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CULTASK, The Coldest Axion Experiment at CAPP/IBS/KAIST in Korea

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The axion, a hypothetical elementary particle arising from Peccei-Quinn solution to the strong-CP problem, is a well-motivated dark matter candidate. The IBS Center for Axion and Precision Physics Research (CAPP) in Korea will explore the dark matter axion using a method suggested by P. Sikivie, converting the axions into microwave photons in a resonant cavity permeated by a strong magnetic field. CAPP's first microwave axion experiment in an ultra-low temperature setup is being launched at KAIST (Korea Advanced Institute of Science and Technology) campus this summer, utilizing top of the line equipment and technology. I will discuss the progress and future plans of the axion experiment.

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1. Axion research at CAPP

The Center for Axion and Precision Physics Research (CAPP) of the Institute for Basic Science (IBS) was founded to launch a state-of-the-art axion dark matter experiment in Korea. CAPP's design of the axion experiment is based on P. Sikivie's haloscope scheme[1] which employs high Q-factor tunable microwave cavity submerged in a very high magnetic field. The signal from the cavity is amplified through the SQUID amplifier and transmitted to the room temperature RF receiver unit to be processed further. The physical temperature of the cavity should be maintained extremely low in order to reduce the noise from the black body radiation, and eventually to improve the signal-to-noise ratio and speed up the experiment. The RF receiver unit to amplify and process the radio frequency signal from the resonant cavity could be considered to be the most sensitive radio on earth. CAPP's plan, as a late starter, is to acquire experience through the collaboration with existing experiments and to build a competitive, qualitatively and quantitatively, axion experiment in Korea through local resources. It requires the powerful 25T magnet delivery from BNL (Brookhaven National Laboratory), the next generation SQUID development from KRISS (Korea Research Institute for Standards and Science) and the superconducting high frequency cavity through the collaboration with KAIST (Figure 1). The ultra high field magnet being developed by BNL has exceptionally big 10cm bore and is based on a new technology called HTS (High Temperature Superconductor). The compact (outer diameter of only 30 cm) design of the magnet was intended to produce even higher field of 35T or 40T magnet by adding another layer of magnet outside in the future. If successful, this magnet will be the highest-field superconducting magnet in the world with HTS technology. Another innovative feature of the design of the magnet is the use of stainless steel as an insulator in superconducting tapes. It will reduce the chance of failure (quench) and minimize the damage that failure could cause. The experience we gain and the success of those outsourced projects would be crucial to building CAPP's own axion experiment and provide very competitive edge over the existing experiments.

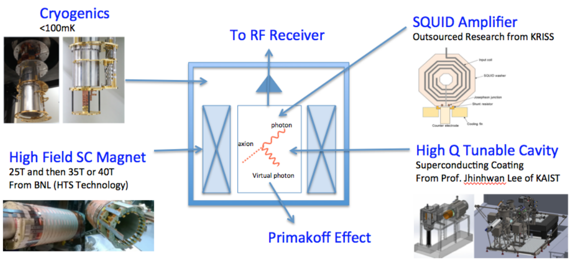

Figure 1: CAPP's plan for axion search

2. CAPP's Ultra Low Temperature Axion Search in Korea (CULTASK)

CAPP's new laboratory located at KAIST Munji Campus will be ready for the first axion experiment in Korea by the end of this year or early next year. The architect's design of the space for 7 dedicated dilution refrigerators with low vibration facility is completed and the construction will begin some time in late summer. While waiting for the building ready, CAPP decided to prepare our axion experiment, taking advantage of the downtime (4 months) of Prof. Hyoungsoon Choi's (KAIST) dilution refrigerator.

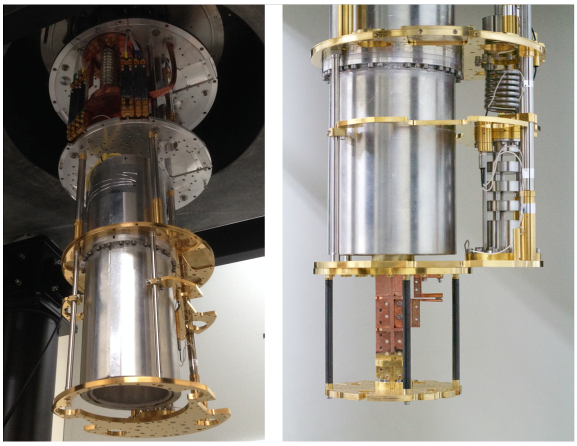

Figure 2: BlueFors LD400 Dilution Refrigerator

The refrigerator (BlueFors LD400) happens to be exactly the same model that will be used for our axion experiment and has preinstalled 8T superconducting magnet (inner bore size: 6 cm) in it. The SQUID amplifiers and the superconducting cavities might not be ready soon enough to be used in this setup, but it is a great opportunity as an engineering run to build an infrastructure and prepare ourselves for the upcoming axion experiment. Figure 2 shows Prof. Choi's dilution refrigerator with superconducting magnet. The cavity with frequency tuning system is designed and fabricated. The tuning rod is made of Alumina.

2.1 High Q-factor cavity development

2.1.1 Fabricated Cavities

We have several prototype cavities fabricated so far. A couple of cavities were made with conventional electroplating (inner surface), with and without annealing. The local machining company made a couple of stainless steel (2 mm thick) cavities back in April and one of them was coated with electroplating and the second one was sent to the coating lab of the Technical University of Munich for 50 micron thick sputtering coating of 6N pure copper. They would also test the possibility of sputtering pure 6N Al inside the stainless steel cavity. One last cavity we outsourced for research and expected to be completed in summer is from STC (Seoul Teracom) of Seoul National University's Prof. Gunsik Park. These cavities will have pure copper sheet (1 mm thick) brazed inside the stainless steel cavity instead of coating. They will be delivered with complete test results.

2.1.2 RRR and RF Q-factor

The RRR (residual resistivity ratio= resistivity@296K / resistivity@4K) of ultra pure copper and aluminum is, in some sense a measure of purity, and could go up to 50000 if annealed properly. The measured Q-factor of the RF cavity is expected to be proportional to the square root of the resistivity assuming that the condition of the surface is perfect and there is no contact problem. However, there is magnetoresistance effect which degrades RRR, tens, even hundreds times when magnetic field is applied. The natural choice of coating on the inner surface is copper, but recent development in material purification shows that high purity aluminum (99.9999%) exhibits exceptional RRR of 50000 when annealed properly and the degradation of RRR in high magnetic field (1-10 T) is much smaller than that of copper[2]. The coating with pure Al was one of the recently added research projects. We have already started joint efforts with KAIST to measure RRR of various samples (4N, 5N, and 6N Cu and Al) with and without annealing. Also we are planning to make test cavities with ultra pure Cu and Al and perform a quick Q-factor measurement (dunk test) with a large neck (5.5 cm diameter) Helium dewar, which can be done in parallel with our engineering run.

2.1.3 Support structure

The thermal simulation study for the support structure with COMSOL Multiphysics package is planned. In case we have trouble lowering the temperature of the cavity, other choice of the support structure could be the copy of Prof. Choi's support structure which he routinely use for reaching 6 mK. Our setup with the cavity has more materials and several heat sources, but should be able to go under 100 mK according to Prof. Choi (simulation should verify too).

2.1.4 Tuning system

The actuator with the controller for tuning system will go through precision test in coming weeks. The step size for the frequency scan in 5 GHz resonant frequency should be around 10 kHz, which corresponds to a thousandth of a degree of the actuator rotation per operation.

2.2 RF electronics and DAQ

2.2.1 Cryo-RF

The cryogenic circulators (isolators) and amplifiers (HEMT) have been received and tested at KRISS by Dr. Yonuk Chong using his dilution refrigerator. He will give us a report of the test and has plans to have a another test with a simple cavity (OFHC mock-up, delivered) with circulators and amplifiers using Cryo-Cooler, whose fabrication is going to be completed in September. The integration of cryo-RF parts into Prof. Choi's dilution refrigerator will be done as soon as we are confident about the performance of our cavity and associated tuning system.

2.2.2 RT-RF Receiver

Both the design and the fabrication of room temperature RF signal processing receiver chain are complete. The initial tests have been done by Dr. Young-Im Kim. The signal digitization or recording of the data has been tested by Dr. Myungjae Lee. The next step is to wait for the healthy signal coming (from the cavity) through cryogenic RF signal processing, which includes cryogenic circulators and amplifiers (HEMT).

3. Conclusion

Our preparation for the engineering run of CULTASK is rather complete at this stage and ready to go. However, we plan to go step by step, placing one thing at a time into the dilution refrigerator and make sure everything works as expected. Along with the engineering run, we will also measure RRR of our pure Cu and Al samples and quick Q-factor measurement with Helium dewar. Our goal is to build a complete axion experiment (minus SQUID) that works before this year is over. We are scheduled to have two dilution refrigerators (BlueFors LD400) and a superconducting magnet installed in Munji Campus in the last week of Jan. next year. What we learn from this engineering run will be crucial to the success of the upcoming axion experiment.

4. Acknowledgments

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References

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