experimentalist, teamed up with Monica Olvera de la Cruz, a theoretician at Northwestern, to evaluate this technique. Given a set of nanoparticles and a specific type of DNA, Olvera de la Cruz showed they can accurately predict the three-dimensional structure, or crystal shape, into which the disordered components will self-assemble.

In the study, strands of complementary DNA act as bonds between disordered gold nanoparticles, transforming them into an orderly crystal. The researchers determined that the ratio of the DNA linker's length to the size of the nanoparticle is critical.

The ratio affects the energy of the faces of the crystals, which determines the final crystal shape. Ratios that do not follow the recipe lead to large fluctuations in energy and result in a sphere, not a faceted crystal, Olvera de la Cruz said. With the correct ratio, the energies fluctuate less and result in a crystal every time.

To achieve a self-assembled single crystal, the research team took two sets of gold nanoparticles functionalized with complementary DNA linker strands. Working with approximately 1 million nanoparticles in water, they heated the solution to a temperature just above the DNA linkers' melting point and then slowly cooled the solution to room temperature, over a period of two to three days.

The very slow cooling process encouraged the single-stranded DNA to find its complement, resulting in a high-quality single crystal approximately 3 μm in size.

The researchers determined that the length of DNA connected to each gold nanoparticle cannot be much longer than the size of the nanoparticle. In the study, the gold nanoparticles varied from 5 nm to 20 nm in diameter; for each, the DNA length that led to crystal formation was about 18 base pairs and six single-base "sticky ends."

"There's no reason we can't grow extraordinarily large single crystals in the future using modifications of our technique," said Mirkin.

Magnetic moment of single holmium atoms stabilized by symmetry

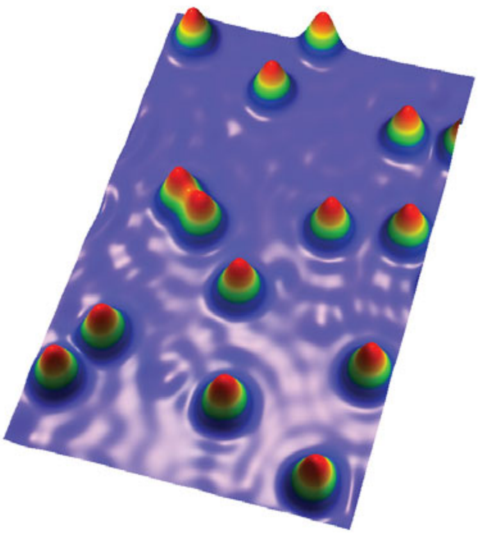
Single or assemblies of magnetic atoms positioned on non-magnetic substrates have great potential in high density magnetic data storage and quantum computing applications. However, they suffer the limitation that the magnetic moments of these atoms are easily destabilized by interactions with the substrate, resulting in very short lifetimes.

An international team including researchers from Karlsruhe Institute of Technology (KIT), the Max Planck Institute (MPI) of Microstructure Physics in Halle, the University of Leipzig, Germany, and the University of Tokyo, Japan, have now found a route to overcome this problem, as described in November 14 issue of Nature (DOI:10.1038/nature12759; p. 242). An individual holmium atom was fixed to a metal surface so that the spin of one holmium electron remains stable for more than 10 minutes. The spin can be descriptively understood as a rotation direction of an electron, giving it a magnetic moment that can align itself in a particular direction in an external magnetic field. A network of several hundred million atoms is necessary for a magnetic bit to remain stable enough for hard disk data to remain safe for years.

"One individual atom fixed to a substrate is usually so sensitive that it keeps its magnetic orientation for mere fractions of a microsecond (200 nanoseconds)," said co-author Wulf Wulfhekel from KIT. Their current research, Wulfhekel said, "not only opens the door to denser computer storage devices, but could also lay the foundation for constructing quantum computers."

In their latest experiment, the researchers placed one individual atom of the rare-earth metal holmium onto a platinum substrate. At temperatures around –272°C, they used scanning tunneling microscopy to measure how the spin of the atom and thus its magnetic moment aligns. They observed that it was almost 10 minutes before the magnetic moment changed its direction. "So once the system has established its magnetic spin, it keeps it for a billion times longer than comparable atomic systems," said Wulfhekel.

Normally, the electrons of the substrate and the atom interact frequently with each other on the quantum mechanical level and destabilize the spin of the atom in microseconds or faster. Holmium and platinum form a quantum system whose symmetry properties switch off the interfering interactions at very low temperatures. "Basically, holmium and platinum are mutually invisible, as far as the spin scattering is concerned," said Arthur Ernst of MPI in Halle and the University of Leipzig. With the aid of external magnetic fields, however, it is possible to align the spin of the holmium and thus to write information. This is precisely what the team of researchers now wants to attempt. If they are successful, this would lay the foundations for the development of compact data-storage devices or quantum computers. ☐


Individual atoms can store data: The image taken by a scanning tunneling microscope shows holmium atoms on a platinum surface. In this quantum system, the spins and thus the magnetic moments of individual holmium atoms remain stable for more than 10 minutes. This creates the basis for storing one data bit in an individual spin. © KIT.