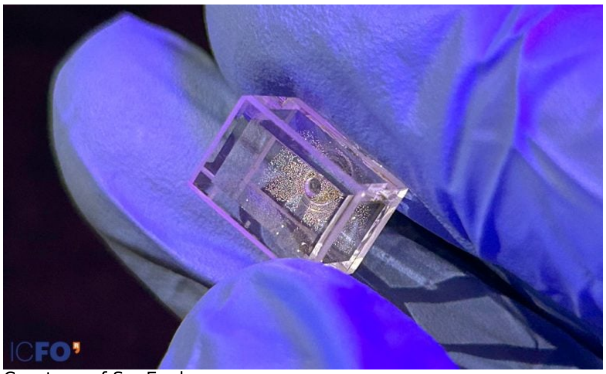
New Imaging Potential Is Unlocked by Atomic Sensors

Posted by Okachinepa 11/12/2024



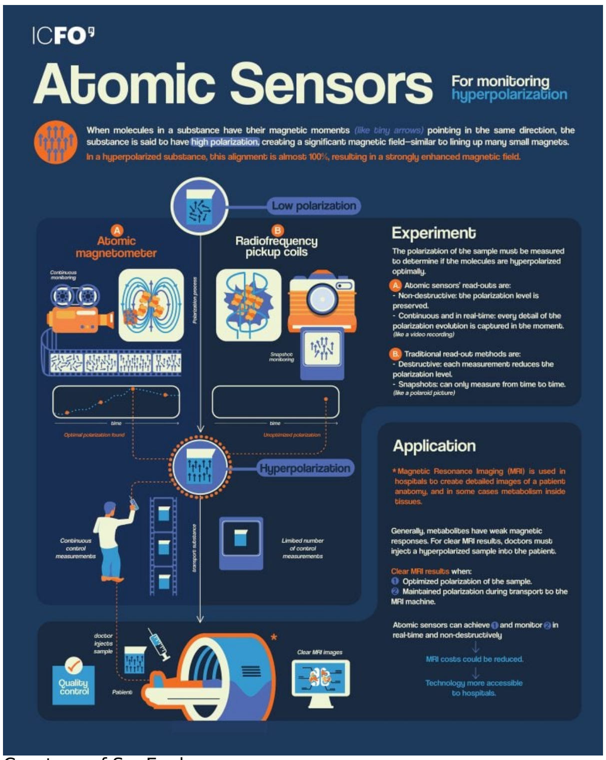
Courtesy of SynEvol
Credit: ICFO

A vital technique in contemporary medicine, magnetic resonance imaging (MRI) provides fine-grained pictures of inside organs and tissues. These massive, tube-shaped MRI machines, which are frequently found in hospitals, use strong magnets to measure and display the body's water and fat molecule densities.

Other chemicals, such as metabolites, can also be mapped in addition to these molecules, but their concentrations are frequently too low to create sharp images. In order to get over this restriction, a method called hyperpolarization is used to increase these materials' magnetic resonance signal and make them more noticeable on MRI images.

Preparing a material outside of the body so that its magnetization—which is essential for producing MRI images—is close to its maximum is known as hyperpolarization. When compared to its natural form, this technique can increase the signal by thousands of times. The drug is injected into the patient after becoming hyperpolarized, and it is then delivered to the intended organ or tissue. However, thorough quality control procedures are necessary to ensure that the material is sufficiently hyperpolarized before this can occur.In other chemicals, such as metabolites, can also be mapped in addition to these molecules, although their concentrations are frequently too low to yield sharp images. In order to get over this restriction, a method called hyperpolarization is used to increase these materials' magnetic resonance signal and make them more noticeable on MRI images.

There are two major issues with current quality control methods. First, these techniques frequently lessen the sample's magnetism throughout the read-out procedure, which lessens the sample's capacity to improve the MRI scan. Second, the measuring process can take a long time, during which the magnetization of the material gradually deteriorates, making it impossible to take multiple measurements at once. As a result, important information that might otherwise help optimize the effectiveness of hyperpolarization is missing. Additionally, there is a chance that the sample may lose its magnetization while being transported to the MRI machine after it has become hyperpolarized. Due to their time-consuming nature, traditional quality control methods might not be able to identify this time loss.



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Recently, ICFO researchers Prof. Morgan W. Mitchell and Dr. Michael C. D. Tayler, along with IBEC researchers Dr. James Eills (now at Forschungszentrum Jülich, Germany) and Dr. Irene Marco Rius, have shown how atomic sensor techniques can overcome the drawbacks of traditional sampling when measuring the magnetization of hyperpolarized materials. The journal PNAS recently published a paper on this discovery.

The team specifically employed optically pumped atomic magnetometers (OPMs), which allow for the real-time detection of the fields generated by hyperpolarized molecules due to their fundamentally different operating principles from conventional sensors. Throughout the whole experiment, including the actual hyperpolarization process, these researchers were able to conduct continuous, high-resolution, and non-destructive observations due to the nature of OPMs.

The authors claim that if the field of hyperpolarization sensing were cinema, earlier techniques would resemble a series of still images, leaving the audience to speculate about the narrative between the frozen images. “Instead, our technique is more like a video, where you see the whole story frame by frame. In essence, you can watch continually and without resolution limitations, so you don't miss anything," says Dr. Michael Tayler, co-author of the paper and an ICFO researcher.

By tracking hyperpolarization in therapeutically important compounds, the team evaluated their OPMs. Because of their exceptional resolution and real-time tracking, the atomic sensors were able to see the evolution of polarization in a metabolite molecule ([1-13C]-fumarate) when exposed to a magnetic field.

The atomic sensors provided a new avenue for optimizing the hyperpolarization from the outset of the process by revealing "hidden spin dynamics" that had previously gone undetected. According to Tayler, "subtle oscillations in the magnetization profile that were previously undetected were obscured by previous methods." "We would have unknowingly reached a suboptimal final polarization in the absence of the OPM." The technique might be used to regulate the polarization process in real-time and halt it at the most advantageous moment, such as when the maximum polarization is achieved.

When the researchers repeatedly magnetized and demagnetized the hyperpolarized fumarate molecule using a magnetic field, they discovered more surprising behavior. They anticipated a smooth transition between states, with the magnetization steadily rising to a maximum and then falling back to zero. Hidden resonances at specific magnetization-demagnetization periods and magnetic fields caused the molecule to exhibit complex dynamics in contrast to these straightforward expectations.

According to Tayler, "this understanding will help us detect when unwanted behavior occurs and adjust parameters (like the cycle duration or the magnetic field intensity) to prevent it."

Thanks in major part to the joint efforts of the Atomic Quantum Optics group at ICFO and the Molecular Imaging for Precision Medicine group at IBEC, the work represents a breakthrough in hyperpolarized MRI technology. The results were made possible in large part by the experience of ICFO in OPM sensing technologies and IBEC in hyperpolarization techniques.

Dr. James Eills, an IBEC researcher and the article's first author, acknowledges that "this is a beautiful example of the new science that can be achieved when researchers from different disciplines work together, and the proximity of IBEC and ICFO meant we were able to collaborate closely and achieve something truly novel."

"The OPM measurements worked beautifully from the start," says Dr. Tayler, reflecting on the team's achievement. As though they were designed just for this purpose, the sensors' extraordinary sensitivity unveiled behaviors we hadn't expected. They are an effective tool for hyperpolarization monitoring because of their simplicity of use and plenty of fresh data.

Integrating portable atomic sensors into clinical sample quality control for MRI is the study's immediate application; the ICFO team is now doing this as part of the Spanish Ministry Project "SEE-13-MRI." In this manner, it would be feasible to reliably certify the polarization level before to injecting drugs into patients and direct molecules to the maximum amount of polarization during hyperpolarization.

The advancement has the potential to drastically down metabolic MRI's expenses and logistical difficulties. If this is the case, it would be employed in many hospitals throughout the world instead of just a few specialist research institutes.

But atomic sensors have much more potential than just medical imaging. Optimising spin-based algorithms in quantum computing, studying high-energy physics targets, or monitoring macromolecules in chemical processes could all be done with the same non-destructive, real-time tracking device that uses optically-pumped magnetometers (OPMs). "We are excited about its further development, as the method we have developed opens up new avenues not only for improving MRI but for various fields that rely on precise magnetic sensing," Dr. Tayler said.
