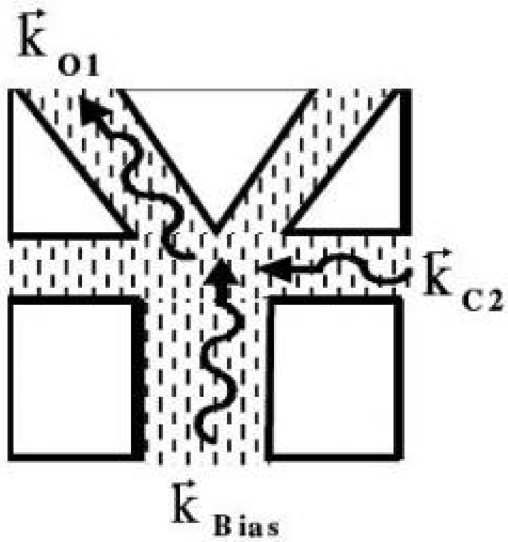
New Digital 'Electronics' Concept May Continue Moore's Law

November 5 2009, By Lisa Zyga



In the NFL logic device, the first SPW (kBias) is launched, followed by the launch of a second SPW (kC2), which steers the first SPW into the left drain terminal for detection, where it's identified as a logic "1". Image copyright: De Los Santos. ©2009 IEEE.

(PhysOrg.com) -- Computers of the future could be operating not on electrons, but on tiny waves traveling through an electron "fluid," if a new proposal is successful. The new circuit design, recently introduced by Dr. Héctor J. De Los Santos, CTO of NanoMEMS Research, LLC, in Irvine, California, may be a promising candidate to replace CMOS-based circuits, and ultimately continue the circuit density growth described by Moore's Law.

As Gordon Moore predicted more than 40 years ago, the number of transistors able to fit on a computer chip has doubled approximately every 18 months. But if the trend is to continue for the years to come, it will have to be with technology other than the conventional CMOS design. As the size of transistors gets down to the nanoscale, CMOS devices begin suffering from several issues, such as increased resistance, decreased channel mobility, and increased manufacturing costs.

To overcome the challenges involved with scaling, researchers from around the world have begun to look for alternatives to CMOS technology. De Los Santos' concept, called nano-electron-fluidic logic (NFL), is based on the flow of plasmons in a fluid-like electron gas (basically an electron fluid). He predicts that logic gates with the NFL design offer the potential for femtosecond switching speeds and sub-femtojoule power dissipations at room temperature - numbers that would be extremely capable of continuing Moore's Law beyond CMOS. De Los Santos' paper will be published in a future issue of *IEEE Transactions on Nanotechnology*.

As De Los Santos explains, the NFL concept takes advantage of the properties of surface plasma waves (SPWs). These waves propagate on the inversion layer at the insulating gate-semiconductor interface (which, in this case, embodies an electric fluid) and behaves as an SPW waveguide. When two SPWs collide, they repel each other. In the device set-up, one SPW is launched from a particular direction to collide with another SPW, causing it to scatter in one of two directions, where it is detected and interpreted as a "1" or, if not detected, a "0."

To begin the process, an SPW is launched into a channel filled with electron fluid that forks into two channels, each with a detector at the end. Under no external forces, the SPW will be split equally so that equal portions will be detected at the two end terminals. But when a second SPW is launched into the main channel from the left or right, it will cause the original SPW to deflect into the opposite fork. For example, a second SPW coming from the right would steer the original SPW down the left fork. When the SPW is detected at the left end terminal, and not the right, the NFL device forms the basis of a logic flip-flop, having the ability to store one bit of memory.

The SPW design is conceptually different from the CMOS design in the sense that it is based on waves rather than particles. De Los Santos compares the SPW concept to a wave in a pond that occurs when a pebble is dropped in the water. In this analogy, the water is the electron fluid, the disturbance is a departure from charge neutrality at a given point in the electron fluid (rather than the departure from the position of equilibrium of a particle moving up and down), and the disturbance carrying the departure from charge neutrality is the SPW.

"Notice that, while the disturbance moves away from its point of origin, a particle at the water surface stays at the same place; it only moves up and down," De Los Santos told *PhysOrg.com*. "Thus, the propagation of the disturbance does not involve the transport of mass. In fact, the disturbance [SPW] moves at a speed faster than that at which the massive water particles [electrons] could be transported. This establishes, qualitatively, why the speed of an SPW is greater than that of an electron."

In comparison, a conventional CMOS logic is based on transporting electrons through a channel by establishing an electron current. As De Los Santos explains, the electron current is made up of an assembly of individual electrons that individually suffer collisions with impurities and the vibrating background semiconductor lattice. These collisions limit the maximum speed, and the minimum power dissipation, attainable to effect a logic function.

“So, NFL is fundamentally based on wave (SPW) launching, propagation and manipulation, and CMOS is based on channel conductivity modulation and particle transport,” he said.

In the case of the NFL device, the key to optimizing its density is to find an optimal device length for the desired operating frequency.

“Once launched, SPWs have a lifetime that depends on the distance they propagate,” De Los Santos said. “If the point at which they are detected is too far away from the point of origin, the SPWs will die before getting there; no logic operation can be performed. The distance being too large, the device size will be too large, and the device density will be small. Now, if the detection point is too close to the origin, the SPWs will bounce/be reflected at the detection point, and propagate back to the point of origin, where they will be reflected again and propagate back to the detection point and so forth; this is a resonance condition. In this case, the device is small, the density is large, but what we have is an oscillator. However, if the point of detection is located at such a distance that the SPW is detected before it dies, so that the round trip back to the launching point is such that it dies before getting there, then we have the right device size, and the right device density for NFL.”

With the resonance limitation in mind, De Los Santos predicts that the ultimate device density would be that of the smallest possible plasmon, which is an electric dipole. Since the smallest electric dipole is an atom, the density would be equal to the areal atomic density of the type of atom used. Compared to current CMOS feature sizes, the NFL logic could potentially perform the same function in just one-fourth the area.

In addition to its potential for high density, the NFL logic has other advantages, such as a quick operation speed and a small energy requirement. SPWs have a propagation velocity of about 1 billion cm/sec, which is two orders of magnitude greater than electrons. On the nanoscale, this velocity enables switching times on the order of femtoseconds, or switching frequencies of approximately 6 THz at room temperature. As for energy, the only power required is that needed to excite an SPW, which can be done by any nonzero DC current. Maintaining the electron fluid requires negligible power consumption, so that the device's overall power consumption is determined by the minimum detectable current.

In addition, the NFL concept is compatible with current lithographic capabilities, allowing it to take advantage of established semiconductor manufacturing infrastructure. NFL logic gates could also be interfaced with conventional electronics. In the future, De Los Santos plans to continue investigating the possibilities of NFL logic.

"Research and development is underway to address NFL-based design, in particular, asynchronous logic design styles, and interfacing with electrons, photonic and plasmonic systems," De Los Santos said. "NFL-based digital logic circuit functions are expected to displace CMOS as a technology that will permeate from the computers, laptops, and cell phones to the communications satellites, instrumentation equipment and automobiles of the future."

<u>More information:</u> Héctor J. De Los Santos. "Theory of Nano-Electron-Fluidic Logic (NFL): A New Digital 'Electronics' Concept." *IEEE Transactions on Nanotechnology*. To be published.