Superconducting Coplanar Microwave Resonator

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Abstract:

We are trying to make on-chip superconducting microwave resonators which are capable of driving spins in semiconductors by using the superconducting metal niobium (Nb). These microwave resonators will work mainly in two ways; Sensing magnetic defects and magnetic order in thin films of new materials; Manipulating and measuring the quantum state of a collection of spin defects for use in quantum technologies. This will aid in the optimization of optics and optoelectronics. In the past, the Rana research group did a similar project with the coplanar microwave waveguide resonator, however, in that experiment, the smaller the dimensions of the metal of the deposited metal, which in that case was copper, then the smaller the extent the magnetic field will radiate outward and there will be greater conductive losses. This is the reason we chose to go with a superconductor, which minimizes conductive losses.

Summary of Research:

This summer research project focused on getting familiar with the cleanroom, learning about what a coplanar microwave resonator is, and aiding in the process of developing one that is superconducting.

The tools we used the most with this project were the AJA sputter deposition system to deposit niobium on a sapphire wafer, along with the ABM contact aligner for the UV exposure to the sapphire wafer, and then development with the Hamatech development tool, which makes the pattern on the sapphire wafer visible using the 726 MlF solution for 60 seconds.

The working principles behind why the device will be resonant at certain frequencies has to do with the transmission lines on the device. A simple analogy can be made with the length of a string where its resonant frequency is directly related to its length by the equation f_o = velocity/2Length, which are considered standing waves.

The same is true of our transmission lines except that in AC electronics, we must consider the voltage and current waves and the rise and collapse of these waves, which will in turn give us a better idea of their resonant frequencies. The inductive and capacitive properties of the superconducting coplanar microwave resonator also gives rise to the resonant frequencies at which the device will operate. Given those two things, transmission line length and the reactive AC components of the device will determine the resonance at which the device operates.

We designed three devices on the sapphire wafer (Figure 1). The respective resonant frequencies of each device are shown in an array on the sapphire wafer and are 2 GHz at 29.62 mm (Figure 2), 4.l GHz at 14.61 mm (Figure 3), and 8 GHz at 7.5 mm (Figure 4).

The idea was to sample materials using the superconducting coplanar microwave resonator, which entailed probing the resonator with a DC power source to get a static magnetic field that shoots out perpendicular to the coplanar microwave resonator's surface, and probing the device with a microwave frequency to be sent inside of the device, which created our oscillating magnetic field.

At microwave frequencies, the spin-states of the electrons will split into two even but opposite energies of $El = +1/2\ g\mu_B B$ and $E2 = -1/2\ g\mu_B B$ where $\sim \Delta E = El - E2$.

From there we could observe the electron's spin behaviors from the bode plot that was characterized from the material we sampled and which will be the future work to be performed on this device.

Conclusions and Future Steps:

The device is now ready for characterization, which means that we will next take a look at the transmission characteristics and see where our device is resonant at. Resonance will occur at microwave frequencies where $\hbar(\omega) = g\ \mu_B f$;.

References:

[1] Standing Waves and Resonance, Chapter 14 - Transmission Lines, Electronics Textbook (allaboutcircuits.com).

[2] Coplanar waveguide resonators for circuit quantum electrodynamics, Journal of Applied Physics 104, 113904 (2008); https://doi.org/10.1063/1.3010859; M. Göppl, A. Fragner, M. Baur, R. Bianchetti, S. Filipp, J. M. Fink, P. J. Leek, G. Puebla, L. Steffen, and A. Wallraff.

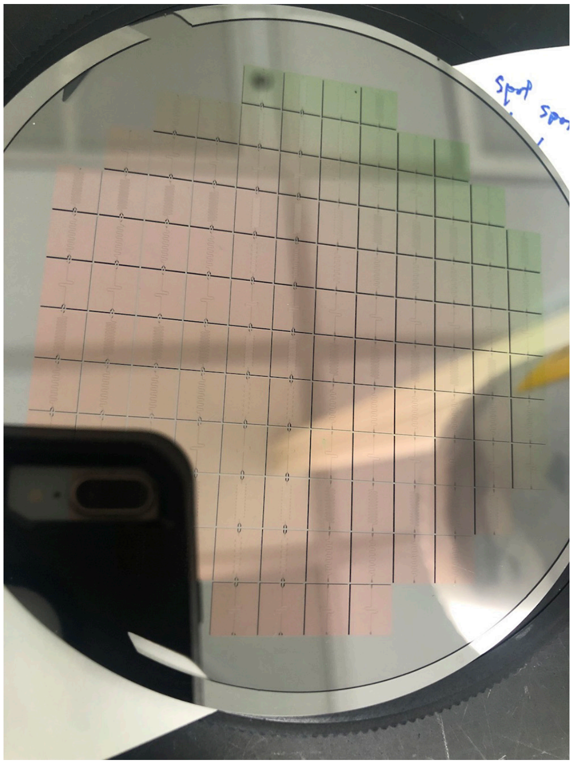

Figure 1: We designed three devices on the sapphire wafer.

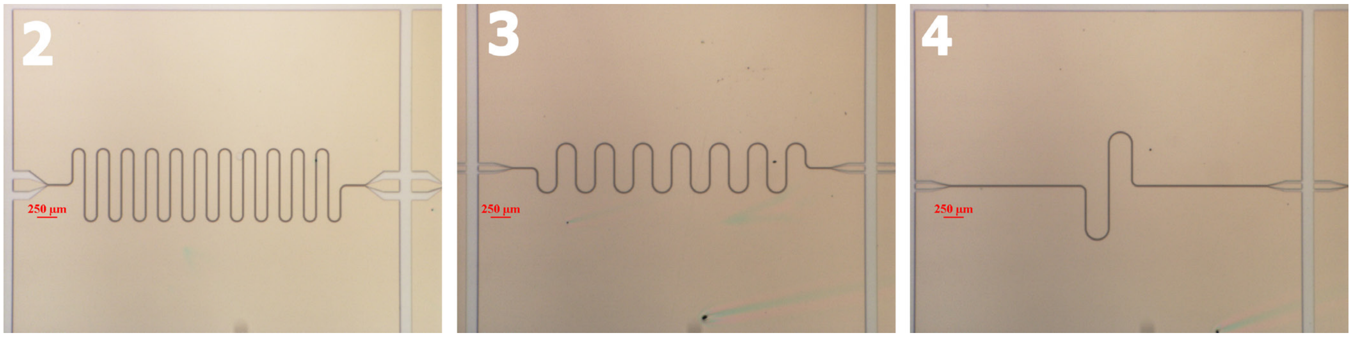

Figure 2-4: The respective resonant frequencies of each device are shown in an array on the sapphire wafer and are 2 GHz at 29.62 mm (Figure 2 left), 4.l GHz at 14.61 mm (Figure 3 middle), and 8 GHz at 7.5 mm (Figure 4 right).