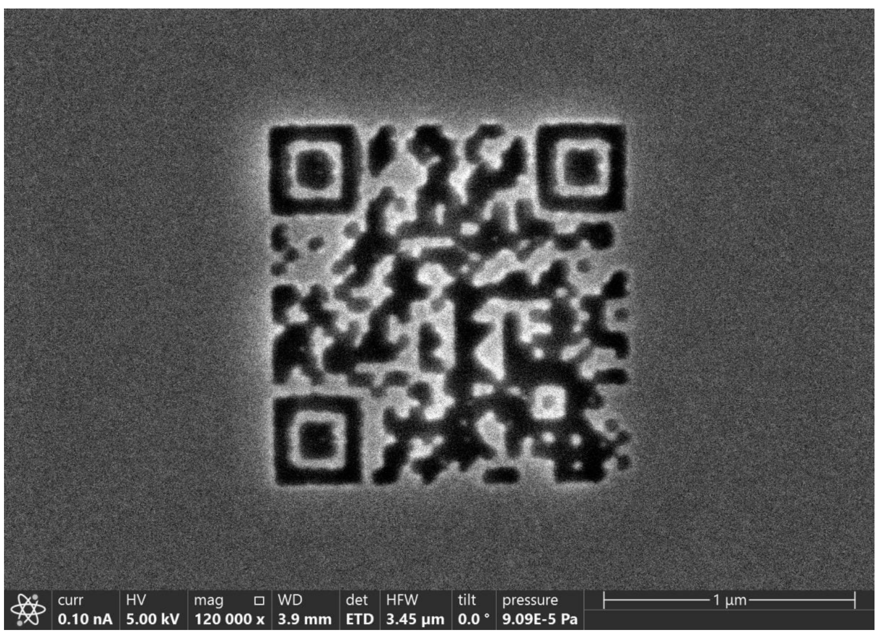
Scientists create the world's smallest QR code, visible only under an electron microscope.

Scientists at TU Wien have created the world's smallest QR code, measuring just 1.98 square micrometers and requiring an electron microscope to read. This ceramic storage technology opens up a future of sustainable data that doesn't require electricity.

How small can a QR code be? Researchers have just pushed the limits to the extreme: so small that it can only be observed with an electron microscope. A team of scientists at TU Wien, in collaboration with data storage company Cerabyte, created a QR code that is just 1.98 square micrometers wide – smaller than most bacteria. This achievement has been officially confirmed and entered into the Guinness World Records.

Beyond simply setting a record for size, the project also opens up a new approach to one of the biggest challenges of the digital age: sustainable data storage. Traditional magnetic and electronic storage devices typically only maintain data stability for a few years before degrading. Meanwhile, encoding information directly into ceramic materials could help data last for hundreds, even thousands of years.



When atomic precision is combined with long-term durability.

According to Professor Paul Mayrhofer from the Institute of Materials Science and Technology at TU Wien, the structure the team created is so sophisticated that it is completely invisible under an optical microscope. However, the most remarkable aspect is not just its small size. Today, fabricating structures at the micrometer scale, even models from individual atoms, is no longer a novelty. The problem lies in the fact that these microscopic structures are often not stable enough to store information long-term and be reliably read back.

At extremely small sizes, atoms can shift or spread to neighboring regions, causing information to fade over time. The research team emphasized that they took a different approach: creating an extremely small QR code that is still stable and can be read repeatedly.

Ultrathin ceramic membranes pave the way for high-density storage.

The key element of the project lay in the materials. The team used thin ceramic films – typically used to coat high-performance cutting tools. For industrial tools, the material must maintain durability and stability even under harsh conditions. This characteristic also makes them ideal candidates for long-term data storage.

To engrave QR codes, scientists use a focused ion beam, creating individual pixels measuring just 49 nanometers—about 10 times smaller than the wavelength of visible light. Therefore, this structure cannot be observed with a conventional optical microscope—similar to how Braille cannot be seen through the thick sole of an elephant's foot. However, under an electron microscope, the QR code appears clear and can be read accurately.

Thanks to this technique, data density reaches extremely high levels. In theory, more than 2 terabytes of data can be stored on an area equivalent to a sheet of A4 paper. Unlike traditional storage technologies, ceramic materials can maintain a stable state for very long periods without requiring a continuous power supply to preserve data.

According to Alexander Kirnbauer, we live in the information age but store knowledge on media with surprisingly short lifespans. Many magnetic and electronic storage systems begin to lose data after only a few years. Without a sustained power supply, cooling system, and regular backups to new devices, valuable information can be lost.

In contrast, ancient civilizations inscribed information onto stone, leaving behind messages that lasted for millennia. Storing data on ceramics follows a similar philosophy: recording data on an inert, durable material that can withstand the ravages of time and remain traceable in the future.

Another key advantage is that ceramic-based storage doesn't rely on electricity or cooling systems. Meanwhile, modern data centers consume enormous amounts of electricity and contribute significantly to global CO? emissions. Therefore, energy-efficient storage solutions are a promising direction.

According to the research team, this is just the beginning. In the future, they aim to test more types of materials, increase data recording speed, and develop a scalable manufacturing process. Their goals extend beyond the laboratory to industrial applications. They are also researching ways to record data structures far more complex than QR codes, with high durability, speed, and optimal energy efficiency.

Demonstrating that information can be stored long-term in sustainable ceramic materials opens up new prospects for the future of data: safer, more sustainable, and far more energy-efficient than current solutions.

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