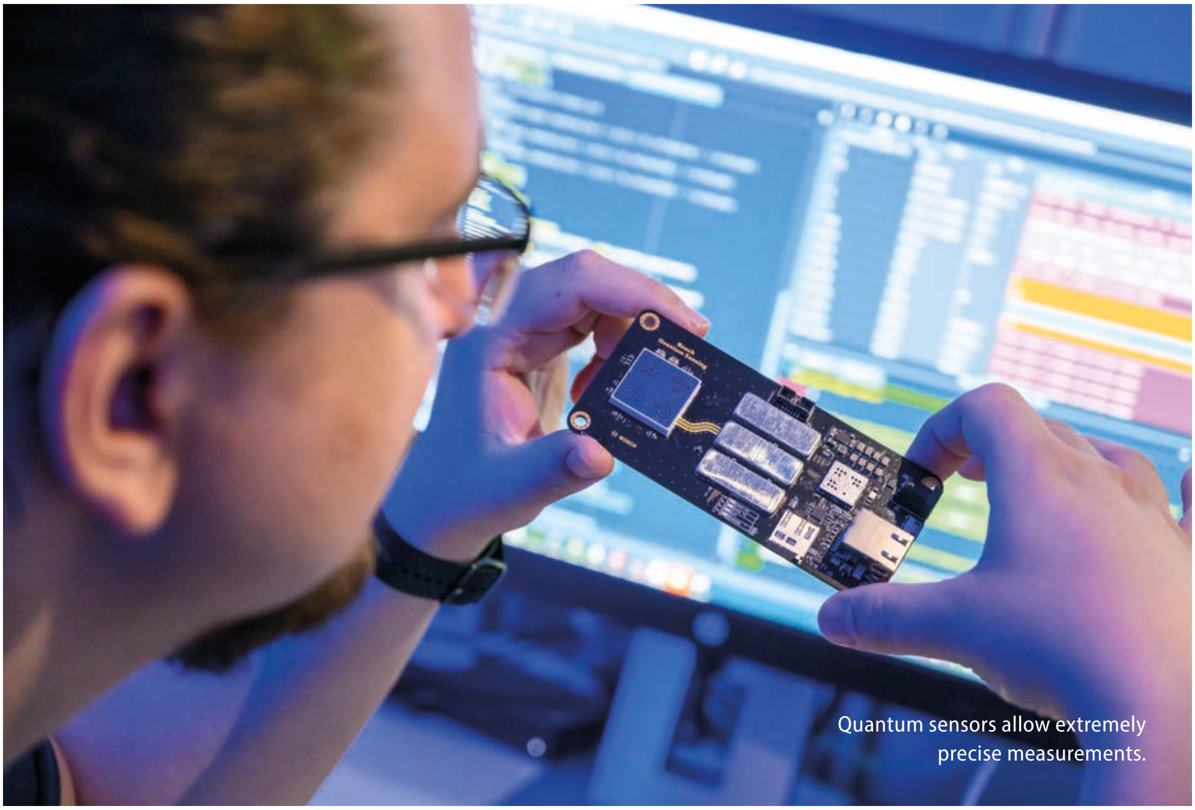

Quantum sensors allow extremely precise measurements.

Quantum sensors with unprecedented precision

Robust and compact solutions provide accuracy and sensitivity for many applications including medical science, navigation, and brain computer interfaces.

Katrin Kobe

The impact of quantum sensing is just as significant as the one expected from quantum computing. Quantum sensors promise an accuracy 1,000 times greater than that provided by today's conventional sensors, opening up new applications in medicine, navigation and more. And quantum sensing is closer to market readiness than quantum computing.

Classical physics describes the macroscopic world, quantum mechanics introduces some counterintuitive concepts. Taking advantage of quantum properties, quantum sensors become sensitive to the smallest changes in the environment. This new generation of sensors achieves an incredible precision by its initialization and its ability to detect individual quantum states. For example, using green laser light to excite electrons in a synthetic diamond target and looking at the number of emitted photons provides a photonics-based system to measure magnetic field strengths.

Today's widely available sensors are already exceptionally accurate – but quantum sensing will deliver measurements that are a thousand times more precise, like some prototype sensors have shown. Sensors based on quantum technology will be compact, robust, and have a wide measurement range.

A new generation

Computers, data networks and lasers use quantum technology every day. These systems of 'GenO' (old) are based on properties that arise from an interacting ensemble of atoms. These 'GenO' quantum devices exploited quantum effects in material systems, such as band gaps in semiconductors. They led to the development of transistors and semiconductor lasers in the last century. The new developments in quantum sensing are based on 'GenN' (new) principles: they focus on individual, specially prepared quantum states to achieve breakthrough precision. State-of-the-art knowledge of quantum physics helps to develop application-specific quantum systems. Individual quantum entities – such as individual atoms, ions or defects in solids – act as extremely sensitive quantum measurement units if they are specifically addressed and utilized. 'GenN' enables extremely sensitive, compact, and robust sensors with higher spatial resolution, higher sensitivity and an extremely wide measurement range.

Today, superconducting quantum interference devices (SQUIDs) and optical traps are bulky systems: they require cryogenic cooling or vacuum for operation. New approaches using alkali gas cells and diamonds with nitrogen vacancy (NV) centers take advantage of economies of scale and become much smaller – holding great promise for cost-sensitive, high-volume applications.

Quantum sensing in practice

Bosch Quantum Sensing is an internal start-up established at the beginning of 2022 following many years of research activity that has developed a quantum magnetometer to measure tiny magnetic fields. This ability is useful because any electrical activity generates a magnetic field, however small it may be. In the long term, this might help to observe the electrical activity in a brain. Bosch Quantum Sensing's prototype magnetometer uses a diamond target with nitrogen atoms added as a defect, the so-called NV centers. In this excellent material, the extra nitrogen atoms provide extra electrons acting as tiny magnetic field-sensing elements.

In addition, the NV centers change the diamond's specific optical and electronic properties: Green laser light excites the electrons to a higher energy level, which then return to their ground state and emit photons. These are visible as red light and are detected by a photodiode.

The energy levels of the NV center are sensitive to changes in the external magnetic field. By this key phenomenon, they function as a magnetometer due to the Zeeman effect. These levels are accessible by microwave radiation. When electrons occupy these specific energy levels and are then excited with green laser light, electrons will no longer decay under emission of red phonons but stay 'dark'. Hence, varying the frequency of the microwave, and thus its energy, and looking at the intensity of red light that the diamond emits allows the determination of the external magnetic field strength.

New applications

The precision of quantum sensing opens up entirely new applications – from the analysis of the ground beneath our feet and the exploration for mineral resources to medical

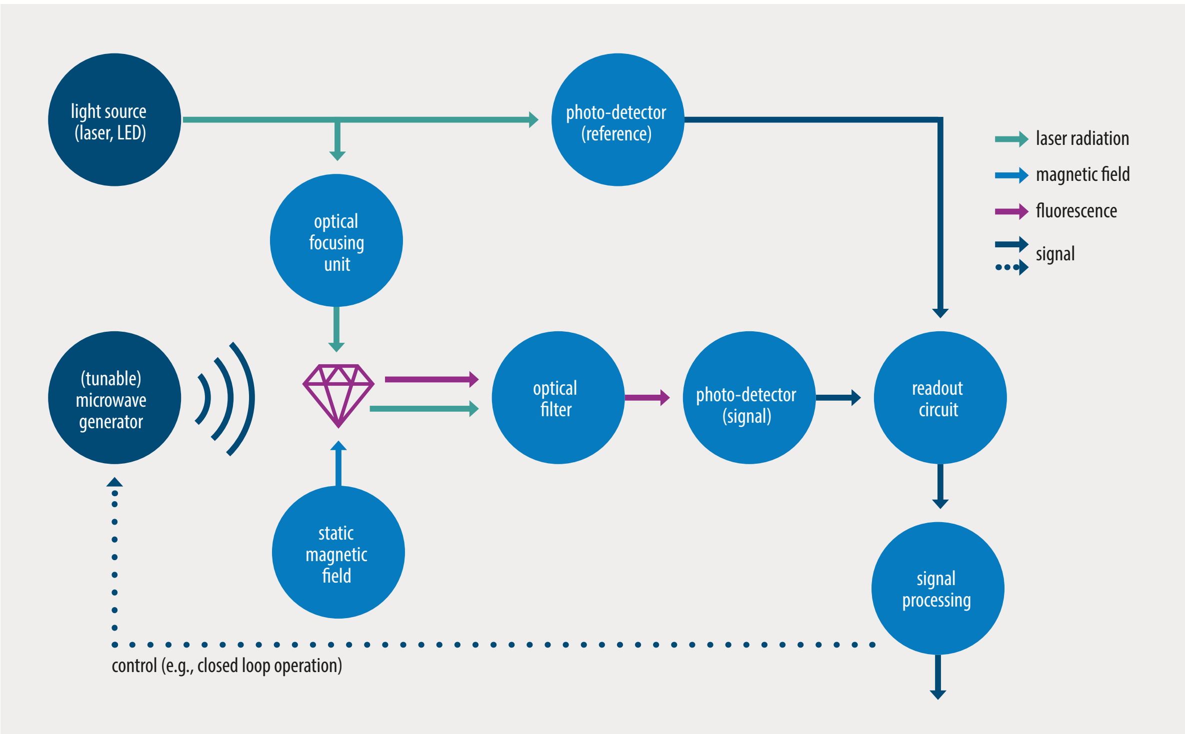

Fig. 1 This scheme illustrates the main components and sensing principle.

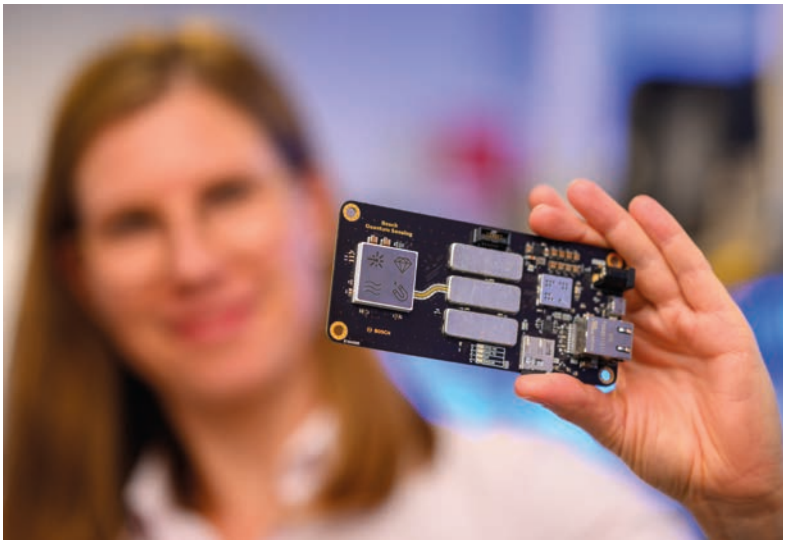

Fig. 2 On the long-term, we aim for further miniaturization and integration on a chip.

applications or the development of very robust navigation.

One of the medical applications is to monitor the heart's natural magnetic field using straightforward, contactless long-term measurements: magnetic-field quantum-sensors provide more data than today's electrocardiography (ECG). Within consumer health applications, 'GenN' sensors extend the scope of monitoring already provided by devices like smartphones and smartwatches. For example, quantum sensors could provide mobile cardiograms to continuously monitor heart activity, an interesting application for drivers in motor vehicles.

In navigation systems, a quantum magnetometer could detect the unique magnetic signal originating from the earth's crust. Providing information on the position independently of signals from satellites enables a more robust navigation in the air, on the road, on the water, and underwater.

The precise measurement of the changes of a magnetic field has lucrative applications in the exploration and the detection of mineral resources. The combination with AI allows a more accurate terrain analysis to determine the right place to drill for underground resources.

Quantum sensors could also improve the battery management systems of vehicles. They could measure the magnetic field precisely which is induced by the electric current and thereby determine the exact charge level of the battery. The result would allow a more reliable and precise determination of the remaining range.

With regard to process improvements, quantum sensors have applications in non-destructive tests of materials. Here, their precision could allow the detection of tiny imperfections such as cracks that are often missed by conventional methods.

Navigation as an example

Bosch Quantum Sensing is working with Airbus to assess the possibility of enhancing the current aircraft navigation systems which enable safe flight operations today. The aim is to further add dissimilar navigation information in civil aviation by utilizing quantum sensor technology for the acquisition of precise positioning data.

Quantum sensors can measure the earth's magnetic field and provide a unique signal to enable aircrafts to operate independently of global positioning signals from satellites.

Airbus and Bosch consider the use of quantum sensor technology to be a highly innovative solution for the support of all other onboard aircraft navigation systems. This has the potential to further increase flight safety by providing dissimilar data. This partnership combines Airbus' expertise in aircraft development and airborne navigation systems with Bosch's in-depth knowledge of quantum sensor technology.

Conclusions

The technology is still being developed, but already promises robust and compact quantum sensors with unrivalled accuracy. Bosch's quantum sensor prototype is currently about the size of a cell phone and is the smallest one available with this level of measurement accuracy. Of course, more advanced sensors will be available in the near future.

During the next two years, Bosch Quantum Sensing plans to work on specific applications with pilot customers in the medical and mobility sectors. Brain computer interfaces remain the long-term strategic target market for quantum sensors – but the number of other possible applications is huge. It is going to be an exciting journey to see where and how this technology improves and transforms our world.

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