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Towards the miniaturization of atomic sensors: a new readout method

ICFO researchers propose a new readout method for atomic sensors. The discovery is an important step towards the miniaturization of sensors like atomic magnetometers; a long-sought breakthrough that will enhance their spatial resolution, among other substantial improvements.

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Some technological devices that aim at high-precision sensing are based on optical pumping (that is, the process in which light is used to raise -or "pump"- electrons from a lower energy level in an atom or molecule to a higher one) and atomic vapor spin physics (that is, the physics associated with the evolution and the interactions of an intrinsic magnetic property of atoms, called spin). For instance, optically pumped magnetometers (OPMs), one of the most sensitive quantum devices to detect very weak magnetic fields, rely on these two principles.

There is an important element that influences the degree of sensitivity and that, consequently, can compromise the performance of such instruments: the readout of the electronic spins' polarization (a property related to how atomic spins orient). Currently, there are state-of-the-art methods that enhance readout effectiveness, but their performance worsens as the dimensions of the sensors are reduced, holding back the miniaturization that most of the modern technologies pursue.

The issue has been recently addressed by ICFO researchers **Maria Hernandez**, **Yintao Ma** (also member of the Xi'an Jiaotong University), **Hana Medhat**, **Dr. Chiara Mazzinghi** (also member of Instituto Nazionale di Ottica, Sesto Fiorentino) and **Dr. Vito Giovanni Lucivero** (also member of the Universita degli Studi di Bari Aldo Moro), led by **ICREA Professor at ICFO Morgan W. Mitchell**. In a Physical Review Applied article, they have demonstrated **a new nondestructive method to monitor the electron spin polarization of an atomic ensemble that, at the same time, allows for miniaturization.**

A new spin-polarization monitoring technique

In the study, the authors utilized three different components (each of them well-established on its own) and brought them all together, something that no one had ever done before.

The first ingredient was the use of an atomic vapor and the exploitation of its optical

properties. In particular, they used rubidium 87, a very regular choice when dealing with sensors as they are naturally sensitive to external changes in their environment.
The second one was the use of an optical resonator. These optical elements, also known as ï¿½optical cavitiesï¿½, improve the spin readout by increasing the interaction length bet een the rubidium atoms and the infrared light, which is used to probe them. Moreover, the v por was placed inside a so-called micro-electromechanical system (MEMS) vapor cell, since his kind of cell enables the miniaturization of sensing devices without this being detrimenta to its qual
ty. And thirdly, the team performed the readout using the Pound-Drever-Hall (PDH) techni ue. The PDH method is widely used to measure changes in the frequency or phase of laser l ght with infinitesimal precision (for instance, in gravitational waves detection). In this case by sending light into the medium and measuring the phase shift through PDH, the researc ers were able to indirectly infer the atomic spin polarization (as the former depends on the latte
). In summary, the team performed PDH readout of the atomic spin polarization of a rub dium 87 vapor housed in a MEMS cell within an optical resonator. The results sugge **enhanced readout (and thus better sensitivity) even in small cells,** a two-fold improvement over previous attempts.

Benefits for future atomic sensors

The researchers claim that their method has potential to provide high efficiency readout for miniaturized atomic vapor sensing and metrology instruments. ï¿½This is an important resu t since it paves the way towards the miniaturization of atomic sensing devices that allow hi h spatial resolution in magnetic field detection. Moreover, in principle, the method can e quantum noise limited, which will enable quantum enhanced detection in miniaturiz d sensorsï¿½, shares Maria Hernandez, leading author of the arti
le. Hernandez has already started building an optical magnetometer based on this technique for micro-bio-magnetic applications. The miniaturization of atomic magnetometers could re ult in sensors with improved spatial resolution and that could also be suitable for spin squeez ng, a milestone the team is looking forward to achiev

Bibliographic reference:

Hernandez, Y. Ma, H. Medhat, C. Mazzinghi, V. Giovanni, and M. W. Mitchell. Cavity-enhanced detection of spin polarization in a microfabricated atomic vapor cell. Phys. Rev. Applied 21, 064014 (2024).

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Maria Fernandez manipulating the setup