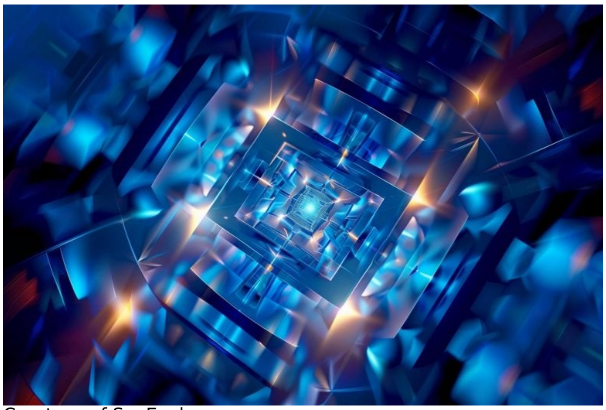
The Brilliant Mystery of Next-Gen Quantum Technology

Posted by Okachinepa 10/21/2024

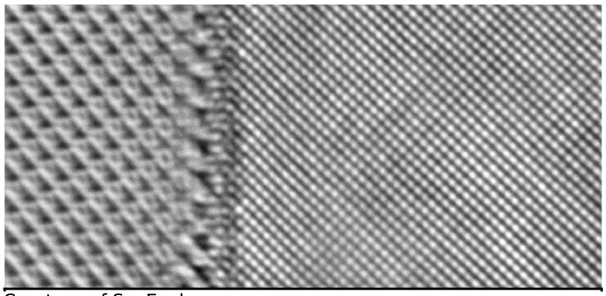


Courtesy of SynEvol
Credit: University of Chicago

Due to its extreme durability, rigidity, and thermal conductivity, synthetic diamond is a material that is well suited for use in both conventional and quantum electronics. It has great qualities for these uses and is chemically stable. The main obstacle is that diamonds can only grow on other diamonds.

Because of this property, called homoepitaxy, using diamonds in technologies such as quantum computers, sensors, telephones, and other gadgets means that either the technology's full potential has to be sacrificed or it has to rely on big, costly diamond chunks.

According to UChicago Pritzker School of Molecular Engineering (PME) Associate Professor Alex High, "Diamond stands alone in terms of its material properties, both for electronics—with its wide band gap, very best thermal conductivity, and exceptional dielectric strength—and for quantum technologies—it hosts nitrogen vacancy centers that are the gold standard for quantum sensing at room temperature." "But it's actually pretty bad as a platform."



Courtesy of SynEvol

Credit: UChicago Pritzer School of Molecular Engineering

A significant challenge for researchers working with diamonds has been resolved by a paper from UChicago PME's High Lab and Argonne National Laboratory that was published on October 10 in Nature Communications. This technique creates a novel way of bonding diamonds directly to materials that integrate easily with either quantum or conventional electronics.

"We provide a surface treatment to the carrier and diamond substrates, which increases their mutual attraction. The two extremely flat surfaces will be glued together by making sure we have a pristine surface roughness," added first author Xinghan Guo, who received his PhD from UChicago PME in the spring. An annealing procedure strengthens and improves the connection. Our diamond can therefore withstand a variety of nanofabrication procedures. It sets our procedure apart from just putting a diamond on top of another substance.

Using this method, the researchers fused silicon, fused silica, sapphire, thermal oxide, and lithium niobate to diamond directly without the need of a "glue" material in between.

For advanced quantum applications, the researchers bonded crystalline membranes as thin as 100 nanometers, while preserving spin coherence, in place of bulk diamonds that are normally several hundred microns thick and are used to study quantum qubits.

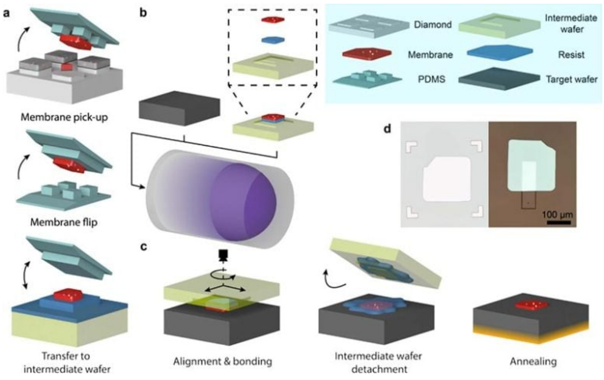
Quantum researchers, as opposed to jewelers, like a diamond with a little imperfection. Researchers are able to construct robust qubits that are perfect for quantum computing, quantum sensing, and other applications by carefully designing flaws in the crystal lattice.

"Diamond has a broad bandgap. It is not active. It's really well-behaved and has excellent thermal and electrical properties, according to F. Joseph Heremans, co-author of the paper and dual employee of Argonne and UChicago PME. Its basic physical characteristics meet several requirements that are advantageous to many different fields. Simply put, integrating with different materials was exceedingly challenging up until now.

However, this required larger—though still microscopic—chunks of the material, as thin diamond membranes were previously impossible to integrate directly into devices. Fourth-year UChicago Engineering student Avery Linder, co-author of the paper, likened the process of creating sensitive quantum devices from these diamonds to attempting to manufacture a single grilled cheese sandwich out of an entire block of cheddar cheese.

Co-author of the article, UChicago PME Assistant Professor Peter Maurer, specializes in quantum biosensing and uses cutting-edge quantum techniques to detect basic biological processes more precisely and precisely at the micro- and nanoscale.

"The integration of diamond-based quantum sensors into real measurement devices, like a commercial microscope or a diagnostic device, has remained an outstanding challenge, even though we have overcome many challenges related to the interface of intact biological targets with these sensors." Maurer stated. "Many of these problems have been resolved by the new work Alex's lab is leading with diamond membrane bonding, which takes us a significant step closer to applications."



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Credit: UChicago Pritzer School of Molecular Engineering

Each carbon atom in a diamond shares four electrons with four other carbon atoms. The hard, long-lasting interior structure of the gem is derived from these covalent bonds, or electron-sharing connections.

However, this results in what are known as "dangling bonds" on lone atoms searching for a mate if there isn't another carbon atom nearby to share electrons with. The scientists were able to directly link the nanometer-scale diamond wafers to other surfaces by producing a diamond surface full of these dangling bonds.

Due to its desire to adhere to another object, Linder suggested that it be compared to a sticky surface. Thus, in essence, we have created sticky surfaces and assembled them.

"This new method could have a big impact on how we manufacture quantum, and even phones or computers," Linder stated.

The development of complementary metal-oxide semiconductors (CMOS) from large individual transistors in labs in the 1940s to the potent, compact integrated circuits found in modern computers and phones is what High compares the new diamond technology to.

"We're hoping that something akin to a CMOS-style revolution for diamond-based quantum technologies can result from our ability to generate these thin films and integrate them in a scalable fashion," he stated.