Application Note
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Application- Integration of the Qlibri Microcavity Platform with a Montana Instruments Cryostation® s200 Optical Cryostat

BACKGROUND

This application note details the performance of the Qlibri Microcavity Platform in a Montana Instruments optical cryostat system. The information and test results in this document have been provided by Qlibri. A brief background to introduce the Microcavity Platform:

Qlibri's Microcavity Platform uses fiber-based Fabry–Pérot microresonators, which enables precise coupling of light and matter. A microscopic fiber mirror is combined with a planar substrate, creating a versatile system. A special feature is its three-dimensional scanning capability: the planar substrate can be scanned in the (x, y) plane, while the resonator length can be modulated along the z-axis (see Fig. 1). This allows sample surfaces to be systematically scanned, individual emitters to be targeted, and coupling conditions to be flexibly optimized. This concept allows investigations under very different conditions—from experiments at room temperature to cryogenic environments—and is suitable for a wide range of applications in materials research, quantum optics, and sensor technology.

A key challenge in implementing such systems is mechanical stability. Mechanical vibrations in the nanometer range lead to limitations, especially in closed-cycle cryostats. Due to the high costs and complex logistics of liquid helium, closed-cycle cryostats are preferred, especially in commercial applications. Special measures have therefore been developed for the Microcavity Platform, including optimized geometries, rigid micropositioners, active control mechanisms, and passive vibration isolation. This enables resonator length stability in the sub-picometer range to be achieved, which allows reliable operation even in highly vibrating environments.

The platform provides access to a wide range of solid-state and nanoscale quantum systems – from nanomaterials and defects in semiconductors to two-dimensional materials and biological samples. It is equally suitable for basic experiments and applications in quantum technology, such as the development of single-photon sources, quantum repeaters, or photonic network nodes. Examples include quantum dots, defects in diamond (NV, SiV, SnV), rare-earth-doped crystals, and organic molecules, which can be specifically addressed using the optical microresonator. Integration into closed-cycle cryostats not only enables precise experimental studies, but also long-term applications based on spin-photon interfaces, such as indistinguishable photon sources or quantum nodes.

EXPERIMENTAL SETUP

The Microcavity Platform was integrated into a Cryostation® s200, which offers a unique combination of large experimental space and high stability at 4 K (<20 mK P-P). With a usable volume of approximately 200 mm in diameter and over 116 mm in height, the system opens a wide range of possibilities for complex experimental setups. Despite its size, the s200 maintains extremely low-vibrations: mechanical vibrations are reduced to <15 nm in 3 axes, enabling even highly sensitive measurements to be performed reliably (for more information on how vibrations are measured on Montana Instruments systems, please refer to this white paper on the subject). Eight side windows and an additional top window provide flexible optical experimentation, allowing access for a wide variety of beam geometries and detection methods. The system is fully automated; at the touch of a button on the user interface touchscreen, the sample chamber is evacuated (flushed with nitrogen if necessary), pulled to high vacuum, and cooled to the desired temperature. A modern API user interface allows seamless integration into common programming languages and automation environments.

The excellent cooling performance and low vibration level enable ultra-stable resonance conditions. Complete installation can be carried out in less than an hour. Note that the s200 is a highly customiazable system, so further ingerations in tandem with the Microcavity Platform, such as additonal DC/RF lines or nanopositioners, are possible. For even greater temperature stability and vibrational performance, the Microcavity Platform can be integreated into a CryoAdvance® 100, which has higher temperature stability (<15 mK P-P) as well as faster cooldown time to base temperature.

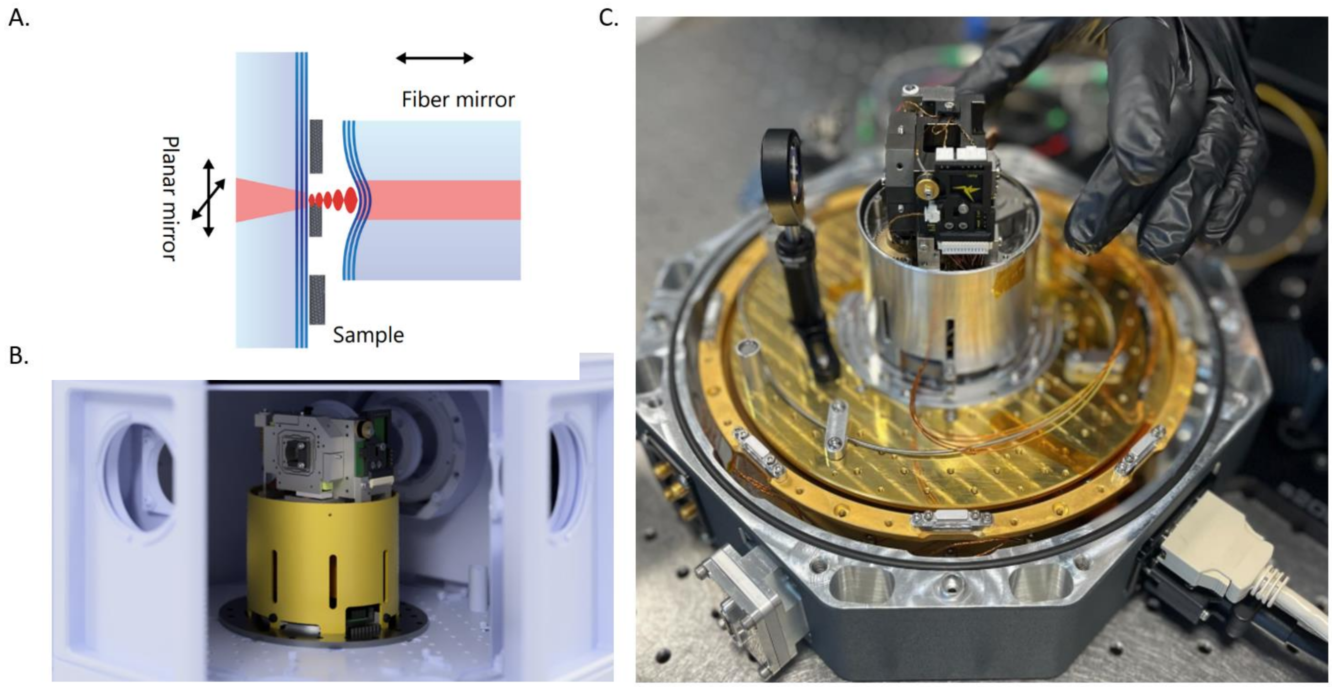

*Figure 1: Structure and embedding of the Qlibri resonator. **A** schematic representation of the structure of a microcavity consisting of a fiber mirror and a planar mirror on which the respective sample is positioned. The optical axis is arranged horizontally. **B** a representation of the microcavity platform inside the Cryostation® s200. **C** installation in the spacious sample chamber of the s200. The collimator lens on the left is used for optical coupling on the horizontal plane.*

Measurement Conditions and Procedures

The vibration assessment was performed directly via the stability of the resonator. For the measurement, edge stabilization (side-of-fringe locking) was used, using a PID controller (which is locked to any resonance peak). The error signal allows conclusions to be drawn about the length stability of the resonator; the detection sensitivity in the measurements extends into the sub-picometer range.

Measurements were recorded at:

- room temperature
- during cooling
- at <9 K sample temperature (platform was around 3.1K)

In addition, various power levels of the GM cooler (up to and including the switched-off state) were investigated to characterize their effects on the vibration behavior of the system.

Results & Discussion

The results show that the vibration level is typically around 150 pm RMS. By adjusting the cooling capacity of the GM cooler, it was possible to reduce this to around 50 pm. With the cooler switched off, stable operation is possible for several minutes without significant warming of the sample (see Fig. 2); due to the large thermal mass of the system, the temperature conditions remain stable. Under optimal conditions, stability below 2 pm was achieved, which allows operation with finesse values of F > 10^5 and thus supports even the most demanding quantum optical experiments. In principle, lower finesse values can also achieve lower, sub-picometer stabilities.

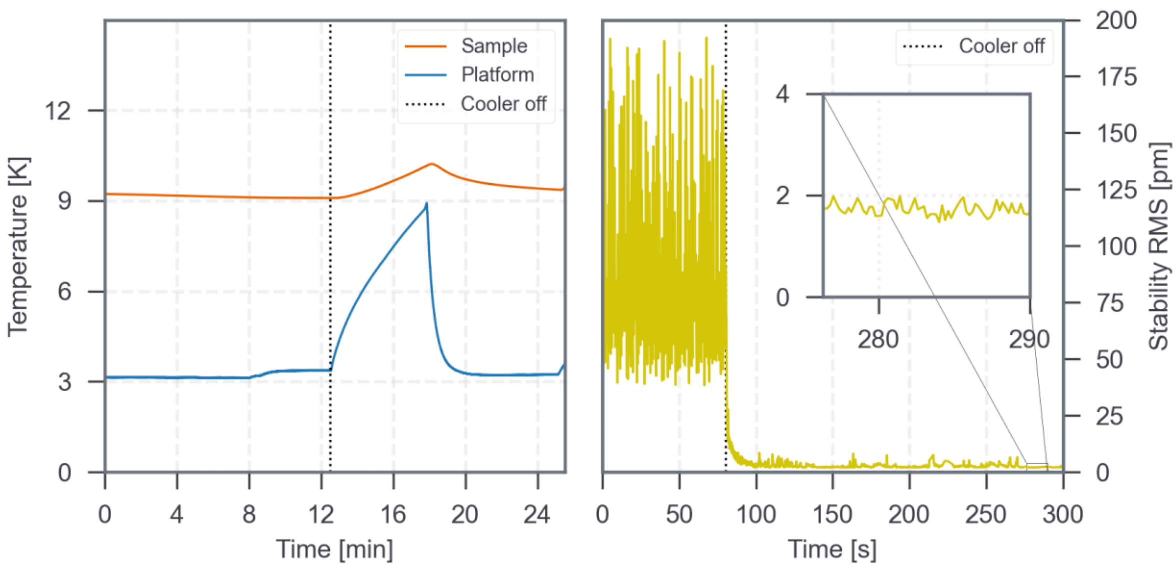

Figure 2: Left: Temperature curves of the Qlibri platform and the cooling head of the Cryostation® s200 as a function of time. Switching off the compressor leads to a slow increase in the temperature of the platform on a time scale of minutes. The Qlibri platform remains temperature-stable during this time due to its thermal capacity. Right: Stability measurements of the resonator length at the time of switch-off. Within a few milliseconds, mechanical vibrations are reduced to 2 pm RMS, enabling ultra-stable measurements.

Conclusions

The Qlibri Microcavity Platform enables ultra-stable operation under cryogenic conditions, and further improvements through customer-specific adaptations are possible and opens access to state-of-the-art experiments in quantum optics. In addition, the integration of external magnetic fields enables targeted control of quantum systems. By using superconducting coils in a Helmholtz configuration, magnetic fields up to 500 mT can be integrated into the setup in a stable and precise manner without compromising mechanical stability. This opens the possibility of fine-tuning optical transitions and making various coupling regimes between light and matter experimentally accessible. Installing the Microcavity Platform in a Montana Instruments optical cryostat ensures excellent vibrational performance at cryogenic temperatures. To further discuss the capabilities of a Montana Instruments cryostat, or for more information on integrating the Qlibri Microcavity Platform into your current Montana Instruments cryostat, please contact a sales engineer.

REFERENCES AND ACKNOWLEDGEMENTS

We would like to thank the team at Qlibri for providing this data and conducting testing with the Cryostation® s200.