Nanomembranes promise new materials for advanced electronics

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(PhysOrg.com) -- The camera in your phone collects light on silicon and translate that information into digital bits. One of the reasons those cameras and phones continue to improve is that researchers are developing new materials that absorb more light, use less power, and are less expensive to produce.

Now, University of Wisconsin-Madison materials science and engineering researchers have introduced innovations that could make possible a wide range of new crystalline materials. Writing in the June 8 web issue of the American Chemical Society journal *ACS Nano*, Research Assistants Deborah Paskiewicz and Boy Tanto along with Scientist Donald Savage and Erwin W. Mueller Professor and Bascom Professor of Surface Science Max Lagally, describe a new approach for using thin sheets of semiconductor known as nanomembranes.

Controlled stretching of these membranes via epitaxy allows the team to fabricate fully elastically relaxed silicon germanium nanomembranes for use as growth substrates for new materials. The team grew defect-free silicon germanium layers with any desired germanium concentration on silicon substrates and then released the silicon germanium layers from the rigid silicon, allowing them to relax completely as free-standing nanomaterials. The silicon germanium film is then transferred to a new host and bonded there. From this stage, a defect-free bulk silicon germanium crystal can be grown (something not possible with current technology), or the silicon germanium membrane can be used as a unique substrate to grow other materials.

Epitaxy, growth that controls the arrangement of atoms in thin layers on a substrate, is the fundamental technology underlying the semiconductor industry's use of these new materials. By combining elements, researchers can grow materials with unique properties that make possible new kinds of sensors or high speed, low-power, efficient advanced electronics. It is the ability to grow them without detrimental defects that makes these alloys useful to the semiconductor industry. However, making high-quality crystals that combine two or more elements faces significant limitations that have vexed researchers for decades.

"Many materials consisting of more than one element simply cannot be used. The distances between atoms are not the same," says Lagally. "When one begins to grow such a layer, the atoms start to interfere with each other and very soon the material no longer can grow as just one crystal because it starts to have defects in it. Eventually, it breaks up into small crystals and becomes polycrystalline, or even cracks."

In addition to its use in the semiconductor industry, silicon germanium is important to the nascent field of quantum computing. A quantum computer makes direct use of quantum mechanical phenomena such as superposition and entanglement to perform calculations. Current computers are limited to two states; on and off, or zero and one. With superposition, quantum computers encode information as quantum bits. These bits represent the varying states and inner workings of atoms and electrons. By manipulating these multiple states simultaneously, a large-scale quantum computer, if it can be built, could be millions of times more powerful than today's most powerful classical supercomputer.

UW-Madison Physics Professor Mark Eriksson uses silicon germanium to make two-dimensional electron gases. "A 'two-dimensional electron gas' is a layer of a semiconductor in which charges are able to move freely over large distances, in analogy with atoms in a real gas, except confined to a thin layer and hence two-dimensional. For quantum computing, this 2-D electron gas is formed in a strained-silicon layer grown on a silicon germanium substrate. Electrodes put on top of a structure containing the 2-D electron gas in the strained-silicon layer allow one to move and control single electrons, turning regions of the quantum well into ‘electron buckets,’ if you will, that are defined by the electric fields from the top electrodes," says Lagally.

A major obstacle to developing a quantum computer is creating multiple quantum buckets as similar as possible. To make rapid progress, researchers need low-defect and consistent materials.

“With the silicon germanium substrates we have been using, the electrostatic fields can be quite uncertain because of the defects in the substrate,” says Lagally. “We believe our new process can fix that. Because the substrate material is uniform, without defects, it should bring more predictability and control to Mark’s efforts.”

Beyond silicon germanium, Lagally says the process should work for a wide range of exotic materials that cannot be grown in bulk but have interesting properties. Materials Science and Engineering Associate Professor Paul Evans develops new ways to probe and apply these materials.

“The thin defect-free substrates that can be produced by transferring and relaxing these layers present exciting opportunities in the growth of materials beyond silicon and other traditional semiconductors,” Evans says. “With this approach, it will be possible to produce defect-free substrates of materials for which no high-crystalline quality bulk materials exist. In complex oxides, this can lead to thin substrates that stabilize specific ferroelectric or dielectric phases. That could lead to better oscillators, sensors and optical devices, that are important to the cell phones, cameras and computers we use everyday.”

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