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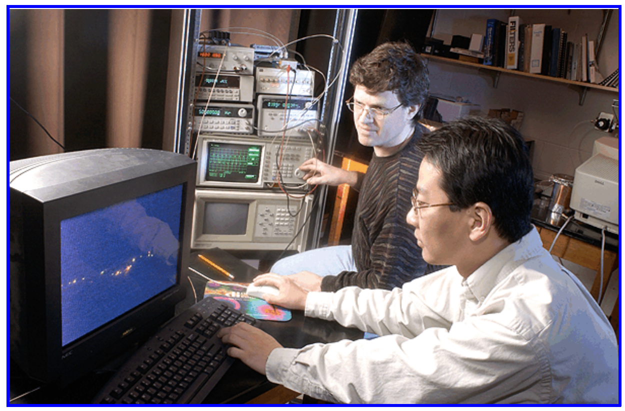
NANOCOMPUTING: SIMPLE OPTOELECTRONIC DEVICES BASED ON ELECTROLUMINESCENT SILVER NANOCLUSTERS PERFORM LOGIC OPERATIONS

Researchers at the Georgia Institute of Technology have demonstrated a new type of nanometer-scale optoelectronic device that performs addition and other complex logic operations, is simple to fabricate and produces optical output that can be read without electrical contacts.

Based on arrays of individual electroluminescent silver nanoclusters, the quantum devices could provide a foundation for new forms of specialized molecular-scale computing. The research, sponsored by the National Science Foundation, was reported in the March 18 issue of the journal *Proceedings of the National Academy of Sciences*.

"In effect, we are demonstrating optoelectronic transistor behavior," said Robert Dickson, a professor in Georgia Tech's School of Chemistry and Biochemistry. "Instead of measuring current output as in standard electronic transistors, we measure electroluminescent output for a given voltage input. Our devices act in a way that is analogous to a transistor with light as the output instead of electrical current."



Robert Dickson and Tae-Hee Lee examine a new type of nanometer-scale optoelectronic device that performs addition and other complex logic operations.

Because the nanoclusters possess different energy levels, they can be addressed individually by varying the voltage injected into the array of clusters with a simple two-terminal system. Avoiding the need for isolated electrical connections to each nanocluster makes the system far easier to fabricate at the nanometer scale than electronic devices of traditional design.

Key to the new devices developed by Dickson and collaborator Tae-Hee Lee is the specific voltages at which the clusters – which contain between two and eight silver atoms – emit light when electrically excited.

To operate, the devices require at least two separate electrical pulses, which can be varied in amplitude. Electroluminescence occurs only after the second pulse, which activates

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nanoclusters within the array depending on the voltage level to which each one responds. Because each nanocluster only responds to very specific voltages, the combined current delivered by the pulses activates only specific clusters, which are observed optically.

"By reading the emission output of two correlated molecules, we can add pulses together and perform a very simple but very important basic addition operation," Dickson noted. "The response is relatively narrow. Only when you have exactly the right voltage do you get a response. We see really clean on-off behaviors with this system."

Applying different pulses can also cause individual clusters to operate as logic gates with AND, OR, NOT and XOR functions. "By using this complicated on-off behavior and the discrete energy levels of different molecules, we can get complicated behavior in a relatively simple device," he said.

Increasing the number of clusters operating together could permit formation of large optoelectronic arrays able to perform complex operations. As long as each cluster could be separated enough to be resolved by a camera, arrays could contain thousands of clusters.

"This suggests the potential for an exciting degree of complexity," Dickson said. "If you can put molecules that have well-defined electronic energy levels into an array addressable with just two terminals, then you can begin to perform very complicated calculations."

Dickson doesn't expect the new optoelectronic devices to replace traditional semiconductor-based computers for ordinary tasks. Instead, they might be used for complex and highly specialized computations that are difficult for traditional computing systems.

"Because of the inherent parallel nature of the system and the discrete energy levels of the clusters, there may be many applications here," he said. "There is inherent beauty in this device being so simple and yet able to perform these interesting calculations. There are a lot of opportunities and challenges."

Dickson hopes the new devices will also encourage a different way of thinking about computing on the nanometer scale.

"Many people are trying to shrink electronics down to the nanometer scale and take advantage of the interesting properties that arise when you make things very small, but often they are using standard architectures to create logic circuits," he said. "We are using a novel architecture to do the same thing, but with an individual molecules with on-off behavior instead of a three-terminal device made very small. I hope that this will encourage people to think about different ways to do these operations."

One advantage of the devices – their optical signal output – also poses a challenge. Because the output signal is in optical form, it cannot be easily passed along to another device for further computing steps. Dickson hopes that challenge can be overcome, but says that for some complex computations, an image of the result may be sufficient.

Dickson and Lee create the nanoclusters by applying current to a slightly oxidized thin film of silver. The current induces electromigration, which creates a nanoscale break junction in the most resistive part of the film. The arrays of nanoclusters form along the break.

For the future, Dickson and Lee want to learn more about how the clusters form, characterize the break region -- and gain more control over the clusters' properties.

"The clusters can be different sizes, contain different numbers of atoms and form in different geometries, and those variations give the different excitation profiles and emission wavelengths," he said. "We can control where the junction forms and we are analyzing and characterizing what's there."

The devices, which operate at room temperature, perform consistently for several hours, but ultimately burn out because of heat.

In August 2002, Dickson and Lee reported in Proceedings of the National Academy of Sciences that they had created the world's smallest electroluminescent light source, using photon emissions from individual molecules of silver. The optoelectronic devices build on that earlier work.

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