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Mechanical Design EDITORIAL

The Innovation Materials

Magnetic sensing takes flight: Levitated magnets redefine precision magnetometry at room temperature

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Received: August 21, 2026; Accepted: October 17, 2026; Published Online: October 19, 2026; https://doi.org/10.59717/j.xinn-mater.2026.100252

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Citation: Li Y. (2026). Magnetic sensing takes flight: Levitated magnets redefine precision magnetometry at room temperature. *The Innovation Materials* **4**:100252.

A FLOATING MAGNET LISTENING TO THE WEAKEST MAGNETIC WHISPERS

Magnetic fields encode information across all scales, from microscopic spin dynamics and electronic correlations to macroscopic biological processes and planetary environments. While superconducting quantum interference devices (SQUIDs), atomic magnetometers, and nitrogen-vacancy (NV) centers in diamond have achieved remarkable sensitivity, they are practical constrained—cryogenic infrastructure for SQUIDs, complex optical pumping and stringent magnetic-shielding requirements for atomic magnetometers, and sophisticated defect engineering for NV-diamond devices. A recent study introduces a fundamentally different strategy: instead of engineering ever-smaller quantum defects, why not let a macroscopic magnet fly?

In a recent study,[1] Wei Ji, Changhao Xu, and collaborators demonstrated a diamagnetically stabilized levitated magnet magnetometer (LeMaMa), in which a freely levitated ferromagnetic particle simultaneously serves as the magnetic sensing element and mechanical oscillator (Figure 1). Remarkably, this room-temperature platform achieves a magnetic sensitivity of 32 $\mathrm{fT}/\sqrt{\mathrm{Hz}}$ at its torsional resonance frequency of 304.84 Hz, approaching the performance of state-of-the-art quantum magnetometers while operating in an ambient environment. The work entitled "Levitated sensor for magnetometry in ambient environment," published in the journal *Science* on August 6, 2026, reveals a new route toward ultra-sensitive magnetic detection based on levitated magnetic matter.

FROM MECHANICAL ISOLATION TO MAGNETIC PRECISION

The central idea of LeMaMa is conceptually simple yet technically profound: remove mechanical contact between the sensor and its environment.

In conventional magnetic sensors, the sensing element is inevitably attached to a substrate or supporting structure. Such coupling introduces mechanical damping, thermal fluctuations, and technical noise, limiting the ultimate sensitivity. Levitated systems provide an elegant solution by eliminating physical contact and creating an isolated mechanical degree of freedom.

However, applying levitation to magnetometry has remained challenging. Magnetic levitation typically relies on superconducting Meissner effects, which require cryogenic temperatures and are unsuitable for compact and practical devices. Ji et al. overcome this limitation by exploiting **diamagnetically stabilized magnetic levitation**: a lifting magnet generates a gradient field that counteracts gravity, while a thin layer of epoxy-glued pyrolytic graphite (EGPG) beneath the sensor magnet stabilizes the levitation at room temperature.

The levitated magnet forms a unique hybrid system in which magnetic and mechanical degrees of freedom are intrinsically coupled. A bias magnetic field provides a restoring torque, transforming the levitated magnet into a mechanical torsional oscillator. When an external magnetic field is applied, the magnetic moment experiences a torque

$$\vec{\tau} = \vec{M} \times \vec{B}$$

which drives angular motion of the levitated magnet. The resulting displacement is detected through an optical readout scheme, converting extremely weak magnetic perturbations into measurable mechanical motion.

Thus, LeMaMa establishes a new sensing paradigm:

magnetic field → magnetic torque → mechanical motion → optical signal

Rather than relying on electronic transitions or microscopic quantum defects, this approach exploits the collective magnetic moment of a macroscopic object coupled to a low-loss mechanical oscillator.

Because LeMaMa operates as a resonant detector, its peak sensitivity is concentrated in a narrow band around the mechanical resonance. The response curve exhibits a full width at half maximum of only about 0.025 Hz, corresponding to a quality factor of about 12,000. Away from resonance, the sensitivity decreases to approximately 200 $\mathrm{pT}/\sqrt{\mathrm{Hz}}$ in the 80–200 Hz range and to about 1 $\mathrm{nT}/\sqrt{\mathrm{Hz}}$ below 15 Hz. The resonance frequency can be tuned between roughly 260 and 318 Hz by adjusting the bias magnetic field, and dynamically tuning it in a closed-loop configuration could substantially extend both the usable bandwidth and the dynamic range. In its present form, the sensor is therefore ideally suited to narrowband signals, or to signals that can be modulated onto the resonance.

TURNING CLASSICAL MAGNETIC ORDER INTO A PRECISION SENSING RESOURCE

One of the most intriguing aspects of LeMaMa is that the sensing element itself is not an exotic quantum defect or an atomic transition, but an ordinary ferromagnetic material.

At first glance, this seems counterintuitive. A ferromagnet contains an enormous number of spins, and magnetic fluctuations associated with these spins might be expected to limit sensitivity. Instead, the authors take advantage of magnetic order itself. Strong interactions within the ferromagnet stabilize the collective magnetic moment, allowing billions of aligned spins to behave as a coherent macroscopic sensing degree of freedom. The spin density (~10^{2} ħ/cm^3) exceeds that of atomic vapor cells by roughly seven orders of magnitude, reducing spin-projection noise significantly. Moreover, strong spin-lattice coupling ensures individual spin disturbances relax within nanoseconds—far faster than the mechanical detection frequency—placing the system in a quasistatic regime ideal for low-frequency measurements.

This concept reflects an emerging direction in quantum sensing: the optimal sensor does not necessarily need to be a single microscopic quantum object. Carefully engineered collective states can also provide extremely stable measurement platforms approaching fundamental limits.

In this sense, LeMaMa bridges two traditionally distinct fields—magnetic materials and precision measurement. Magnetic order, usually regarded as a property to be studied, becomes an active resource for sensing.

This perspective opens new possibilities for designing sensors based not only on individual spins, but also on collective magnetic states, magnetic textures, and emergent phenomena in quantum materials.

ENGINEERING AWAY THE NOISE

Achieving femtotesla-level sensitivity requires more than simply levitating a magnet. The ultimate performance is determined by the delicate balance between magnetic response and various noise sources.

A major challenge arises from magnetic noise generated by thermal currents in surrounding conductive materials. According to the fluctuation-dissipation principle, random thermal motion of electrons in conductors produces fluctuating currents, which generate magnetic field noise. In LeMaMa, such Johnson magnetic noise from nearby conducting components can directly perturb the sensing magnet and limit sensitivity.

To suppress this limitation, the authors carefully engineered the experimental environment. The conventional aluminum vacuum chamber was

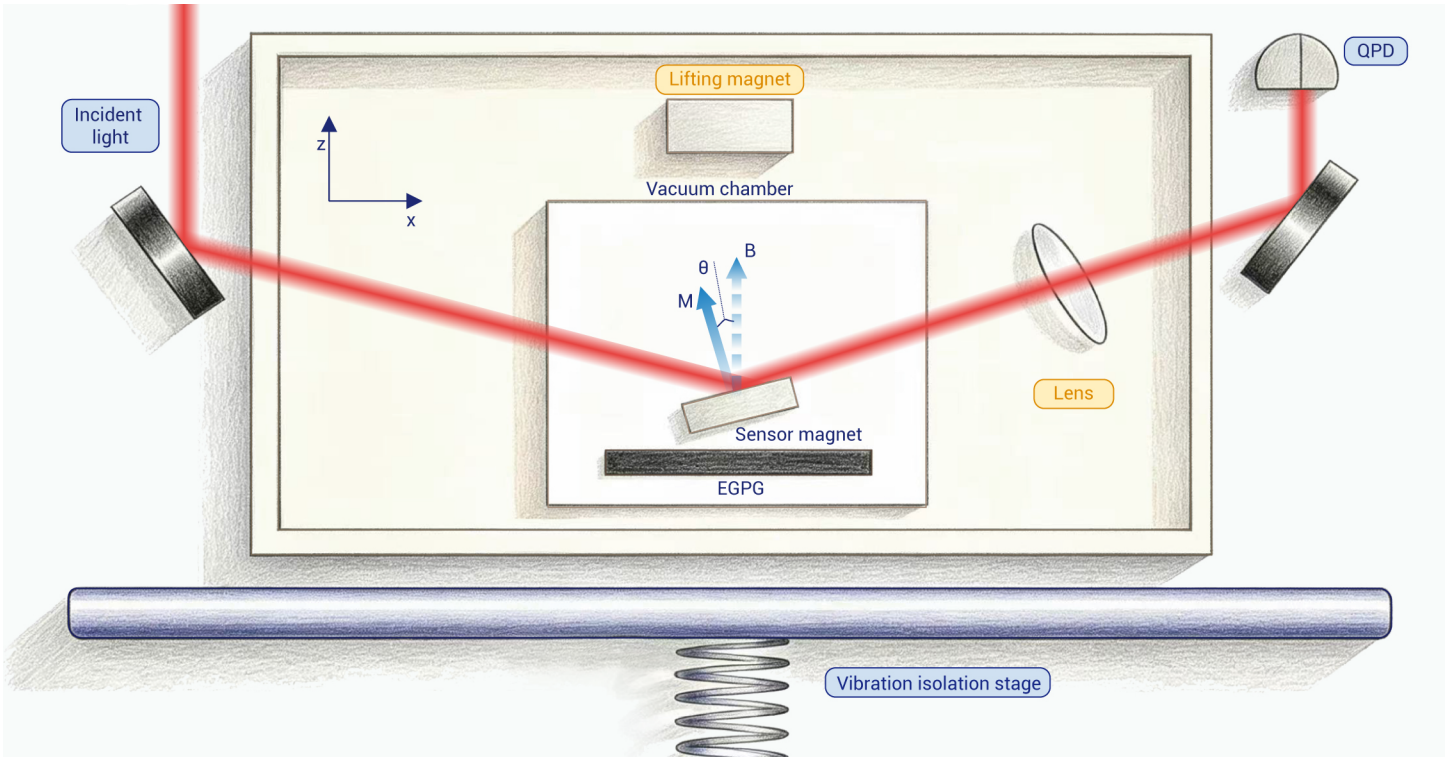


Figure . Schematic diagram for the room-temperature diamagnetically stabilized levitated magnet magnetometer (LeMaMa).

replaced with a glass chamber to eliminate magnetic noise originating from thermal currents in metallic structures. Furthermore, instead of using a continuous pyrolytic graphite plate, the diamagnetic platform was redesigned using isolated graphite particles embedded in epoxy. This strategy preserved diamagnetic levitation while reducing large-scale current loops responsible for magnetic fluctuations, which reduced the dominant Johnson noise from 110 fT/$\sqrt{\text{Hz}}$ to 30 fT/$\sqrt{\text{Hz}}$.

These improvements highlight an important lesson for precision measurement: sensitivity is not achieved solely by increasing signal strength, but by engineering every component of the measurement chain, from the sensing element to the surrounding environment.

BEYOND REPLACING EXISITING MAGNETOMETERS

The significance of LeMaMa extends beyond a new sensitivity record. Different magnetometry platforms occupy different technological niches. SQUIDs remain among the most sensitive magnetic sensors but require cryogenic infrastructure.[2] Atomic magnetometers provide exceptional sensitivity but demand carefully controlled optical and magnetic environments.[3] NV-center sensors offer nanoscale spatial resolution but involve sophisticated defect engineering.[4]

In contrast, LeMaMa operates at **room temperature, tolerates fields up to the millitesla range, and functions in ambient conditions** with minimal shielding. The sensor-to-sample distance can be reduced to below one millimeter, a crucial advantage for biomagnetic applications where proximity determines signal strength. Such technology may impact several areas:

- **Biomedical science.**

Weak magnetic signals generated by biological activity, including cardiac and neural processes, are typically measured using large cryogenic systems or highly controlled environments. Portable levitated magnetometers could provide new opportunities for room-temperature biomagnetic sensing.

- **Quantum materials and condensed matter physics.**

Many modern materials host extremely weak magnetic phenomena, including unconventional magnetic orders, spin textures, and emergent quantum states. Ultra-sensitive magnetometry based on levitated magnetic matter could offer new probes for these systems.

- **Fundamental physics.**

The ability to detect extremely weak magnetic interactions may enable searches for exotic spin-dependent forces and subtle magnetic signatures beyond conventional experiments.

THE FUTURE: LEVITATED MAGNETIC MATTER AS A NEW PLATFORM

The broader message of LeMaMa is that levitated matter is evolving from a tool for force sensing into a general platform for quantum technologies.

A levitated magnet is not merely a detector. It is a dynamical system where magnetic, mechanical, and potentially quantum degrees of freedom interact. Future developments may combine levitated magnets with cavity optomechanics, superconducting circuits, spin-wave excitations, and topological magnetic materials, creating hybrid platforms for exploring new regimes of sensing and quantum control.

The combination of levitated mechanics and magnetic materials may ultimately enable a new generation of sensors in which collective magnetic phenomena, rather than isolated quantum defects, define the limits of measurement.

The future of magnetometry may not only come from cooling systems closer to absolute zero or engineering increasingly complex microscopic structures. Sometimes, the most sensitive sensor may simply be the one that is allowed to fly.

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DECLARATION OF INTERESTS

The author declares no competing interests.