Counter Intuitive Physics of Ballistic Transport in the State-of-the-Art Silicon CMOS

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In small enough semiconductor devices, the electron mean free path for collisions with impurities and lattice vibrations exceeds the device size. Such collisionless electron transport is called "ballistic" or "quasi-ballistic". The electron mean free path in silicon at room temperature is on the order of 20 to 50 nm. This is much greater than the 5 nm minimum feature size of modern silicon CMOS with the channel lengths on the order of 20 nm. Such transistors are used, for example, in the iPhone 12. The current-voltage characteristics of the quasi-ballistic Si CMOS look similar to those of much longer transistors. But the physics of the ballistic transport is very different, counter intuitive, and has important qualitative consequences for the design of the advanced Si CMOS integrated circuits. Since electrons hit contacts more often in short channel devices, the measured field effect transistor mobility is determined by "the ballistic mobility" proportional to the device length. At high frequencies, the electron inertia starts playing an important or even a dominant role. The device impedance becomes strongly affected by the electron inertia. The waves of the electron density (plasma waves) enable the Si CMOS response well into the terahertz (THz) range of frequencies. At high excitation levels, these waves are transformed into shock waves. The rectification and instabilities of the plasma waves enable a new generation of THz and sub-THz plasmonic devices. These devices could be implemented in Si, p-diamond, III-V, and III-N materials systems. The 300 GHz band 6G Wi-Fi, advanced homeland security, VLSI testing, and cancer detection are but examples of applications of this plasmonic technology, which is sensitive to the phase of the impinging THz radiation. New emerging plasmonic applications include a field effect transistor THz spectrometer, a travelling wave THz detector, a THz frequency to digital converter, THz scanning cyber hardware security, and tunable "twisted plasmon" absorbers.