RESEARCH NEWS

Quantum sensor technology

"From quantum sensors to quantum computers"

Prof. Oliver Ambacher, head of the Fraunhofer Institute for Applied Solid State Physics IAF in Freiburg, on the potential applications of quantum sensor technology and the role it plays in quantum computing.

Mr. Ambacher, your institute is conducting extensive research in the field of quantum sensor technology. What's so special about this technology?

Ambacher: Quantum sensors are very small and sensitive, so they can measure the tiniest of signals with extreme spatial resolution. This is important, for example, for testing nanoelectronic circuits in the semiconductor industry. Currently, it can be very difficult to troubleshoot circuits that don't work. We are developing diamond-based quantum sensors, which additionally have the advantage that they function at room temperature. This is an important prerequisite for market acceptance of quantum sensors.

In what other areas might quantum sensors also be of interest?

Quantum sensor technology can also be used in medicine. Currently, brain waves are measured with the aid of superconductors, which require complex cooling with liquid helium and very large machines. With quantum sensors, it could one day be possible to perform these measurements using only a thin sensor film on the head instead of a bulky cap. This would not only put less strain on patients, but the procedure would also be more cost-effective for hospitals.

When might we see large-scale use of quantum sensors?

Superconducting sensors are already being used in medicine to detect brain injuries or brain tumors, or to measure brain activity following a stroke. Quantum sensor technology has already caught on in nanoelectronics, too, for performing fault analysis on modern electronic circuits. We are actually already in the second generation of quantum technology, and now we are asking ourselves things like: Where is there still room for additional improvement? What does industry need? What other applications can we develop?

And where is there still room for improvement?

In cooling, for example: we are currently working extremely hard to enable quantum sensors to be used at room temperature. This would broaden the fields of application

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and facilitate integration into industrial processes. We use diamond because carbon is very light and very strongly bound in the crystal. With a nitrogen-vacancy center, we trap a single electron in the diamond lattice, where we position and control it. The electron is our sensor for detecting weak magnetic fields. The interaction between the electron and the vibrating carbon atoms in diamond is very weak, which is why, once the electron is positioned, we can keep it in that position for a very long time and use it for measuring. The challenge here is that the crystals in which the electrons are trapped must be of the highest quality. Among a billion atoms, there must be no more than one atomic defect. This necessitates a high art of crystal growth.

Since the start of the year, you have been building an application lab for quantum sensor technology at Fraunhofer IAF. What exactly is happening there?

We are setting up three user-friendly quantum sensor systems that industrial companies or other research institutes can use for their projects. We hope this will give us many new ideas for potential areas of application. When we learn directly from customers what their needs are, we can take those into account in later optimization steps.

What role do quantum sensors play in quantum computers?

Our quantum sensor is essentially a qubit, as the sensor electron in the diamond has two quantum mechanical states. Thus, like a qubit, it is a two-level system that can be quantum mechanically controlled and manipulated. While we use a single qubit as a measuring instrument in sensor technology, in quantum computers, we would have to place 50 or 100 next to each other in an array in order to build a memory chip or a processor. Since the same competences are required for both, our lighthouse project on quantum magnetometry has created the ideal conditions for successfully advancing this development also in pursuit of making quantum computers a reality.

Fraunhofer launched a quantum computing initiative with IBM this year to advance the research on that in Germany. Quantum computers are still being built in the US and China. What does Germany or Europe have to offer in terms of hardware to counter this?

We mustn't forget that key components, including parts of the quantum processors and microwave amplifiers in the IBM quantum computer, are built in Europe and Germany. There is a rich ecosystem of research groups, start-ups, SMEs and large companies with extensive expertise in quantum computing here. We definitely don't have to hide. What we still lack is a joint initiative. We need to pool our expertise to jointly develop and demonstrate a successful European quantum computer.

What will the European quantum computer then be able to do that the market doesn't offer yet?

We can already see limitations in the existing quantum computers, such as the complexity of their processors. They're also not even close to being scalable. Although superconducting quantum computers are currently the most powerful computers in existence, their high error rate prevents them from exceeding 50–100 qubits – far too few to compute future optimization algorithms. In addition, their architecture needs to be tailored to the application. Many imagine that we're going to have "the" quantum computer, but I don't see it that way. I think it's going to be a hybrid – in other words, a quantum computer module that can be built into a conventional PC. You will then use your conventional PC, and when you have problems that it can't solve, you can switch on your quantum computing module. This module must then be optimized for your specific application.

Fraunhofer has had access to an IBM quantum computer since April 2020. What do you expect this access to yield?

The IBM quantum computer will significantly boost our learning curve, as it allows us to directly test initial applications. If you think about conventional computers, Microsoft eventually managed to create a software that gives users a convenient way to write letters or edit images. Now we have to do the same for quantum computers to make them useful for a broad user base. We need access to the IBM quantum computer to enable us to even build and operate the next generation for ourselves. That's why this initiative is important and appropriate.

The cooperation initially runs until 2024. What happens after that?

Fraunhofer has already pieced much of the puzzle together, from optics, to electronics, to software development. With the national Fraunhofer Center for Quantum Computing and its regional competence centers, we can again drive extensive developments in all of these areas. We are also currently in intensive exchange with the Max Planck Society and the Helmholtz Association. Our pooled expertise would cover everything from basic research to application. If our best researchers join forces across organizations and disciplines, I'm convinced that, together with additional partners, we can build a European quantum computer in a couple of years.
The interview was conducted by Mandy Bartel.

Picture 1: Prof. Oliver Ambacher, head of the Fraunhofer Institute for Applied Solid State Physics IAF in Freiburg.

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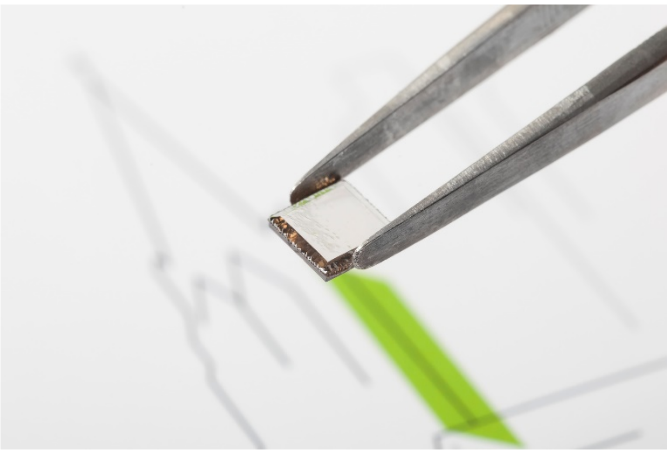

Picture 2: Components based on diamond plates don't rely on extensive cooling: they will enable future quantum computers to be used at room temperature.

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