Graphene replaced with copper

Graphene replaced with copper Graphene nanoribbons have a current-carrying capacity two orders of magnitude higher than copper Recent research into the properties of graphene nanoribbons provides two new reasons for using the material for interconnects in future computer chips. In widths as narrow as 16 nm, graphene has a current-carrying capacity approximately a thousand times greater than copper while providing improved thermal conductivity. The current-carrying and heat-transfer measurements were reported by a team of researchers from the Georgia Institute ofTechnology(Atlanta, GA).

The same team had previously reported measurements of resistivity in graphene that suggest the material’s conductance would outperform that of copper in future generations of nanometer-scale interconnects. The graphene nanoribbons have a current-carrying capacity two orders of magnitude higher than copper at these size scales, according to Raghunath Murali, a senior research engineer at Georgia Tech. {draw: frame} Composed of thin layers of graphite, graphene has been studied by the Georgia Tech team as a potential replacement for copper in on-chip interconnects wires.

The graphene nanoribbons have a current-carrying capacity of more than 108 A/cm2, which makes them very robust in resisting electromigration and should greatly improve chip reliability. This electromigration phenomenon causes transport of material, especially at high-current density and leads to a break in the wire and, consequently, chipfailure. The research team also discovered that the graphene nanoribbons also have excellent thermal conductivity properties and can conduct heat away from devices.

They found that graphene nanoribbons have a thermal conductivity of more than 1, 000 W/m Kelvin for structures less than 20 nm wide. This will help the interconnects serve as heat spreaders in future generations of integrated circuits, according to Murali. They used electron beam lithography to construct four electrode contacts, then used lithography to fabricate devices consisting of parallel nanoribbons of widths ranging between 16 and 52 nm and lengths of between 0. 2 and 1 µm.

The breakdown current density of the nanoribbons was then studied by slowly applying an increasing amount of current to the electrodes on either side of the parallel nanoribbons. A drop in current flow indicated the breakdown of one or more of the nanoribbons. In the study of 21 test devices, the researchers found that the breakdown current density of graphene nanoribbons has a reciprocal relationship to the resistivity. Because graphene can be patterned using conventional chip-making processes, manufacturers could make the transition from copper to graphene without a drastic change in chip fabrication.

The data they developed so far look very promising for using this material as the basis for future on-chip interconnects. Visit www. youtube. com/watch? v= kd6zzwhfEqw to view a video explaining graphene’s thermal-conductivity capabilities. Though one of graphene’s key properties is reported to be ballistic transport—meaning electrons can flow through it without resistance—the material’s actual conductance is limited by factors that include scattering from impurities, line-edge roughness and from substrate phonons—vibrations in the substrate lattice.

Use of graphene interconnects could help facilitate continuing increases in integrated circuit performance once features sizes drop to approximately 20 nanometers, which could happen in the next five years, researchers said. At that scale, the increased resistance of copper interconnects could offset performance increases, meaning that without other improvements, higher density wouldn't produce faster integrated circuits. This is not a roadblock to achieving scaling from one generation to the next, but it is a roadblock to achieving increased performance.

Dimensional scaling could continue, but because we would be giving up so much in terms of resistivity, we wouldn't get a performance advantage from that. That's the problem we hope to solve by switching to a different materials system for interconnects Survey in graphene replaced with copper PORTLAND, Ore. —Graphene will carry nearly 1, 000-times more current and run over 10-times cooler than conventional copper interconnects below 22-nanometer line widths, according to researchers at the Georgia Institute of Technology (Georgia Tech).

The speed (electron mobility) of graphene has already been touted as better than copper, but this Georgia Tech data on nanoribbons as small as 16-nanometers quantifies just how superior carbon is to copper. The graphene nanoribbons tested at Georgia Tech could carry as much as 10 billion amps per square centimeter—nearly a thousand times greater than copper. " No one had measured graphene's current carrying capacity before this," said Raghunath Murali, a senior research engineer in Georgia Tech's Nanotechnology Research Center. One possible reason that this property of graphene was not touted before is that there were no experimental results until our work. " The superior current carrying capability of carbon formed into graphene nanoribbons is also combined with less heat build-up, since carbon's thermal conductivity is much higher than copper. Nanoribbons have a thermal conductivity of 1, 000-to-5000 watts per meter Kelvin—ten times greater than copper. The Georgia Tech researchers also claim that graphene nanoribbons will mitigate electro-migration which is an increasing problem for copper as line widths descend to the nanoscale. If the current carried through a wire is close to the current-carrying capacity of the wire, then the chances of electromigration are greater than if the current in the wire is much smaller than the current-carrying capacity," said Murali. " Graphene has over two orders of magnitude greater capacity than copper, thus if a graphene wire is compared to a copper wire carrying the same current, then the graphene wire will better resist electromigration. " Murali's team obtained their graphene samples by removing layers from a graphite block and depositing them on a silicon-on-insulator (SOI) wafer.

E-beam lithograhy was used to construct the metal contacts and cut the parallel lines of graphene into lines 16-to-52 nanometers wide and 200-to-1000 nanometers long. There are three hurdles remaining to commercialization of carbon interrconnects, according to the researchers at Georgia Tech: perfecting methods of growing monolayers of graphene over entire wafers (since today only small centimeter-sized areas can be easiliy grown in monolayers), fabricating vias to interrconnect graphene nanowires, and integration of carbon into the back-end of process on a CMOS line.

Murali performed the work with fellow researchers Yinxiao Yang, Kevin Brenner, Thomas Beck and James Meindl. This research was funded by the

Semiconductor Research Corporation, the Defense Advanced Research Projects Agency (DARPA), the Interconnect Focus Center, the Nanoelectronics Research Initiative and the Institute for Nanoelectronics Discovery and Exploration (INDEX). Replacing silicon {draw: frame} Silicon transisitors are approaching the point where further miniturization will no longer be possible. It is expected that once silicon transistors reach 16nm size, optical lithography will no longer be capable of making smaller images.

Thus, unless all preogress in transistor size is terminated and performance improvements are limited to processor architecture alone, it is very likely that chip manufacturers will move to graphene as a way to get smaller transisitors. One example is that graphene transistors are very " leaky" compared to those made of silicon- that is, more charge can escape from them. This means that graphene chips are likely to run much hotter than silicon chips. Graphene has several very appealing traits. Electrons meet much less resistance from graphene than they do from silicon, traveling through it more than 100 times as easily.

And because graphene is essentially a two-dimensional material, building smaller devices with it and controlling the flow of electricity within them are easier than with three-dimensional alternatives like silicon transistors. The finding underscores graphene's potential for serving as an excellent electronic material, such as silicon, that can be used to develop new kinds of transistors based on quantum physics. Because they encounter no obstacles, the electrons in graphene roam freely across the sheet of carbon, conducting electric charge with extremely low resistance.

The research team, led by Chun Ning (Jeanie) Lau, found that the electrons in graphene are reflected back by the only obstacle they meet: graphene's boundaries. " These electrons meet no other obstacles and behave like quantum billiard balls. " They display properties that resemble both particles and waves. " when the electrons are reflected from one of the boundaries of graphene, the original and reflected components of the electron can interfere with each other, the way outgoing ripples in a pond might interfere with ripples reflected back from the banks. he " electronic interference" by measuring graphene's electrical conductivity at extremely low (0. 26 Kelvin) temperatures. She explained that at such low temperatures the quantum properties of electrons can be studied more easily. The electrons in graphene can display wave-like properties, which could lead to interesting applications such as ballistic transistors, which is a new type of transistor, as well as resonant cavities for electrons, that a resonant cavity is a chamber, like a kitchen microwave, in which waves can bounce back and forth. Scientifically, it has become a new odel system for condensed-matter physics, the branch of physics that deals with the physical properties of solid materials. Graphene enables table-top experimental tests of a number of phenomena in physics involving quantum mechanics and relativity. Bearing excellent material properties, such as high current-carrying capacity and thermal conductivity, graphene ideally is suited for creating components for semiconductor circuits and computers comparing with silicon. Its planar geometry allows the fabrication of electronic devices and the tailoring of a variety of electrical properties.

Because it is only one-atom thick, it can potentially be used to make ultra-small devices and further miniaturize electronics. Image shows graphene, which can act as an atomic-scale billiard table, with electric charges acting as billiard balls. (Credit: Lau lab, UC-Riverside) Silicon has been the main ingredient in microchips since they replaced vacuum tubes in electronics. But the common element graphene, found in pencils, may one day supplant silicon on the billion-dollar foundries of IBM, Intel and AMD.

Graphene shares the characteristics that make silicon so ubiquitous, not just in computers and cell phones, but in such applications as medical and aviation sensors, ultrahigh-frequency analog electronics for preparing signals for fiber-optic transmission or for radars. Graphene can do what silicon can, only better. Graphene has extraordinary electron-transport properties; its monolayer thickness yields exquisite sensitivity to changes inenvironment, and its mechanical and thermal properties equal or exceed those of the best conventional materials.

The superior properties of graphene and graphene-related materials present an extraordinary opportunity for enabling new classes of electronic, optoelectronic and electromechanical devices and sensors The first commercial use for graphene may be as an electrical coating for LCD screens, solar cells, and touch screens. Thin, transparent, extremely conductive, and strong, it seems ideal for the job. ONE OF THE APPLICATION Graphene Quilts to Keep Things Cool December 21, 2009 {draw: frame} Graphene University of California, Riverside (UCR) Professor of Electrical

Engineering and Chair of MaterialsScienceand Engineering Alexander Balandin is leading several projects to explore ways to use the unique capabilities of graphene “ quilts” as heat conductors in high-power electronics. Graphene is a recently discovered single-atom-thick carbon crystal, which reveals many unique properties. In Balandin’s designs, graphene “ quilts” (large-area overlapping networks of graphene flakes) will play quite an opposite role of your grandma’s quilts. They will remove heat instead of retaining it.

His work on graphene heat-conducting coats for heat removal from high-power gallium-nitride transistors is being funded by a recently awarded $420, 000 grant from U. S. Office of Naval Research (ONR). It aims at an experimental proof-of-concept demonstration to be conducted in Balandin’s Nano-Device Laboratory (NDL). In addition to the ONR grant, Balandin received a new three-year subcontract with the Interconnect Focus Center (IFC), based at the Georgia Institute of Technology, that deals with graphene interconnects and heat spreaders for three-dimensional (3-D) electronics.

According to the International Technology Roadmap for Semiconductors, in the next five years, up to 80 percent of microprocessor power will be consumed by the interconnect wiring—a driver for the search for new interconnect materials and innovative methods of heat removal. Another recent subcontract awarded to Balandin is with the Functional Engineered Nano Architectonics (FENA) center based at UCLA. In this center, he investigates the problems of energy dissipation in graphene nanostructures and nanodevices. Combined new funding secured by Balandin this month for the three projects exceeds $1 million.

The centers’ funding comes from the Semiconductor Research Corporation (SRC) and Defense Advanced Research Project Agency (DARPA). Because graphene is only one molecule thick, it didn’t lend itself to traditional methods of thermal conductivity measurement. Balandin led a team of researchers that first measured it using an original non-conventional technique in 2008. The procedure involved a non-contact approach on the basis of Raman spectroscopy utilizing the inelastic scattering of photons (light) by phonons (crystal vibrations).

The power dissipated in graphene and corresponding temperature rise were detected by extremely small shifts in the wavelength of the light scattered from graphene. That was sufficient to extract the values of the thermal conductivity through an elaborate mathematical procedure. Balandin’s research group discovered that the thermal conductivity of large suspended graphene sheets varies in the range from about 3000 to 5300 W/mK (watts per meter per degree Kelvin) near room temperature. These are very high values, which exceed those of carbon nanotubes (3, 000-3, 500 W/mK) and diamond (1, 000-2, 200 W/mK).

As a result of his findings, Balandin has proposed several innovative graphene-based approaches for thermal management , which might lead to creation of a new technology for local cooling and hot-spot spreading in the high-power-density and ultra-fast chips. A detailed description of Balandin’s graphene and thermal management research can be found in his invited popular science article, “ Chill Out,” in the October 2009 issue of IEEE Spectrum, the magazine of the The Institute of Electrical and Electronic Engineers (IEEE).