Atomic Computational Elements Using Silicon Dangling Bonds

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Modern transistors are pushing against the limiting boundaries of size, speed, and energy consumption. A potential successor addressing these issues is found with silicon dangling bonds (DBs) which can be placed as individual atomic building blocks in new computational schemes [1]. The energy states of DBs reside in the silicon substrate's band gap, electronically isolating them from the bulk. They can hold 0, 1, or 2 electrons, giving them a positive, neutral or negative charge state, respectively. They are effectively single-atom quantum dots that can be patterned [2] and erased [3] with atomic precision. All these unique properties allow us to fabricate novel nanoelectronic architectures.

Here, using the results obtained with all-electronic time-resolved scanning tunneling microscopy (TR-STM) and non-contact atomic force microscopy (nc-AFM), we discuss the fundamental properties of single DBs and present the first examples of functional DB structures. First, we show that the ionization of isolated dopants modifies the electronic transport properties of single DBs [4,5]. By using a single DB as a charge sensor of the isolated dopants surrounding it, we measure single dopant charge dynamics on the nanosecond timescale [5]. Furthermore, a new physical mechanism for atomic scale negative differential resistance is introduced [6,7]. We directly probe the on-site Coulomb interaction on the atomic scale and measure the carrier capture through an atomic mid-gap state [6,7]. Finally, we demonstrate that a coupled DB pair acts as a binary bit. By aligning them end to end, we are able to create functional computational units. We use nc-AFM to characterize our structures and present the first examples of reversible information transmission through a binary wire and an OR gate [8].

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