face so as to physically limit the number of metal atoms that could join together in each cluster.

While measuring the properties of the clusters, the researchers found that, in one cluster, the circular dichroic effect exceeded 300 ppm in the yellow-green region. In another cluster, the effect exceeded 1000 ppm in the red and near-infrared. As reported in the researchers' article in the March 30 issue of the *Journal of Physical Chemistry*, these optical measurements suggest that the clusters have a helical structure.

Schaaff said, "Such effects had not previously been measured in metal-cluster compounds, and it's kind of a shock that small metals might prefer to have a helical structure."

Using gel electrophoresis to separate the clusters by weight, Schaaff found that certain cluster sizes dominated, with 28-atom assemblies—slightly less than 1 nm across—being the most common. The chiral properties varied by the size of the cluster and, therefore, were only observed clearly when the clusters were separated by weight.

Only clusters with 40 or fewer atoms displayed the intense optical properties. The optical effect changed direction as the researchers moved from one cluster size to the next, suggesting a direct correlation to the energies of the conduction electrons in the metal's outer shell.

Whetten, a professor in the School of Physics and School of Chemistry and Biochemistry, said, "Even though the optical absorption increases more or less monotonically here, the preferences for right- versus left-handed light changes direction from one band to another." He said that the effect may be related to the high level of confinement created in the conduction electrons by formation of the small clusters, but research has not yet confirmed this. A helical geometrical pattern or "tiling" of the glutathione adsorption sites (gold-sulfur bonds) could also affect the circulation of the conduction electrons, he said.

Feedback-Controlled Lithography Enables Molecule Manipulation on Atomic Scale

Researchers at the University of Illinois—Urbana-Champaign have tethered individual organic molecules at specific locations on silicon surfaces. Joseph Lyding, a professor of electrical and computer engineering and a researcher at the university's Beckman Institute for Advanced Science and Technology, and his research team first passivated the silicon bonds with hydrogen. They then used an ultrahigh vacuum scanning tunneling microscope to break individual silicon-hydrogen bonds and dislodge hydrogen atoms from selected sites.

Graduate student Mark Hersam said, "By removing individual hydrogen atoms, we create holes in the clean silicon surface. Since these holes—or dangling bonds—serve as effective binding sites, molecules injected in the gas phase will spontaneously self-assemble into the predefined patterns."

A technique called feedback-controlled lithography gives the patterning process an atomic precision. "Feedback-controlled lithography works by actively monitoring the microscope feedback signal and the tunneling current during patterning, and immediately terminating the patterning process when a bond is broken," Lyding said. "By operating the microscope under feedback control, a carefully controlled dose of electrons can be written along a line or over an area to locally depassivate the surface and create templates of individual dangling bonds."

As reported in the June issue of *Nanotechnology*, the researchers demonstrated the feasibility of their technique with three organic molecules: norbornadiene, copper phthalocyanine, and carbon-60 buckyballs. The researchers said that one advantage of organic molecules is that their end groups can be functionalized for potential electronic or mechanical switching properties.

Hersam said that while the technology for economically tethering billions of molecular devices on a chip surface does not yet exist, they can fabricate small numbers of the devices and test their function. He said, "This is an important step in bridging the gap between molecular electronics and silicon technology."

Single-Isotope Silicon Helps Chips Keep Their Cool

In Vol. 15 of *Solid State Communications*, a research group from the Max Planck Institute for Solid State Research in Stuttgart reports a substantial enhancement of the thermal conductivity in a bulk silicon crystal made from only one isotope (^{28}Si). At room temperature, single-isotope silicon (SISSI) is a 60% better heat conductor than natural silicon, which consists of three stable isotopes: 92.2% ^{28}Si, 4.7% ^{29}Si, and 3.1% ^{30}Si. At 77 K, the temperature of liquid nitrogen, the enhancement amounts to a factor of 2.4, while at 20 K, where the thermal conductivity has its maximum, it is close to a factor of 6. The maximum thermal conductivity of SISSI (30,000 $Wm^{-1}K^{-1}$) exceeds that of the best natural heat conductor, namely diamond, by a factor of 2.5.

The thermal conductivity enhancement in SISSI is based on the fact that phonons, the quantized lattice vibrations, are scattered by fluctuations of their atomic masses, as present in most conventional crystals, which contain a mixture of different stable isotopes. The suppression of this scattering in isotopically enriched crystals results in an enhancement of the thermal conductivity that can be strong. For example, the removal of about 8% of the "isotopic impurities" (present in natural silicon) in the nominally isotopically pure SISSI crystal (enriched to 99.8588% ^{28}Si) investigated by the researchers is sufficient to increase the thermal conductivity by almost an order of magnitude. The thermal-conductivity enhancement varies with temperature due to the presence of other phonon-scattering mechanisms, such as boundary scattering (at low temperatures) and "umklapp" scattering (at high temperatures).

Hysteresis and Spikes Observed in Quantum Hall Effect

Researchers at Columbia University and Bell Laboratories have recently observed strong hysteresis and the formation of sharp peaks in the integral quantum Hall effect (IQHE) in magneto transport experiments on two-dimensional electron gas (2DEG) at ~0.1 K. The researchers used 300-Å-wide quantum-well structures of modulation-doped GaAs/AlGaAs, grown by molecular-beam epitaxy (MBE). The well is δ-doped on both sides with silicon impurities at a distance of 950 Å and 750 Å for two different types of samples; the density is 2.3×10^{11} cm^{-2} and 3.2×10^{11} cm^{-2}, respectively. The researchers performed transport measurements using standard lock-in techniques in a dilution refrigerator with a base temperature of 70 mK. The results are similar for both ac and dc current.

The hysteretic spikes on the magnetoresistance R_{xx} are most pronounced at integral filling factors υ between 3 and 12, and the details of the hysteresis vary among the peaks. The time scale of the peak decay is in the range of minutes to several hours, which is enormously long for 2DEG resistance decay. Momentary grounding of the contacts, however, causes a dramatic decrease in the amplitude of the peaks, suggesting the presence of a nonuniform, nonequilibrium configuration in the specimen. In addition, the hysteresis and peaks disappear if a negative voltage bias is applied to the gate at the back of the sample.

The researchers conclude, in the May 15 issue of *Physical Review B*, that there exists a parallel conducting path in the form of a low-density, disordered, two-