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A Rigid, Thermally-Isolating Suspension for an ADR

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Motivation

- Make mechanically robust suspension
- Improve rigidity of the pulser stage through ADR regeneration cycles
- Minimize heat leak to improve hold time

Kevlar Suspension

Kevlar

- is strong in longitudinal direction but weak in transverse: weakens around loop
- has negative longitudinal thermal expansion coefficient: expands as temperature goes down and tension decreases
- creeps in time: also reduces tension [1]

Heat leak of Kevlar 29 in liquid He to 0.1 K: $19T^{2.1}$A/L μW [2]

Thermal Isolation for SCUBA-2 [3]

- Use mechanically hard material to achieve rigid thermal isolation: sapphire disks
- Use hard powder to reduce contact area: diamond or alumina powder
- Highest thermal resistance achieved: sapphire disks with diamond powder with conductance of $0.26(T/1K)^{2.9}\mu\mathrm{WK}^{-1}$.
  Since diamond is harder than sapphire, Bintley *et al* were concerned the powder might fracture disks over many cycles and decided to use alumina powder. We did this also.
- Mechanical structure with two sapphire disks and alumina powder in between achieved 2.57 μW heat leak between 80mK and 1.1 K

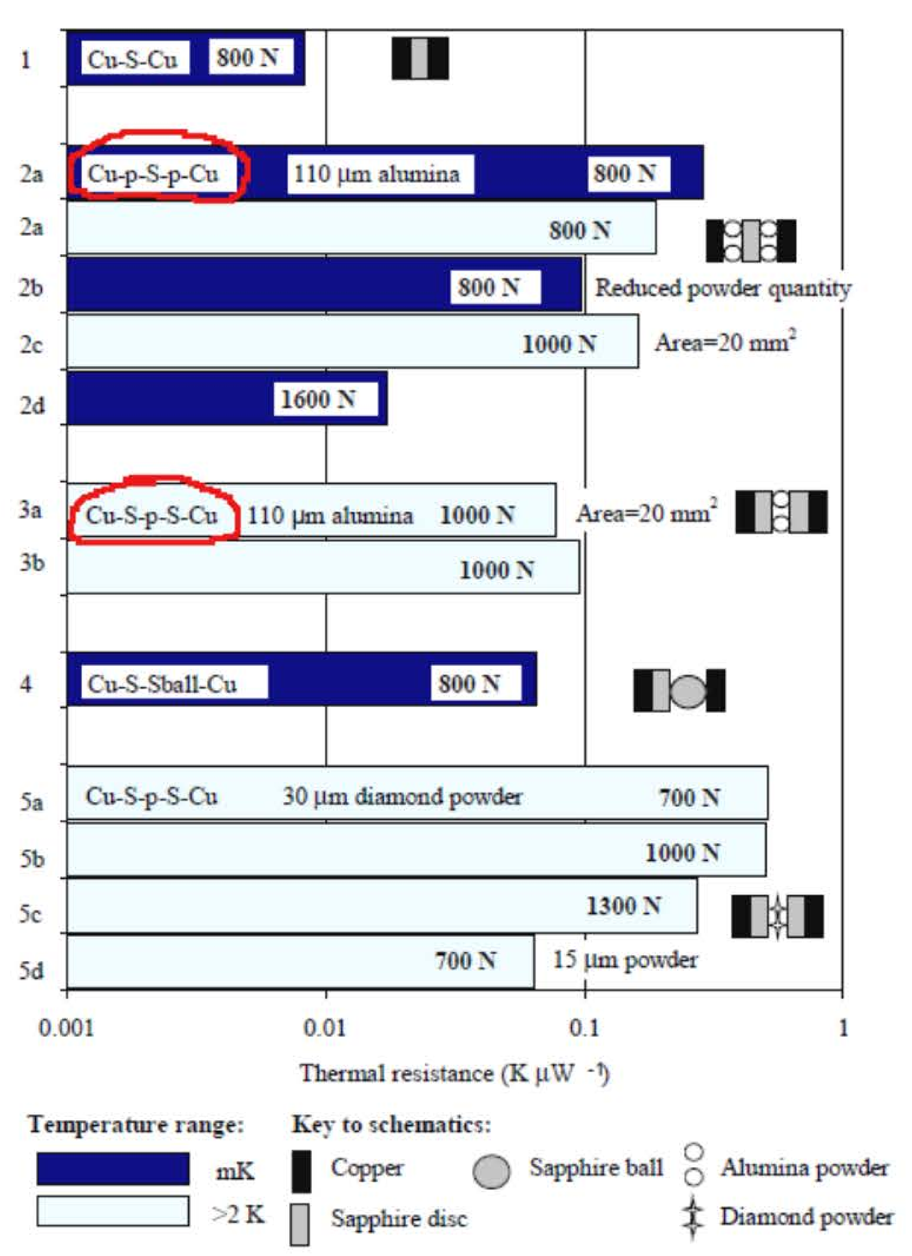


Figure 1: Measured thermal resistance at 2K for the different sapphire thermal isolation joint measurements. x - axis: thermal resistance in logarithmic scale, y - axis different configurations. Figure from Bintley *et al* [3]

Expected Heat Leak

Using heat conductivity for sapphire-powder-sapphire configuration, $7.3\cdot10^{-6}(T/1\mathrm{K})^{3.2}\mathrm{WK}^{-1}$, from Bentley *et al* [3], we calculated heat leak from 50 mK ADR to 600mK GGG temperature as

$$P=\int_{T_{cold}}^{T_{hot}}\sigma dT = 7.3\cdot10^{-6}\frac{T^{4.2}}{4.2}\Big|_{0.05}^{0.6} WK^{-4.2} = 0.2\mu W$$

We have 6 stacks of 6 sapphire disks between ADR stage and GGG stages, 3 above and 3 below.

Abstract

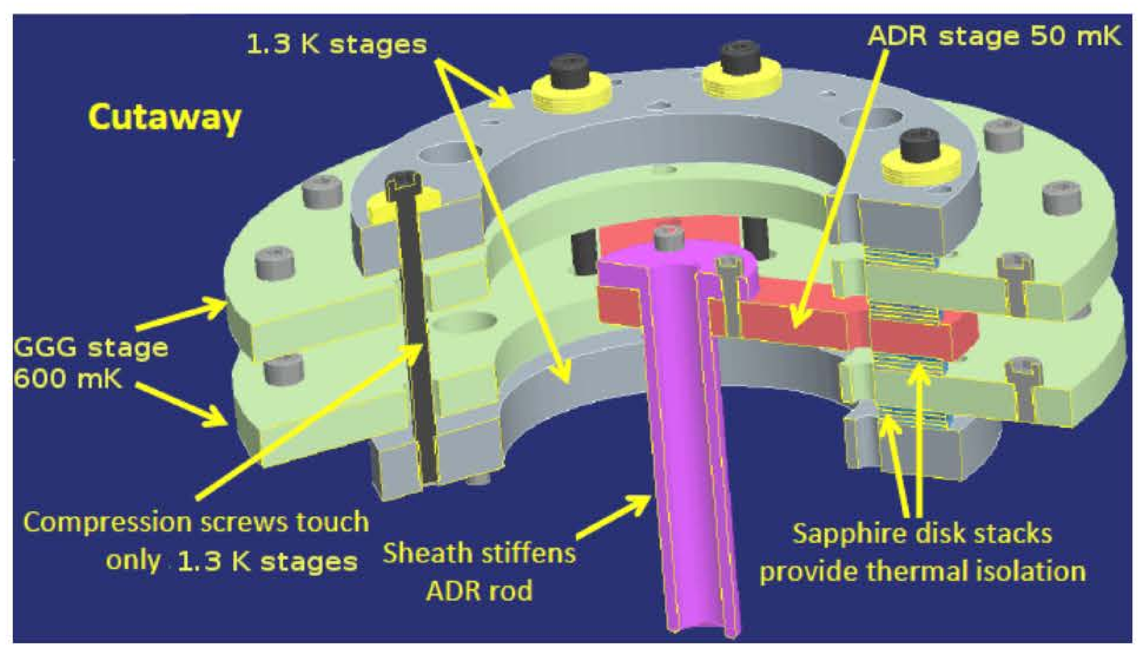
We have recently developed a scanning optical pulser for the precise measurement of device-to-device reproducibility, position-dependent response, and other important characteristics of low-temperature particle detectors. By making maps of the reflected light, we can measure the position of the detectors (mounted on the ADR) under the scanner (mounted on the 3K flange) to micro-meter precision. We find that the detector position typically changes approximately 3-4 μm from ADR regeneration to ADR regeneration. Further, when the ADR is allowed to warm at zero field over many hours from its base temperature to approximately 1K, an additional change in the measured position of approximately 10 μm is seen. The origin of these position shifts is unknown. One candidate mechanism is the slow relaxation of mechanical stress in the fiber suspension of the ADR. For best precision in positioning the scanning pulser it would be useful to reduce or eliminate these position shifts. We have recently fabricated a new rigid suspension for our ADR based on the stacked-sapphire disk approach that was successfully used in SCUBA-II. In this report we describe the design and initial performance testing of this new suspension.

Design

Compact suspension has 5 isolated stages at 3 different temperatures:

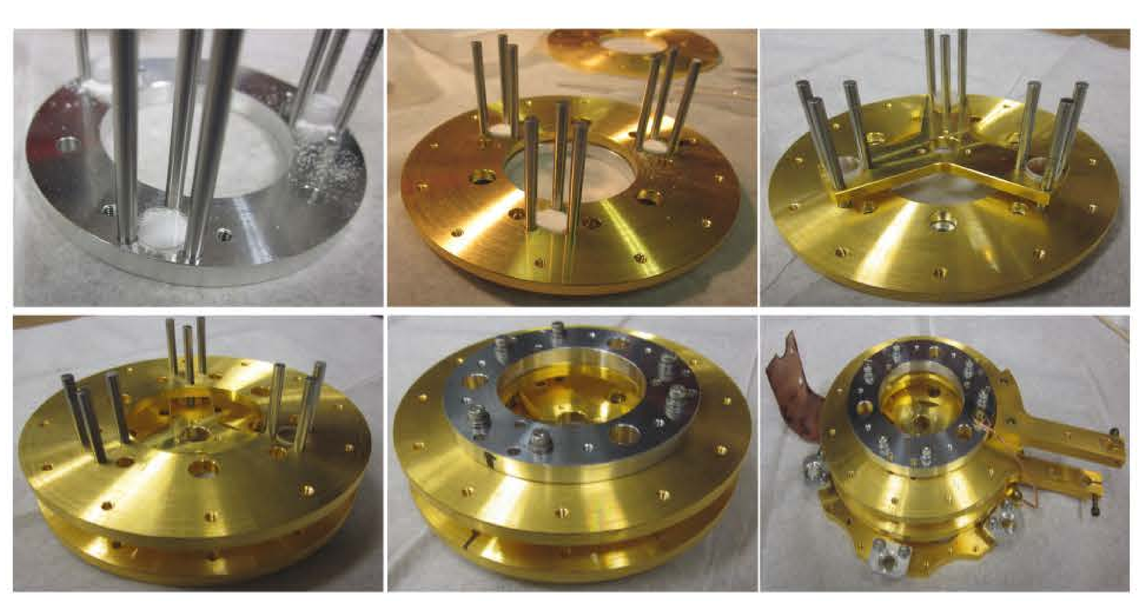
- top and bottom stages are heat sunk to **1K pot** (~1.3K)
- 2^{nd} and 4^{th} stages are heat sunk to **GGG** pill (~600mK)
- center stage holds **ADR** rod (~50mK)

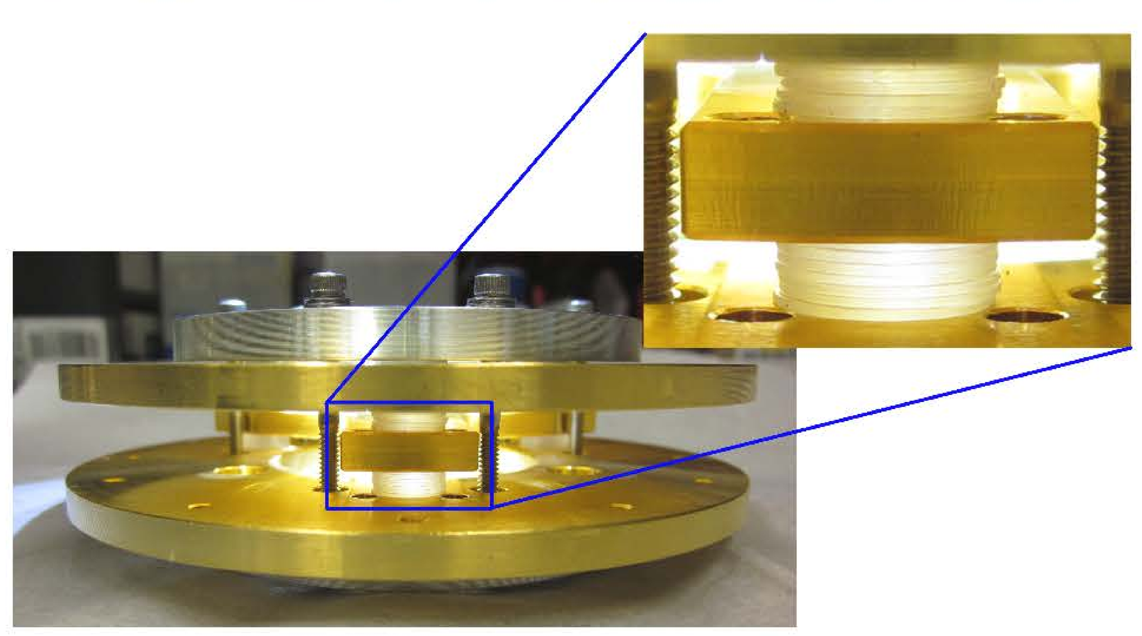
Drop in replacement for previous Kevlar suspension



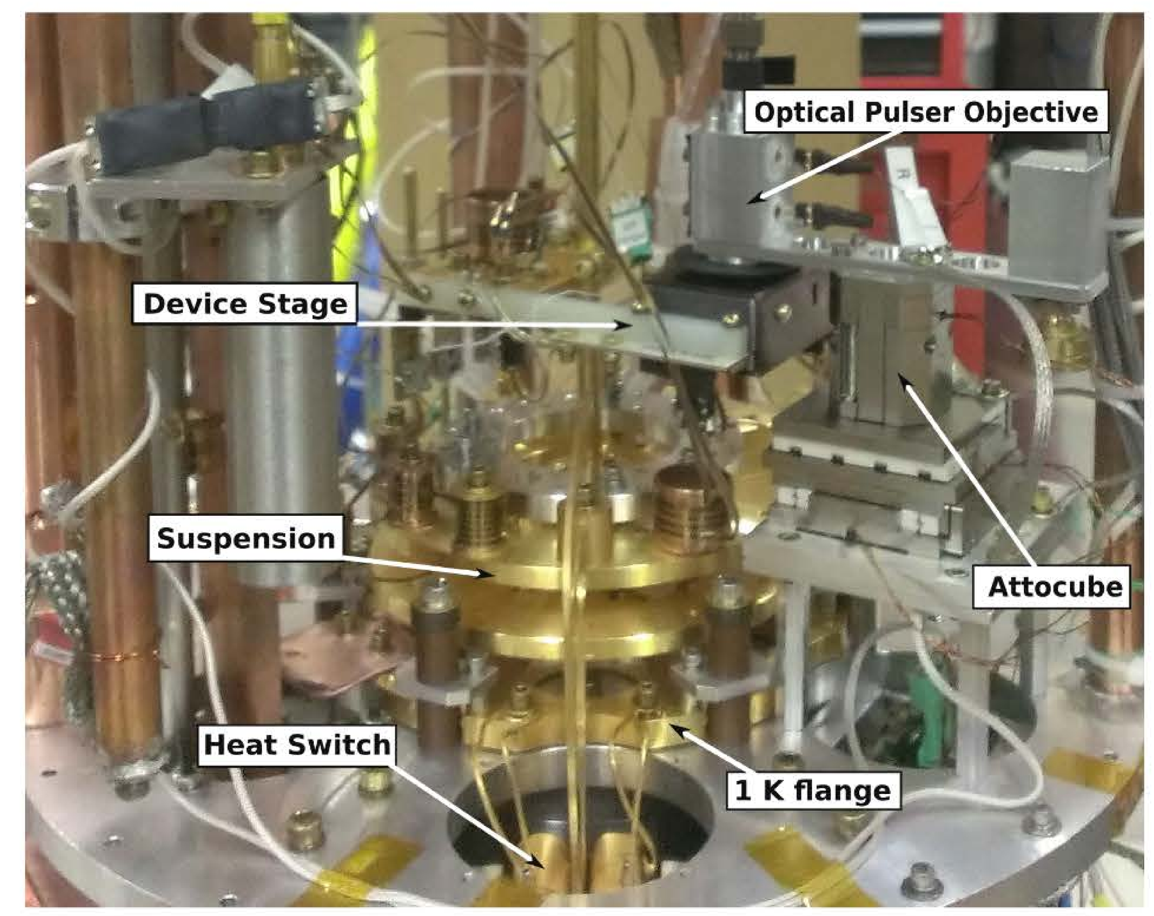
Assembly

- Takes 2-3 hours to assemble: much quicker than making Kevlar suspension.
- Use 9 gauge pins to align plates and the disks.
- 72 sapphire disks in 3 columns $(6+6+6+6)$: with 10 mm diameter, 0.5 mm thickness.
- 110 micron alumina powder in between sapphire disks and between disks and plates. Powder covers approximately 60 % of the disks' surfaces.
- Use Belleville washers to apply clamping force (~1000N on each sapphire stack)

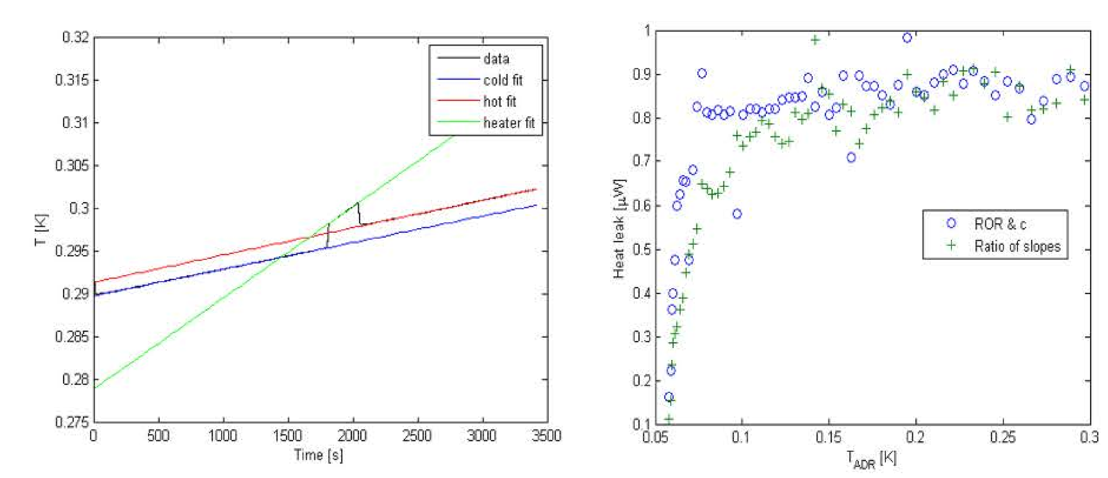




Performance



Heat leak is measured by using slopes in temperature vs time plots before and after heat pulse. Before heat pulse and during heat pulse:

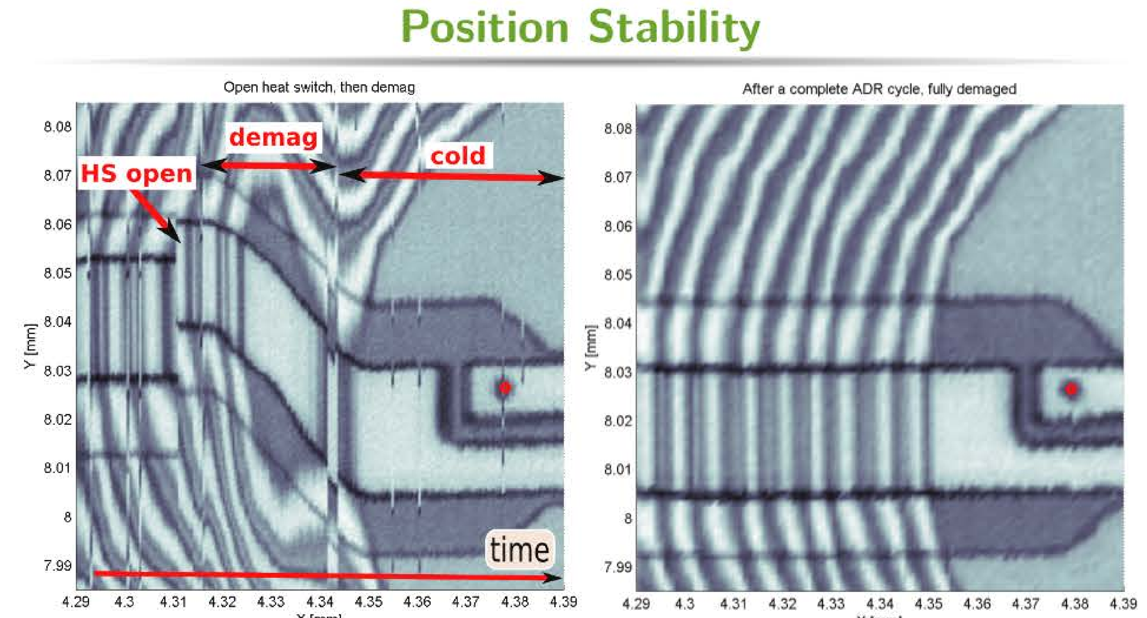


$$\left(\frac{dT}{dt}\right)_1=\frac{P_{leak}}{c} \qquad \left(\frac{dT}{dt}\right)_2=\frac{P_{leak}+P_{heater}}{c}$$

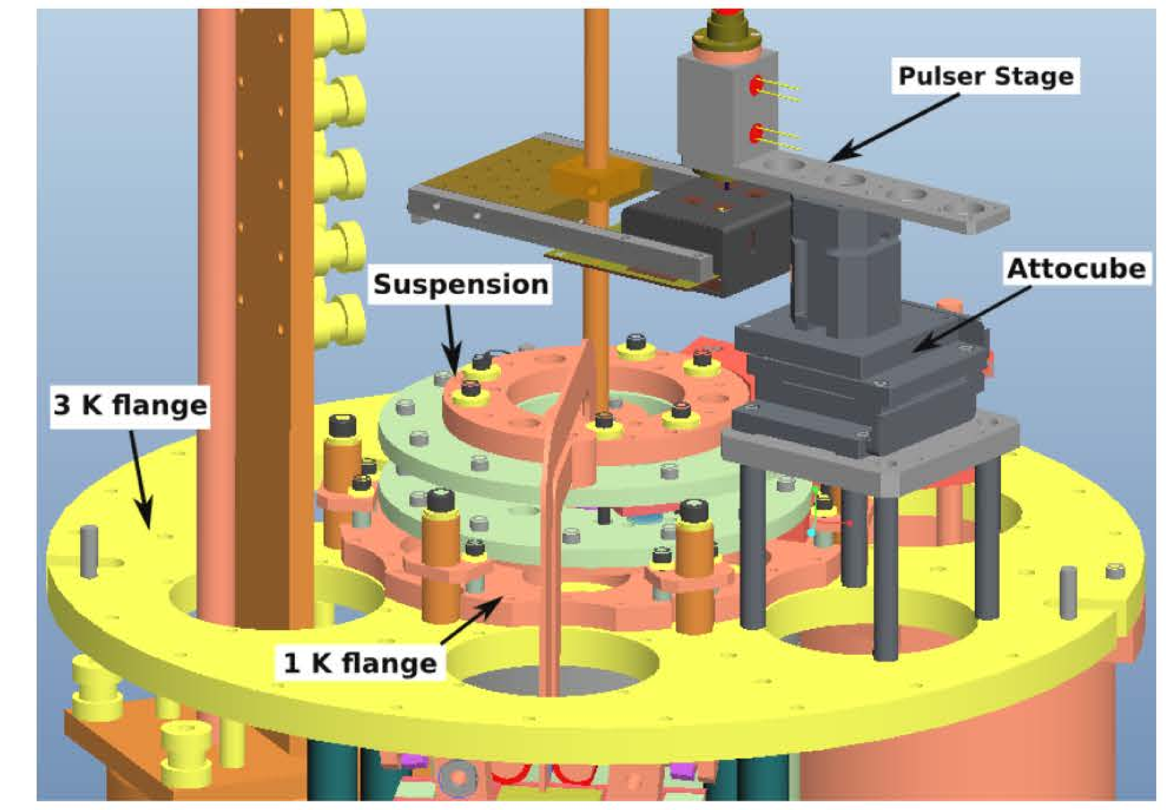
First Prototype: 2+6+6+2 disks

- Setting for heater: 2 μW pulses for 240s with 1800s relaxation time
- GGG ranged from 282 to 425 mK
- Hold time under 100 mK was 17.4 hours with 65 wires heat sunk on it
- Typical heat leak, dominated by 65 wires, is around 1 μW

Position Stability

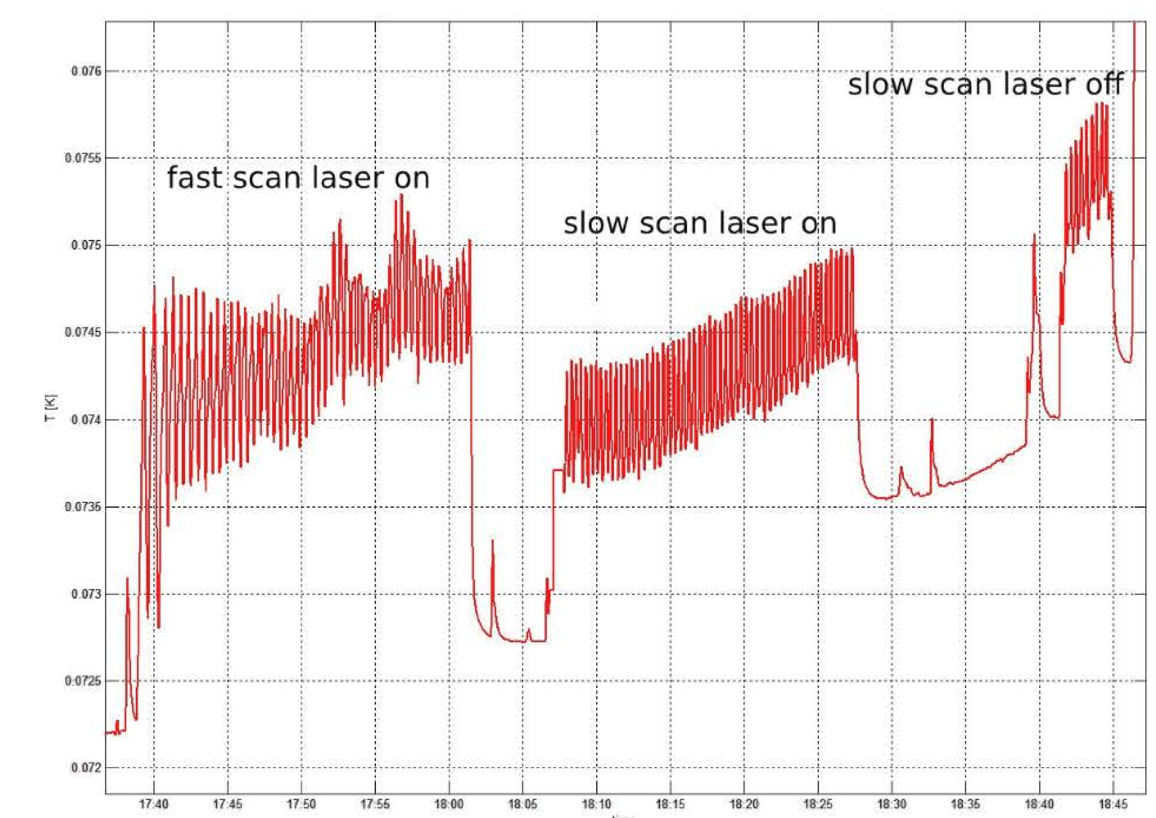


- First image: first few minutes heat switch closed, then opened. 10 minutes later, started the demag. For the rest of the scan the stage sat cold.
- Second image: taken 24 hours later, after a complete remag/demag cycle, including closing the heat switch. Displacement is 1.2 μm.



Impact of Increased Rigidity

Unexpectedly, increasing rigidity increased sensitivity to vibration. Both Attocube and suspension are rigidly attached to the 3 K flange, thus acoustic energy created during Attocube scan results in heat in the ADR stage. We observe change and fluctuation in ADR temperature during attocube scan. Heating level was estimated to be 0.25 μW



Status/ Future Work

- The new suspension worked so well on the first try that it has permanently replaced our Kevlar suspension.
- The performance measurements presented here were obtained in the course of doing our science measurements (i.e. large number of items bolted to the ADR rod and large wire count). We hope soon to obtain ultimate performance measurements of the suspension with only a heater and a thermometer on the ADR rod.
- UNM has filed a provisional patent for the new design, we are seeking funding to develop versions compatible with commercial ADR designs.
- 4 more disks were added to each disk stack in between GGG and 1 K pot stages, for a 6+6+6+6 configuration. That data is being analyzed.

Conclusion

Our new suspension:

- is mechanically robust
- thermal isolation exceeds our Kevlar suspension
- holds ADR rigidly with displacement of $\Delta=1.2\ \mu m$
- is easy to assemble

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