beams. They also found that control of the intensity of the optical beams was critical to observing transistor-like action in the single molecule.

Sandoghdar said, "Many more years of research will still be needed before photons replace electrons in transistors. In the meantime, scientists will learn to manipulate and control quantum systems in a targeted way, moving them closer to the dream of a quantum computer." Thus component parts such as the new single molecule optical transistor may also pave the way for a quantum computer.

Mechanical Stress Leads to Self-Sensing in Solid Polymers

Parachute cords, climbing ropes, and smart coatings for bridges that change color when overstressed are several possible uses for force-sensitive polymers being developed by N. Sottos, D. Davis, and colleagues at the University of Illinois—Urbana-Champaign (UIUC). The polymers contain mechanically active molecules called mechanophores. When pushed or pulled with a certain force, specific chemical reactions are triggered in the mechanophores.

"This offers a new way to build function directly into synthetic materials," said Sottos, a Willett Professor of materials science and engineering at UIUC. "And it opens the door to creating mechanophores that can perform different responsive functions, including self-sensing and self-reinforcing, when stressed."

In previous work, Sottos and collaborators showed they could use mechanical force to induce a reaction in mechanophore-linked polymers that were in solution. Now, as reported in the May 7 issue of *Nature* (DOI: 10.1038/nature07970; p. 68), the researchers show they can perform a similar feat in a solid polymer.

The researchers used molecules called spiropyrans, a class of molecular probes that serve as color-generating mechanophores, capable of vivid color changes when they undergo mechanochemical change. Normally colorless, the spiropyran used in the experiments turns red or purple when exposed to certain levels of mechanical stress.

"Mechanical stress induces a ring-opening reaction of the spiropyran that changes the color of the material," said D. Davis, a graduate research assistant and the article's lead author. "The reaction is reversible, so we can repeat the opening and closing of the mechanophore."

To demonstrate the mechanochemical response, the researchers prepared two different mechanophore-linked polymers and subjected them to different levels of mechanical stress. In one polymer, an elastomeric mechanophore-linked poly(methyl acrylate) (PMA), the material was stretched until it broke in two. A vivid color change in the polymer occurred just before it snapped. The second polymer, a glassy mechanophore cross-linked poly(methyl methacrylate) (PMMA), was formed into rigid beads 100–500 μm in diameter. When the beads were squeezed, they changed from colorless to purple. The color change that took place within both polymers could serve as a good indicator of how much stress a mechanical part or structural component made of the material had undergone.

"We've moved very seamlessly from chemistry to materials, and from materials we are now moving into engineering applications," Sottos said. "With a deeper understanding of mechanophore design rules and efficient chemical response pathways, we envision new classes of dynamically responsive polymers that locally remodel, reorganize or even regenerate via mechanical regulation."

Working Model of a Two-Qubit Electronic Quantum Processor Developed

L. DiCarlo, J.M. Chow, L.S. Bishop, B.R. Johnson, D.I. Schuster, L. Frunzio, S.M. Girvin, and R.J. Schoelkopf of Yale University, J.M. Gambetta of the University of Waterloo, J. Majer of Vienna University of Technology, and A. Blais of the Université de Sherbrooke have implemented simple algorithms using a quantum processor based on microwave solid-state technology—similar to that found in computers and cell phones. The new processor is far from conventional, however, in that it uses the potent power of quantum mechanics to bring the dream of quantum computing a small but significant step closer to reality.

"Our experiment can only perform a few very simple quantum tasks, which have been demonstrated before using other systems such as photons, trapped ions, and nuclear magnetic resonance," said Robert Schoelkopf, a principal investigator and professor of applied physics and physics at Yale. "But this is the first time it has been done in an all-electronic device, which looks and feels much more like a regular microprocessor."

As reported in the June 28 online issue of *Nature* (DOI: 10.1038/nature08121), the research team used artificial atoms as quantum bits, or qubits. Although made from over a billion aluminum atoms in a superconducting electronic circuit, these qubits behave as single atoms. The difference is that the manufactured atoms are much larger and therefore easier to control than single atoms or other types of qubits.

The devices were fabricated on an *R*-plane α Al_2O_3 wafer with 180-nm thick Nb coplanar waveguides. The artificial atoms (qubit structures), based upon interdigitated capacitors and split-junction structures, were fabricated using double-angle evaporation of Al (20/90 nm) with intermediate oxidation.

Just like a single atom, an artificial atom can be stimulated into different energy states, akin to the "on" and "off" states of the bits in conventional computers. But following the counterintuitive laws of quantum mechanics, the scientists can also place these artificial atoms in "superpositions" of quantum states—both "off" and "on" at the same time. This wider variety of possible states allows for greater information storage and processing power.

"The success of the experiment relied on integrating three previously demonstrated capabilities," said Leonardo DiCarlo, lead author of the article. According to DiCarlo, the key building blocks included local tuning of qubits on nanosecond timescales, which enabled the researchers to switch the interaction between the qubits "on" and "off" abruptly; a joint readout scheme that efficiently reveals two-qubit correlations; and state-of-the-art coherence times of about 1 μs for both qubits.

"There have been several earlier instances of two-qubit logic gates, but to do a quantum computation, you need to be able to control single qubits, and you also need to be able to make two qubits interact," said Schoelkopf. "With this experiment we don't just operate one gate; we string together 10 one-qubit gates and 2 two-qubit gates."

"Both qubits in the two-qubit gates have to work at the same time, so you have to be able to reliably make two qubits with long coherence times," said Steve Girvin, co-author of the article and co-principal investigator. "We used a charge-based qubit, which normally would be sensitive to electrical noise. But we developed one that stays insensitive to noise for a long time, up to three microseconds."

"There's a tension between using larger-scale manmade systems like ours as qubits, which are easier to make, test and control, versus using individual atoms, which stay coherent longer, but are much more difficult to couple together in complex ways," said Schoelkopf.

"But there's an advantage to using a superconducting circuit, which is all controlled electronically," he said. "The goal is to make a scalable device, with thousands and thousands of qubits working together. This is still a long way off, but the idea of using standard integrated circuit technology makes it easier to imagine that it might be possible someday."

Although the quantum processor itself must be kept just above absolute zero in order to maintain the superconducting properties of the circuit, DiCarlo said that the rest of the system looks like a typical processor, with only wires going into the system and wires coming out.

But Schoelkopf cautions it will still be some time before solid-state quantum computers become the industry standard.

"I'm relatively optimistic that we should be able to combine three or more qubits soon," Schoelkopf said. "But to make a system which will actually perform computations on your laptop would take a thousand qubits. It's hard to see that far into the future, but this experiment is a significant step forward."

Creep in Concrete Occurs at the Nanoscale Level

M. Vandamme of Université Paris-Est and F.-J. Ulm of the Massachusetts Institute of Technology (MIT) have determined that creep in concrete is caused by the rearrangement of particles at the nanoscale. Ulm, a professor in the Department of Civil and Environmental Engineering at MIT, said, "We can't prevent creep from happening, but if we slow the rate at which it occurs, this will increase concrete's durability and prolong the life of the structures."

Previously, Ulm had discovered that the basic building block of cement paste at the nanoscale—calcium-silicate-hydrates, or C-S-H—is granular in nature. His research had demonstrated that C-S-H naturally self-assembles at two structurally distinct but chemically similar phases when mixed with water, each with a fixed packing density close to one of the two maximum densities allowed by nature for spherical objects (64% for the lower density and 74% for high).

Now, as reported in the *Proceedings of the National Academy of Sciences* online Early Edition the week of June 15 (DOI: 10.1073/pnas.0901033106), Ulm and Vandamme explain that concrete creep comes about when these nanometer-sized C-S-H particles rearrange into altered densities: some looser and others more tightly packed.

They also explain that a third, more dense phase of C-S-H can be induced by manipulating the cement mix with other minerals such as silica fumes, a waste material of the aluminum industry. These reacting fumes form additional smaller particles that fit into the spaces between the nano-granules of C-S-H, spaces that were formerly filled with water. This has the effect of increasing the density of C-S-H to up to 87%, which in turn greatly hinders the movement of the C-S-H granules over time.

The researchers show experimentally that the rate of creep is logarithmic, which means slowing creep increases durability exponentially. They demonstrate mathematically that creep can be slowed by a rate of 2.6.

Ulm said, "With this new understanding of concrete, we could produce filigree: light, elegant, strong structures that will require far less material."

An estimated 5–8% of all human-generated atmospheric CO_2 worldwide comes from the concrete industry. According to the engineers, their research may likely lead to concrete infrastructure capable of lasting hundreds of years rather than tens, which will bring enormous cost-savings and decreased concrete-related CO_2 emissions. More durable concrete means that less building material and less frequent renovations will be required.

DENISE BREHM

Bandgap Controlled in Bilayer Graphene

Graphene is the two-dimensional crystalline form of carbon, whose extraordinary electron mobility and other unique features hold great promise for nanoscale electronics and photonics. But there is a catch: Graphene has no bandgap. Now Y. Zhang of the University of California at Berkeley, F. Wang of UC–Berkeley and Lawrence Berkeley National Laboratory (LBNL), and their colleagues have engineered a bandgap in bilayer graphene that can be precisely controlled at 0–250 meV.

Moreover, the research team's experiment was conducted at room temperature, requiring no refrigeration of the device. Among the applications made possible by this breakthrough are new kinds of nanotransistors and—because of its narrow bandgap—nano-light-emitting diodes and other nanoscale optical devices in the infrared range.

As reported in the June 11 issue of *Nature* (DOI: 10.1038/nature08105; p. 820), the researchers built a two-gated bilayer device—a field-effect transistor (FET)—which is a type of transistor that controls the flow of electrons from a source to a drain with electric fields shaped by the gate electrodes. Their nano-FET used a silicon substrate as the bottom gate, with a thin insulating layer of silicon dioxide between it and the stacked graphene layers. A transparent layer of aluminum oxide lay over the graphene bilayer; on top of that was the top gate, made of platinum.

The researchers then determined the bandgap by measuring the device's optical transmission as a function of optical wavelength. They used the infrared beamline of synchrotron light from the Advanced Light Source at LBNL, focused on the graphene layers, to measure the device's optical transmission. As the researchers tuned the electrical fields by precisely varying the voltage of the gate electrodes,