Table-top dilution cryostat: Sionludi

A series of table-top dilution cryostats has been realized at the Néel Institute. These cryostats, which are highly appreciated by our experimentalists, make it possible to reach temperatures of about 30 mK in only 3 hours. The currently available cooling power is about 200 pW at 100 mK and the minimum temperature is about 15 mK.

Dilution cryostats achieve very low temperatures by diluting liquid He^3 in liquid He^4. The mixing process is endothermic, thus extracting heat from the surroundings. This allows, cooling of experimental samples or devices to very low temperatures. Our new, improved dilution cryostats (see picture) were developed by the cryogenic, experimental, and mechanical engineering teams of the Néel Institute, inspired by the design of the "spiral-down" dilution refrigerator called "Sionludi", which was invented by A. Benoit in 1990. 20 years of user-experience allowed us to improve the performance as follows:

- two times faster cooling
- 4 times higher cooling power
- 4 times lower temperatures
- reduced liquid He consumption (less than 8 Blow/day)

The outer two stages, at 80 and 20 K, are cooled by means of a counter-flow heat exchanger, in which we find the He^4/He^3 injection lines and the He^4 pumping line. The third stage at 4 K is permanently cooled from a liquid He^4 storage vessel located directly under the cryostat. This stage can also be used to cool heavy experimental parts close to the sample, such as superconducting field coils.

The fourth stage at 0.8 K is thermalized to the so-called "still". The still continuously extract the He^3 from the mixture, thus allowing a steady-state operation. The fifth stage at 50 mK can absorb a heat load of about 1 mW. The last stage is the mixing-chamber stage with a base temperature of about 15 mK. These last three stages represent the heart of the dilution refrigerator where only the He^3/He^4 mixture circulates. They contain a Joule-Thomson heat exchanger, which replace the 1-K-bom of a classical dilution system. It also contains the condensation impediment, the still, a counter-flow heat exchanger, several discrete heat exchangers, and the mixing chamber.

This device has received an increasing interest for users because of the following principal advantage:

Greatly improved accessibility of the cold volume. Contrary to traditional dilution refrigerators, the coldest part of the cryostat is easily accessible. This cold volume is situated at the top of the apparatus, separated from the 300 K vacuum chamber only by 3 to 5 thermal shields. This is an unquestionable advantage for rapid sample-changing and for direct optical or mechanical access.

Compactness and rigidity: The mechanical structure of the Sionludi design makes it compact and rigid, which allows us to achieve a high level of stability. For example, it can be used for cooling STMs (Scanning Tunneling Microscopes) or more spins. We recently achieved two important steps towards these challenging goals.

Concerning the latter objective, for quantum dots containing two Mn atoms (which give complex spectra with up to 60 or 36 lines, e.g. Fig. 2 at top right), we have shown that the precessional motions of the Mn spins become correlated with each other under optical excitation, as a result of their mutual interaction with the carrier spins. This carrier-mediated interaction could be exploited in the future to control the coupling between two Mn spins.

In our research, the quantum dot is an island of the semiconducting compound GaAs inside a layer of ZTe. Absorption of an incident photon creates an electron-hole pair (an "exciton") in the quantum dot, see Fig. 1. Invariably, a photon is emitted when the two carriers annihilate each other.

With a single Mn atom introduced in the dot, the energy and polarization of the photon emitted or absorbed by the dot depends on the spin state of the 5/2–5/2 magnetic atom. This is due to the exchange interaction present in the excited state, between the confined electron-hole pair and the Mn spin. The exciton acts as an effective magnetic field, directed along the dot’s growth axis z. This effective field splits the 5S-1/2 spin states of the Mn atom (which are almost degenerate in the absence of the exciton), leading to a 6-line optical spectrum at quantum dot temperature.

We had already shown that laser excitation resonant with one of these optical transitions can be used to localize a Mn spin and to probe its dynamics optically. The Mn atom behaves like an optically addressable long-lived localized Mn spin and to probe its dynamics optically: The Mn atom behaves like an optically addressable long-lived localized Mn spin and to probe its dynamics optically: The Mn atom behaves like an optically addressable long-lived localized Mn spin and. Additionally, the optical Stark effect could be exploited in the future to control the coupling between two Mn spins.

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