PhD thesis defense

Friday November 14th, 2:30 pm
Hall C. Bloch, Build. 774, Orme des Merisiers, CEA - Saclay

Towards a spin ensemble quantum memory for superconducting qubits

Cecile Grezes

Processing quantum information requires quantum-mechanical systems with long coherence times and that can be easily coupled together to perform logic operations. Superconducting qubits are well suited to perform the rapid logic gates since they couple very strongly to microwave fields, but have coherence times limited so far to tens of microseconds. This limitation has motivated proposals to combine them to a physical system better protected against decoherence. In this hybrid architecture, a memory provides the long-lived register of N quantum states and a few-superconducting qubit processor performs qubit gates to create multi-qubit entanglement. The implementation comes however with new challenges. The multi-qubit register must be able to store N quantum states (“write”), retrieve each of them on-demand (“read”), and be re-initialized between successive experimental sequences (“reset”).

This thesis work discusses the development of these three memory operations in a hybrid quantum circuit, in which collective degrees of freedom of an ensemble of NV center spins in diamond are used as a multimode quantum memory for superconducting qubits. In the first part of the thesis, I present the details of our quantum memory protocol. It relies on the coupling of the NV ensemble to a resonator with tunable frequency and quality factor. Incoming quantum states are written by resonant absorption of a microwave photon in the spin ensemble, and then read out of the memory by applying a sequence of control pulses to the spins and to the resonator.

The second part of the thesis reports our experimental efforts towards the implementation of this protocol, which requires a combination of the most advanced techniques of superconducting quantum circuits and pulsed electron spin resonance. The write step of the protocol is demonstrated in a first experiment by integrating on the same chip a superconducting qubit, a resonator with tunable frequency, and the NV ensemble. Arbitrary qubit states are stored into the spin ensemble via the resonator. After storage, the resulting collective quantum state is rapidly dephased due to inhomogeneous broadening of the ensemble and a refocusing sequence must be applied on the spins to bring them to return in phase and to re-emit collectively the quantum state initially absorbed as an echo. In a second experiment, we demonstrate an important building block of this read-out operation, which consists in retrieving multiple classical microwave pulses down to the single photon level using Hahn echo refocusing techniques. Finally, optical repumping of the spin ensemble is implemented in order to reset the memory in-between two successive sequences. This set of results shows that a spin-ensemble quantum memory for superconducting qubits is within reach of future experiments.