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Helium-Free Magnetic Refrigeration Advances Quantum Research

By Jim McMahon

Cryogenic technology is becoming a cornerstone of quantum research, where even the smallest environmental disturbances can disrupt delicate systems. A new helium-free, continuous adiabatic demagnetization refrigeration (cADR) platform developed by kiutra GmbH is pushing the boundaries of ultra-low temperature performance, enabling stable cooling below -273°C while simplifying operation and scalability.

This innovation is particularly important as quantum computing, sensing, and communication technologies continue to evolve. These applications depend on maintaining quantum states — especially in qubits — which are highly sensitive to heat and environmental noise.

Extreme Cooling

Quantum computers rely on qubits that can exist in multiple states simultaneously, enabling powerful computational capabilities. However, these states are fragile. Thermal energy introduces noise that can destabilize qubits, reducing coherence and limiting performance. To counteract this, quantum systems are operated at cryogenic temperatures close to absolute zero. At these temperatures, thermal fluctuations are minimized, allowing qubits — particularly those based on superconductivity — to function reliably and perform complex operations.

Magnetic Refrigeration

Traditional cryogenic cooling methods rely on liquid helium, which is expensive, complex to manage, and increasingly scarce. Magnetic refrigeration offers a more efficient and scalable alternative by leveraging the relationship between magnetic fields and entropy in certain materials.

Cryogen-free, continuous magnetic refrigeration isn't just an alternative — it's a smarter, more scalable foundation for the future of quantum technology.

In this process, magnetic moments within a material are manipulated to control temperature. When a magnetic field is applied, the moments align, reducing entropy and increasing temperature. As the system returns to equilibrium and the field is removed, the material cools significantly, reaching sub-Kelvin temperatures.

This approach provides a simpler and potentially more sustainable path to achieving the extreme cooling required for quantum applications.

Understanding Adiabatic Demagnetization Refrigeration

Adiabatic demagnetization refrigeration (ADR) is a key method within magnetic cooling. The process begins by pre-cooling a material — often a paramagnetic salt — using a conventional cryocooler. The material is then exposed to a strong magnetic field, aligning its magnetic moments and generating heat, which is removed by the cooling system.

Once thermally isolated, the magnetic field is gradually reduced. As the magnetic moments return to a more disordered state, they draw energy from the material itself, causing its temperature to drop dramatically into the milli-Kelvin range.

While effective, traditional ADR systems operate in a “single-shot” mode, meaning they can only maintain ultra-low temperatures for a limited time.

Continuous Cooling

Continuous ADR (cADR) overcomes this limitation by using multiple ADR units that alternate between cooling and regeneration. This allows for uninterrupted cooling at ultra-low temperatures.

kiutra’s platform incorporates at least two ADR stages, enabling continuous operation down to approximately 100 milli-Kelvin. Unlike helium-based systems, this solution is cryogen-free, requires minimal maintenance, and offers a user-friendly interface for automated operation.

The compact design and scalability make it particularly attractive for industrial and research environments where consistent performance and ease of use are critical.

Enabling Precision Vibration Isolation

A specialized version of the platform, the S-Type Optical, introduces free-beam optical access, allowing researchers to conduct advanced optical experiments at sub-Kelvin temperatures.

Equally important is the integration of Negative-Stiffness vibration isolation from Minus K Technology. Quantum systems are extremely sensitive to vibration, which can introduce unwanted energy and disrupt quantum states. Even minor environmental disturbances — such as sound waves or mechanical movement — can degrade performance.

The Negative-Stiffness system passively isolates vibrations without requiring power, compressed air, or active control. Its design enables extremely low natural frequencies, achieving high levels of isolation across both vertical and horizontal axes. This ensures a stable environment for precision measurements and quantum operations.

As quantum technologies move from research to real-world applications, the need for reliable, scalable, and efficient cryogenic systems is growing rapidly. Helium-free magnetic refrigeration, particularly in continuous formats like cADR, offers a compelling solution.

By combining ultra-low temperature performance with ease of use, modular design, and vibration isolation, these systems are helping to unlock new possibilities in quantum computing and beyond.

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