be moved via the gate electric field, and its positional displacement is sensed via a change in the drain current of the MOSFET underneath. Secondly we discuss new operating principles of hybrid NEMS-MOS-SET (single-electron transistor) systems. In MOS-NEMS and SET-NEMS structures, a movable gate integrated into MOSFET and SET works as a binary capacitive switch and results in unique device characteristics which cannot be realized with conventional MOSFETs and SETs. For example, MOS-NEMS gives an extremely small subthreshold slope beyond a theoretical limit (S~60mV/dec) for MOSFETs. SET-NEMS enable to switch the period of Coulomb current oscillation of SETs, (Fig. 3) and this may be utilized for signal encoding in the periodicity realizing the offset charge independent SET logic. Moreover we discuss new electronic and phononic properties emerging in further scaled Si NEMS structures for exploring future nano information device applications.

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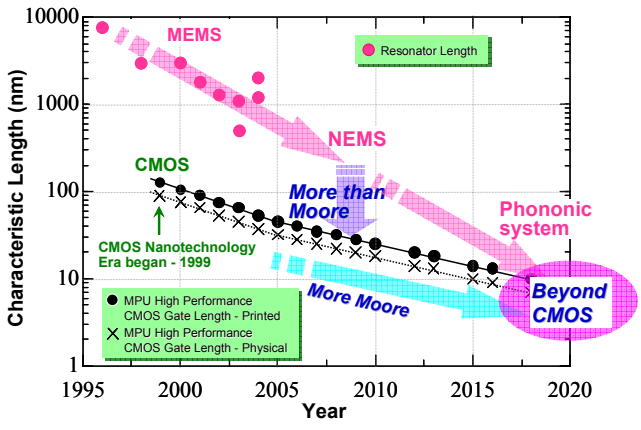

Fig.1 Trend of CMOS gate length downscaling (ITRS 2005) and that of recently- reported MEMS

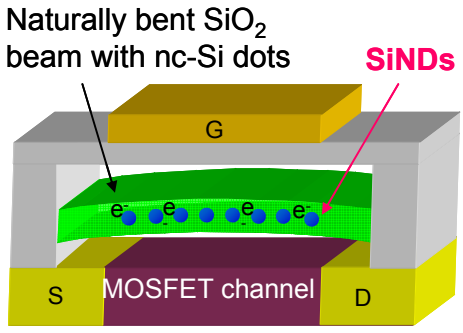

Fig.2 Schematic NEMS structure.

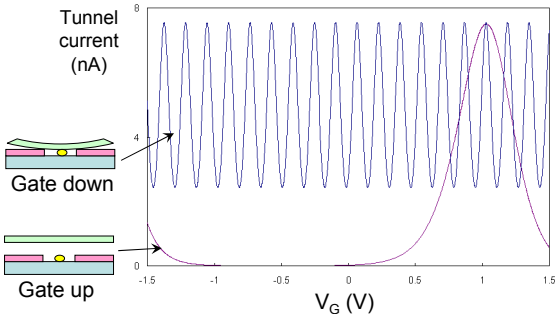

Fig.3 SET-NEMS characteristics