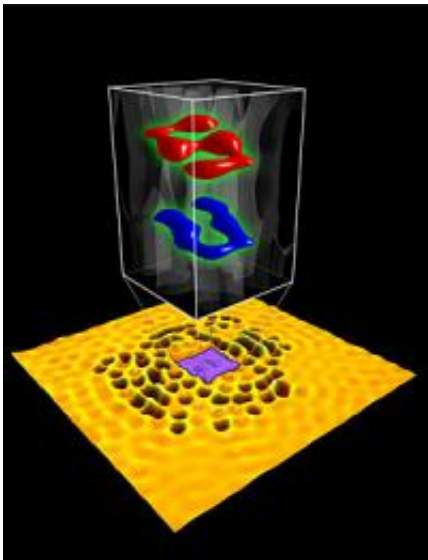


Sub-atomic-scale Writing Using a Quantum Hologram Sets New Size Record (Video)

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The initials for Stanford University are written in electron waves on a piece of copper and projected into a tiny hologram.

(PhysOrg.com) -- Physicists have set a new world record for the smallest writing, with features of letters as small as 0.3 nanometers, or roughly one third of a billionth of a meter. The accomplishment demonstrates that information can be stored more densely than previously thought. The research was conducted at the Stanford Institute for Materials and Energy Sciences (SIMES), a joint institute of Stanford University and the U.S. Department of Energy's SLAC National Accelerator Laboratory.

In achieving this feat, Stanford researchers have reclaimed bragging rights for creating the world's smallest writing, a distinction the university first gained in 1985 and lost in 1990.

The researchers encoded the letters "S" and "U" (as in Stanford University) within the interference patterns formed by quantum electron waves on the surface of a sliver of copper. The wave patterns even project a tiny hologram of the data, which can be viewed with a powerful microscope.

"How densely can you encode information on a computer chip?" said Hari Manoharan the assistant professor of physics who directed the work of physics graduate student Chris Moon and other researchers. "The assumption has been that basically the ultimate limit is when one atom represents one bit, and then there's no more room—in other words it's impossible to scale down below the level of atoms. But in this experiment we've stored some 35 bits per electron to encode each letter. So one bit per atom is no longer the limit for information density."

The quest for small writing has played a role in the development of nanotechnology for 50 years, beginning decades before "nano" became a household word. During a now-legendary talk in 1959, the remarkable physicist Richard Feynman argued that there were no physical barriers preventing machines and circuitry from being shrunk drastically. He called his talk, "There's Plenty of Room at the Bottom."

Feynman offered a \$1,000 prize for anyone who could find a way to rewrite a page from an ordinary book in text 25,000 times smaller than the usual size (a scale at which the entire contents of the Encyclopedia Britannica would fit on the head of a pin). He held onto his money until 1985, when he mailed a check to Stanford grad student Tom Newman, who, working with Electrical Engineering Professor Fabian Pease, used

electron beam lithography to engrave the opening page of Dickens' *A Tale of Two Cities* in such small print that it could be read only with an electron microscope.

That record held until 1990, when IBM researchers famously spelled out the letters of their company name by arranging 35 individual xenon atoms.

Now, in a paper published online Sunday in the journal *Nature Nanotechnology*, the researchers describe how they've created letters one fortieth the size of the original prize winning effort and less than one quarter of the size of the IBM initials.

Working in a vibration-proof basement lab, Manoharan and Moon began their writing project with a scanning tunneling microscope, a device that not only sees objects at a very small scale but can also be used to move around individual atoms. The team used it to drag single carbon monoxide molecules into a desired pattern on a copper chip the size of a fingernail.

On the two-dimensional surface of the copper, electrons zip around, behaving as both particles and waves, bouncing off the carbon monoxide molecules the way ripples in a shallow pond might interact with stones placed in the water. The ever-moving waves interact with the molecules and with each other to form standing "interference patterns" that vary with the placement of the molecules.

By altering the arrangement of the molecules, the researchers can create different waveforms, effectively encoding information for later retrieval. To encode and read out the data at unprecedented density, the scientists have devised a new technology, Electronic Quantum Holography.

In a traditional hologram, laser light is shined on a 2-dimensional image and a ghostly 3D object appears. In the new holography, the 2-dimensional "molecular holograms" are illuminated not by laser light but by the electrons that are already in the copper in great abundance. The resulting "electronic object" can be read with the scanning tunneling microscope.

Several images can be stored in the same hologram, each created at a different electron wavelength. The researchers read them separately, like stacked pages of a book. The experience, Moon said, is roughly analogous to an optical hologram that shows one object when illuminated with red light and a different object in green light.

For Manoharan, the true significance of the work lies in storing more information in less space. "We miniaturized their size so drastically that we ended up with the smallest writing in history. And we write the letters so small that the bits that comprise them are subatomic in size," he said. "There's a grand new horizon below, in the subatomic regime. Indeed, there's even more room at the bottom than we ever imagined."

In addition to Moon and Manoharan, authors of the *Nature Nanotechnology* paper, "Quantum Holographic Encoding in a Two-Dimensional Electron Gas," are physics graduate student Laila Mattos, electrical engineering graduate student Brian Foster and applied physics graduate student Gabriel Zeltzer.

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Provided by Stanford University

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