Prediction of intrinsic magnetism at silicon surfaces could lead to single-spin magnetoelectronics

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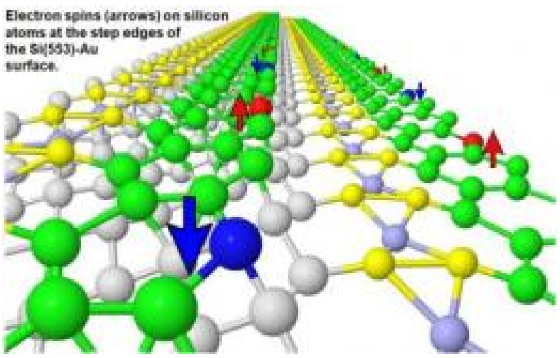


Electron spins (arrows) on silicon atoms at the step edges of the Si(553)-Au surface. Credit: Naval Research Laboratory

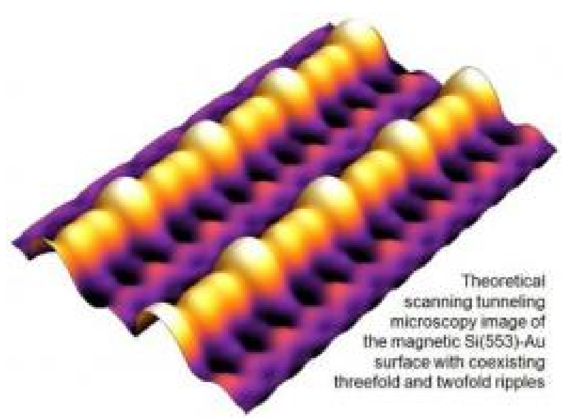
The integration of single-spin magnetoelectronics into standard silicon technology may soon be possible, if experiments confirm a new theoretical prediction by physicists at the Naval Research Laboratory and the University of Wisconsin-Madison.

The researchers predict that a family of well-known silicon surfaces, stabilized by small amounts of gold atoms, is intrinsically magnetic despite having no magnetic elements. None of these surfaces has yet been investigated experimentally for magnetism, but the new predictions are already supported indirectly by existing data. The complete findings of the study are published in the August 24, 2010, issue of the journal

Nature Communications.

Silicon provides a unique entry point for combining magnetoelectronics based on single spins with standard electronics technology. If a single-spin device can be built on a silicon wafer, input and output electronics can be directly integrated with the magnetic part of the device. This has been an obstacle for current spintronics approaches. For example, spin injection from a metal into silicon is very inefficient unless the metal/semiconductor interface is carefully optimized.

These latest results have the advantage that nature itself guides, by a self-assembly process, the formation of long chains of polarized electron spins with atomically precise structural order. "This integration of structural and magnetic order is crucial for future technologies based on single spins at the atomic level" said Dr. Steven Erwin, a physicist at NRL and lead theorist on the project.



This is a theoretical scanning tunneling microscopy image of the magnetic Si(553)-Au surface with coexisting threefold and twofold ripples. Credit: Naval Research Laboratory

The magnetic silicon surfaces, one of which is illustrated here, naturally form steps which are stabilized by chains of gold atoms (yellow). According to the team's calculations, some of the silicon atoms at the step edges have unpaired electrons that are fully spin polarized and probably magnetically ordered at sufficiently low temperatures.

The atom chains on the Si(553)-Au surface were discovered in the group of co-author Dr. Franz Himpsel at the University of Wisconsin-Madison. Several other groups worldwide have been investigating such "one-dimensional" silicon surfaces in recent years. As Himpsel noted, "The idea of creating magnetism in a nonmagnetic material by manipulating its structure has long intrigued scientists. The hope of realizing this idea in silicon has been widely discussed for decades, but so far none of these speculations has held up under scrutiny."

The work of Erwin and Himpsel suggests several experiments, such as spin-polarized scanning tunneling microscopy, to test their predictions directly. But there is already indirect experimental evidence to support the possibility of magnetism at silicon surfaces.

Two research groups, at Yonsei University in Korea and at Oak Ridge National Laboratory in the US, have found that Si(553)-Au develops periodic "ripples" with two different periodicities at low temperatures. One ripple occurs along the silicon step edges with three times the normal periodicity, and the other along the gold chains with two times the normal periodicity. The prediction of Erwin and Himpsel, shown here, reproduces this pattern perfectly. Moreover, this pattern only emerges when magnetism is allowed in the calculation. When magnetism is "turned off" in the theory, the ripples completely vanish. Thus the observation of threefold and twofold ripples offers indirect - if preliminary - confirmation of magnetism.

Linear chains of spin-polarized atoms provide atomically perfect templates for the ultimate memory and logic, in which a single spin represents a bit. One potential application is a "spin shift register" recently proposed theoretically by Gerald D. Mahan, a theoretical physicist at Pennsylvania State University. Another application is the storage of information in single magnetic atoms. Erwin and Himpsel's work also predicts that the magnitude, and even the sign, of the spin coupling can be changed by doping electrons or holes into surface states.

The closely related Si(111)-Au surface can be electron-doped by adsorbates (for example, silicon adatoms) on the surface. By varying this adsorbate population one can perform band-structure engineering with extraordinary precision. The possibility of tuning surface magnetism on Si(553)-Au and its relatives using surface chemistry suggests a fascinating new research direction.

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Provided by Naval Research Laboratory