Superconducting multi-resonators structure for spin manipulation and readout

Franco, G., Cochran, J. and Chiorescu, I. (NHMFL, Physics - FSU)

Introduction

Under the research direction of quantum devices, we are developing on-chip coplanar superconducting resonators, using microwave pulses in reflection mode. Microwaves are pumped into the cavity and when the excitation radio frequency (RF) and the cavity resonance are matched, the reflected signal shows a large dip (the energy enters the cavity). We found a new way to tune *in-situ* the coupling of the cavity (if need is), by using the losses generated by vortices. This flexibility is combined with a large coupling between the cavity and a sample containing quantum spins (see [1]). To optimize the cavity-spins coupling, we are developing $\lambda/4$ resonators ended with a short-circuit where the sample is to be placed. In addition, we have the option to place a SQUID in the short-circuit, to perform spin detection with very high sensitivity.

Experimental

The design of the chip is done by means of Sonnet and Comsol simulations followed by optical lithography. If a SQUID is added as spin detector (instead of analyzing the reflected microwave signal) we use an additional stage of electron-beam lithography. The resonator provides a narrow frequency window with concentrated energy, which would be affected by the interaction with the SQUID loop (if any); however COMSOL simulations and device characterization will provide a clear understanding of the resonance profile. The chip is fabricated using Nb film sputtered on Si wafers by our collaborator Dr Lei Chen from SIMIT-Shanghai. Measurements are performed at NHMFL.

Results and Discussion

We have fabricated test resonators with a straight short-circuit at their end and performed preliminary measurements in our dilution refrigerator. The microwave power can be tuned from a low-power regime into a high-power regime, by varying the amount of attenuation at various thermal stages. In the case of high-power regime, an interesting coupling of two resonator modes was observed. The presence of another resonator before the input of the $\lambda/4$ resonator creates a maximum at the entrance as well, while the fundamental mode has a maximum at the location of the short-circuit (see inset of Fig. 1). The modes are thus interacting and the coupling is increasing with the excitation power.

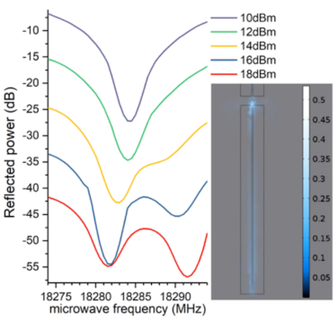

Fig. 1. Smoothed reflected signal for five values of the nominal microwave power and a cavity simulation in inset (see text).

In Fig. 1, we show smoothed reflected power for five values of the nominal microwave power (shifted vertically). The higher the power, the higher the splitting between modes. The inset is a COMSOL simulation at the cavity resonance, showing the B-field (scale in T per 1V signal) at the entrance of the cavity (top) and at the bottom short-circuit. It is worth noting this aspect here, because engineering of resonator modes is demonstrated to have important use in performing quantum gates. In our case, the $\lambda/4$ resonator is coupled with an undesired resonator mode formed in-between the chip input and the coupling to the actual resonator. This low-Q mode brings energy at the resonator input and it is possible to visualize it with COMSOL simulations as well. Although low-Q, the presence of the mode shows that it is possible to achieve a coupling between serially connected resonators. The strength of the interaction is measured to depend on the intensity of the microwave excitation (similar phenomena has been observed using parametric frequency conversion [2]).

Conclusions

We present preliminary studies showing a coupling between two resonators, visible as an eigenvalue splitting in their resonance spectra. The splitting is dependent on microwave power and can be used to tune the interaction between a cavity containing a spin qubit and a bus to transfer the information into.

Acknowledgements

The National High Magnetic Field Laboratory is supported by the National Science Foundation through NSF/DMR-1644779 and the State of Florida.

References

[1] Guang, Y. *et al*, Appl. Phys. Lett. **111**, 202601 (2017).
[2] Zakka-Bajjani, E., *et al*, *Nat. Phys.* **7,** 599 (2011).