Launching Axion Experiment at CAPP/IBS in Korea

Woohyun Chung[1],

[1]Center for Axion and Precision Physics Research, IBS, Korea

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The main research focus of the Center for Axion and Precision Physics Research (CAPP) at IBS is to establish a state-of-the-art axion experiment in Korea and to search for relic axion particles converting to microwave photons in a resonant cavity submerged in a strong magnetic field. The initial stage of building our axion experiment, CULTASK (CAPP Ultra Low Temperature Axion Search in Korea) is completed at KAIST (Korea Advanced Institute for Science and Technology) Munji Campus with successful installation of two new dilution refrigerators (one with 8T superconducting magnet) which could lower the temperature of cavities to less than 50 mK. A resonant cavity (10 cm OD) and the support structure were fabricated and installed with the frequency tuning system employing a sapphire rod driven by a piezoelectric actuator. The RF measurements were also performed for evaluating and improving noise figures using cryogenic HEMT amplifiers. I will discuss the status and progress of CULTASK, soon to be complete with a DAQ and monitoring system, and future plans. I will also present the recent results from the development of high Q-factor, ultra pure Cu and Al cavities under high magnetic fields, utilizing the two refrigerators.

1 R&D Projects for Axion research at CAPP

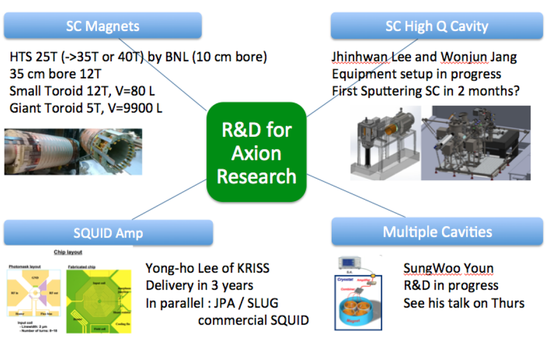

Figure 1: CAPP's R&D projects for axion search

The Center for Axion and Precision Physics Research (CAPP) of the Institute for Basic Science (IBS) is launching a state-of-the-art dark matter axion experiment in Korea. The design of the axion experiment at CAPP is based on P. Sikivie's haloscope scheme[1]. Axions resonantly convert to microwave photons by a reverse Primakoff interaction inside a tunable cavity permeated by a strong magnetic field. The feeble signal from the cavity is amplified through a SQUID amplifier and transmitted to a room temperature RF receiver unit to be processed further.

CAPP is driving a research and development plan to achieve the sensitivity required for the entire range of axion models. The

R&D plan includes high field superconducting magnets with various bore sizes (5, 10 and 35 cm inner diameter), high Q-factor superconducting cavities, high-gain gigahertz superconducting quantum interference device (SQUID) amplifiers and multi-cavity phase locking scheme for higher axion mass (Figure 1).

A powerful 25 T superconducting magnet will be developed and delivered by BNL (Brookhaven National Laboratory) in 2 to 3 years. The ultra high field magnet being developed by BNL has exceptionally big 10 cm bore and is based on a next generation technology called HTS (High Temperature Superconductor). The compact (outer diameter of only 30 cm) design of the magnet is intended to produce even higher field of 35T or 40T by adding another layer of LTS magnet outside in the future. If successful, this magnet will be the highest-field superconducting magnet in the world with HTS technology.

Prof. Jhinhwan Lee of KAIST (Korea Advanced Institute of Science and Technology) is leading the effort of coating superconductors inside resonant cavities. Various configurations and different coating materials are being experimented now to overcome the effect of high magnetic field (>8T) that goes through the cavity and to achieve the high Q-factor ($> 10^6$) for the resonant mode of choice (TM_{010}). The first sample of dc SQUID amplifiers (center frequency of 2.5 GHz) developed by Dr. Yong-Ho Lee of KRISS (Korea Research Institute of Standards and Science) will be delivered and tested this year. 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 is being tested in engineering runs right now.

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

	BF3	BF4
Model	BlueFors LD400	BlueFors LD400
Magnet	None	8T (AMI), 12cm ID
RF lines	24	8
DC lines	72	72
Cool down to <10 mK	20 ~ 24 hours	40 ~ 48 hours
Base temp at MXC	9 mK	7 mK w/ SC magnet
MXC temp w/ Load	11 mk w/ Al cavity (4cm id) and HEMT amp	30 mk w/ 10 kg OFHC copper support structure and cavity + HEMT amp + Network Analyzer + Piezo Controller

Figure 2: Properties of BlueFors LD400 Dilution Refrigerators at KAIST Munji campus

Two dilution refrigerators (BlueFors LD400) were delivered, installed and tested in March this year at CAPP's new laboratory located at KAIST Munji campus. One refrigerator(BF3) is designed for testing RF components (directional couplers, cryogenic circulators, resonant cavities and HEMT or SQUID amplifiers) and the other(BF4) refrigerator equipped with 8T superconducting magnet (12 cm inner bore) is for setting up a small scale axion engineering run. Figure 2 shows the characteristics of two new BlueFors dilution refrigerators. These refrigerators are designed to cool down and warm up relatively quick (20 $\sim$ 24 hours or 40 $\sim$ 48 hours when there is a 50 kg magnet attached) and fully automatic with a script so that it could cool down all the way with a touch of a button.

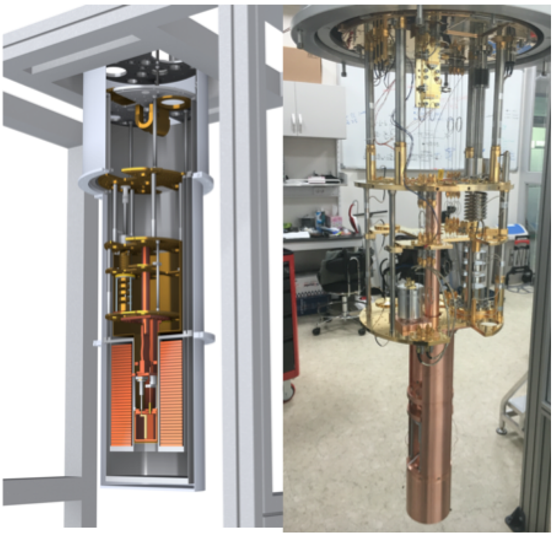

Figure 3: BlueFors LD400 dilution refrigerator with cavity and frequency tuning system installed

We have designed a pure copper resonant cavity with 9 cm inner diameter (2.5 GHz for TM_{010} mode) and a support structure with frequency tuning system (Figure 3). The physical temperature of the mixing plate which is thermally linked to the cavity and the support structure is around 30 mK now (7mK without cavity) with antenna probe and frequency tuning rod connected to piezoelectric actuators. Sapphire (dielectric) tuning rod is designed to be thermally linked to 100 mK plate. The piezoelectric actuators are used to control frequency tuning rod (rotator) and probing antenna (linear) inside the refrigerator.

2.1 High Q-factor cavity development

Variety of sample cavities (OFHC Cu, 5N Al and 6N Al) were prepared to test the enhancement of Q-factor in a cryogenic temperature. The technique of annealing is crucial for improving a Q-factor and we are at the stage of calibrating annealing furnace for now. The other important factor that has an impact on Q-factor is surface roughness. The high precision diamond-cutting technology is employed and the surface tolerance is less than 50 nm.

2.1.1 Superconducting Al cavity

Al cavity becomes superconducting around 1.2K, which may not be very helpful for axion experiment with powerful magnetic field, because the critical field for Al is around 10 mT. However, it could provide us insights on how to design the cavity when superconducting coating is available. Al cavity of conventional design (cylinder with two lids) gets superconducting and Q-factor rises around 200,000 (TM_{010} mode) when the temperature is about 800 mK. Poor contact between lids and cylinder wall is suspected for not completely superconducting. The examination of TE_{011} mode (no electric field along z direction) shows 2 to 20 million Q-factor (depending on the temperature). It is clear that the contact problem could be a limiting factor even when we have a superconducting cavity. One important lesson we learn from the simulation of cavity is that the Q-factor of TM_{010} doesn't change when a perfect cavity is sliced vertically, even when split pieces were separated a little. We fabricated Al split cavity by machining two equal whole half pieces (by digging out half cylinder), effectively eliminating a contact problem, and the Q-factor goes up to over 2 million. It is also much easier to coat two half pieces (or many pieces) of cavity and we don't have to worry about the contact problem any more. We are actually applying this technique when coating superconductors to inner surface of cavities now.

2.2 Engineering Run in 2016

We are setting up a small scale, mid-to-low sensitivity axion experiment with BF4 as a starter. This detector includes 8T superconducting magnet, 9 cm inner diameter OFHC Cu cavity, cryogenic RF chain (antenna probe, directional coupler, cryogenic circulators and amplifiers), and a system of room temperature RF receiver. In addition, there should be a DAQ system (CULDAQ) that controls, monitors the whole detector, and collects and stores data for analysis. The frequency tuning system with a sapphire tuning rod controlled by piezoelectric actuator is going through a precision test now and could be added later when we are confident.

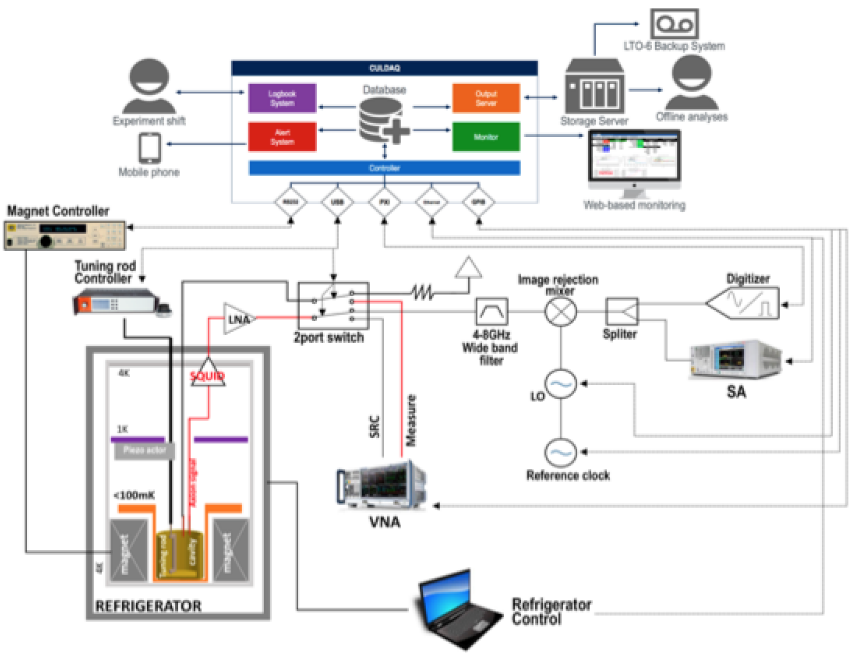

Figure 4: CULTASK DAQ system: CULDAQ

Figure 4 shows a complete axion detector set-up. We won't be able to reach KSVZ[2][3] sensitivity without SQUID amplifiers and superconducting cavity that should be available in a couple of years. However, this engineering run could provide us a great opportunity to prepare ourselves for evaluating and maximizing performance of other RF electronics components.

Cryogenic circulators (isolators) and amplifiers (HEMT) have been received, tested at KRISS by Dr. Yonuk Chong and will be verified at our BF3 refrigerator. The design and fabrication of room temperature RF receiver electronics setup is complete with mixers, filters and a spectrum analyzer. The digitization of signal and the recording of the data has been tested already. The data acquisition system (CULDAQ) that also controls and monitors switches, network analyzer, piezo controller, spectrum analyzer will be ready by September.

3 Plans beyond 2016

The construction of 7 low vibration pads at the axion experimental site in KAIST Munji campus will be compete by the end of September and 4 more dilution refrigerators are to be installed early next year. Two 8T NbTi superconducting magnets (12 cm and 16 cm inner bore) will be used with two BlueFors dilution refrigerators and 18T 5cm bore HTS magnet is scheduled to be delivered in 2017. More superconducting magnets with much bigger bore sizes (35 cm and 50 cm) are also planned in the pipeline. Powerful magnets with different bore sizes along with the efforts on multi-cavity phase locking study would help us to search axions throughout the whole possible mass range. The improvements on booting axion conversion power by developing superconducting high-Q factor cavity and employing quantum limited SQUID amplifiers will pave a way to reach KSVZ QCD axion sensitivity region and beyond.

4 Conclusion

The preparation for the engineering run of CULTASK is complete at this stage and ready to go forward and collect physics data at least for a single frequency this year. The experimental space of 7 low vibration pads at KAIST Munji campus will be ready in a couple of months and more refrigerators are scheduled to be installed early next year (2017). The addition of SQUID amplifiers, ultra high field magnets and high Q-factor cavities with superconducting coating will improve the sensitivity and make a major contribution to axion research in coming years.

5 Acknowledgments

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