PIRE GEMADARC

FEBRUARY 2020 NEWSLETTER – SPECIAL ISSUE

RESEARCH ACCOMPLISHMENTS AND IMPACTS TO DATE

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1. Introduction To PIRE-GEMADARC Membership Institutions

PIRE-GEMADARC is comprised of 13 institutions across Canada, China, Germany, India, Taiwan, and the United Sates whose logos are shown below in Figure 1. Together we aim to advance germanium material and germanium detector technology for the next generation of dark matter and neutrino physics experiments including neutrinoless double-beta decay. *---Written by Prof. Dongming Mei from the University of South Dakota in the U.S.A.*

Fig.1: PIRE-GEMADARC partnership.

2. PIRE-GEMADARC Research Goals

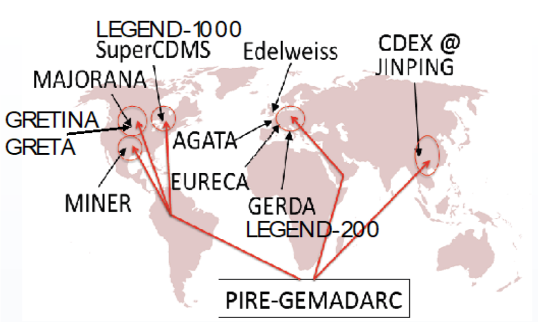

Fig. 2: PIRE-GEMADARC involves global major Ge-based experiments, world-class underground laboratories, and leverages best R&D research in the world.

The three research goals are to: (1) gain new knowledge by developing novel materials and detectors to improve the sensitivity of dark matter and neutrino experiments; (2) advance education and training by providing international training opportunities to undergraduate STEM majors, graduate students, postdocs, and early career faculty as well as developing a diverse workforce in physics and engineering; and (3) promote global research partnerships by improving collaboration on Ge-related R&D activities through integrative global partnerships. Figure 2 shows a broad global partnership.

---Written by Prof. Dongming Mei from the University of South Dakota in the U.S.A.

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Submit news or ideas to:
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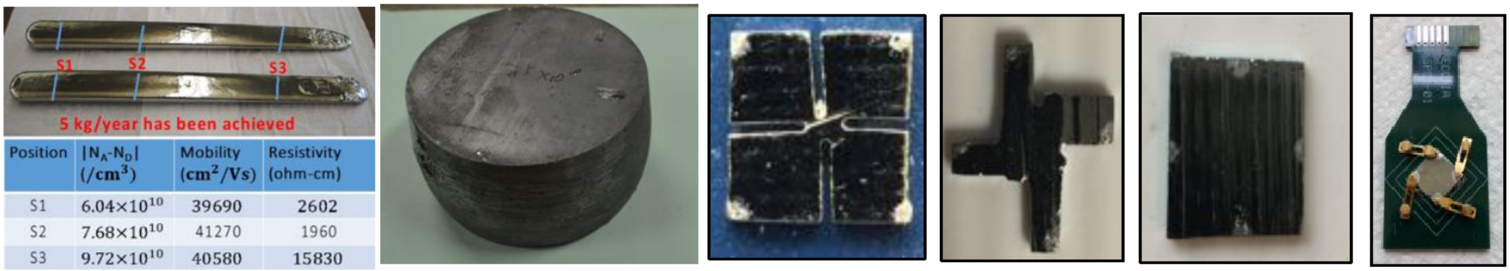
3. PIRE-GEMADARC Research Objectives

The three major research goals have specific research objectives. Task 1 – Material Advancement aims to achieve 5 kg purified germanium ingots with an impurity level of $10^{10}/cm^3$ each year. This will serve as the input material for growing 4 kg of detector-grade crystals (1-3$\times$ $10^{10}/cm^3$) each year to be used in the development of novel detectors. Task 2 – Detector Development aims to innovate Ge internal charge amplification technology for low-mass dark matter searches and coherent neutrino nucleus scattering detection. Fabrication of SuperCDMS-type detectors to address issues such as charge trapping, surface leakage current, and electrical breakdown at higher fields at cryogenic temperature. We must also conduct R&D on detectors to address the needs from LEGEND for neutrinoless double-beta decay. All the above objectives require multiple crystal growths to meet detector requirements. This can be only possible with in-house crystal growth and detector fabrication abilities such as possessed within the PIRE-GEMADARC consortium, which provides two weeks turn-around and integrates research with education. Commercial companies will not be able to make such a such fast turn-around if crystals or detectors do not meet our requirements. They will need at least 4-6 months to re-deliver crystals and detectors. *---Written by Prof. Dongming Mei from the University of South Dakota in the U.S.A.*

4. Material Advancement Accomplishments



Position	$\|N_A-N_D\|$ ($/cm^3$)	Mobility (cm^2/Vs)	Resistivity (ohm-cm)
S1	6.04×10^{10}	39690	2602
S2	7.68×10^{10}	41270	1960
S3	9.72×10^{10}	40580	15830

Fig.3. Left: the zone-refined ingots; Middle: a big crystal with a diameter of 10 cm and a length of 7.4 cm as well as the top impurity of 2.06×10$%/' ( ) and the bottom impurity level of 2.68×10$%/' ( ) ; Right: the four pictures show the geometries of the samples used in characterizing the systematic error of the Hall Effect system.

During the first two years of the grant period, we have published a paper (G. Yang, K. Kooi et al., Applied Physics A, 124 (2018) 381.) with three additional papers are under development by three graduate students. The goal of zone-refining of 5 kg of germanium ingots per year with an impurity level of $10^{10}/cm^3$ has been achieved by students. The production of 4 kg of detector-grade crystals each year has also been achieved by students. In particular, a large-size crystal of about 2.96 kg was grown. The systematic error in the characterization of crystals using the Hall Effect system has been studied by a graduate student. Figure 3 shows the zone refined ingots, a big detector-grade crystal (~2.96 kg), and a few geometries of samples used in studying the systematic uncertainty. *---Written by Prof. Dongming Mei from the University of South Dakota in the U.S.A.*

5. Novel Detector Development Accomplishments

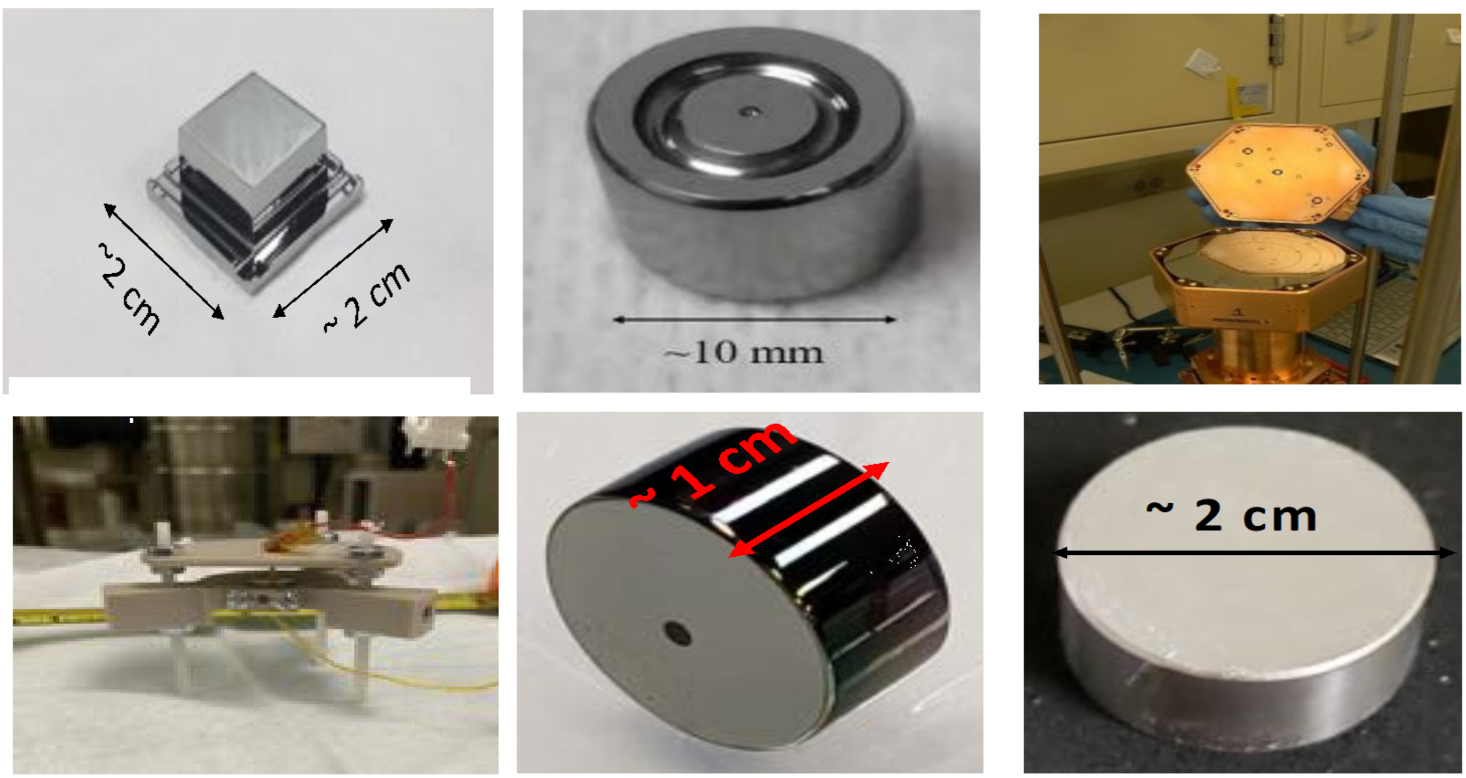


Fig. 4: Upper left: A planar detector made at USD; Upper middle: A point contact detector made at Tsinghua; Upper left: A SuperCDMS detector made at TAMU using USD-grown crystal; Lower left: the test setup for testing miniPPC detectors at UNC; Lower middle: a miniPPC detector made at TAMU; Lower right: another miniPPC detector made by a graduate student at TAMU using a USD-grown crystal.

Within the first two years, we have published four papers (W.-Z. Wei et al., JINST, 13 P012026 (2018), X.-H. Meng et al., JINST, 14 P02019 (2019), D.-M. Mei et al., EPJC 78 (2018) 187, D.-M. Mei and W.-Z. Wei, Phys. Letters. B 785 (2018) 610) regarding the development of novel detectors for low-mass dark matter searches and neutrinoless double-beta decay. Two more papers are under development and will be submitted for publication shortly. Ge internal charge amplification (GeICA) technology has been moved forward in both theory and experimental development. Several detectors have been fabricated and tested at Tsinghua University and USD. Monthly conference calls hosted by ASIOP have involved participants from BHU, Sichuan University, Tasinghua, and USD. A SuperCDMS-style detector has been fabricated at TAMU and tested at UMN. We have observed the time-dependent impact ionization for the first time. A couple of miniPPC detectors have been fabricated at TAMU for LEGENG R&D with testing conducted at UNC. A graduate student at UNC presented the design ideas at the APS DNP meeting in 2018. Figure 4 shows some work-in-progress for the detector development. *---Written by Prof. Dongming Mei from the University of South Dakota in the U.S.A.*

6. Improvement of Detector Performance Accomplishments

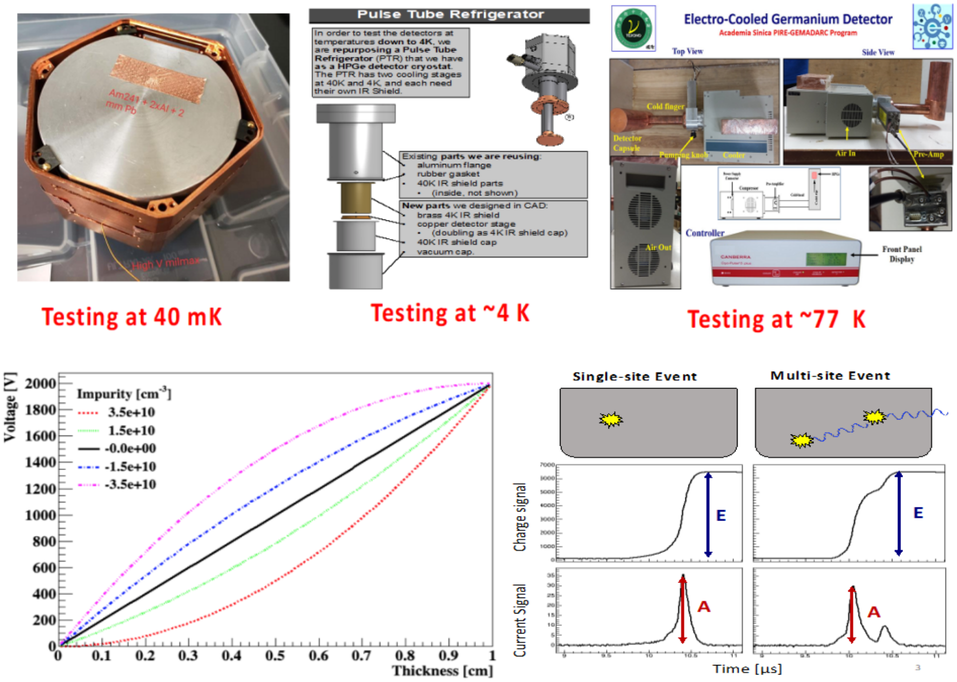


Fig. 5: Upper left, middle, and left: Testing detectors at 40 mk, ~4 k, and 77 K. Lower left: The filed distribution in a planar detector using GeFiCa; Lower right: New ideas on pulse shape analysis.

The collaboration has been testing detectors at 40 mK and 77 K for the detectors fabricated at TAMU, USD, Tsinghua, and LBNL. In addition, ASIOP has been testing a Ge detector with mechanical cooling with low-noise to achieve a threshold of 200-300 eV for low-energy neutrino physics. USD is also working on a testing facility with a pulse tube refrigerator to test the detectors made at USD at ~4 K. We aim to have a better understanding on the charge transport and charge trapping within detectors in different temperature regimes. A paper regarding charge trapping at 77 K has been released to the archive (arXiv: 1909.05806) and submitted to a physics journal for publication. A special Germanium detector Field Calculator (GeFiCa) has been developed by a graduate student under the guidance of a young faculty memebr at USD to calculate electrostatic potentials and fields inside Ge detectors with various geometries. New ideas on pulse shape discrimination using machine learning algorithms have been explored at UNC. Figure 5 displays the work-in-progress. *---Written by Prof. Dongming Mei from the University of South Dakota in the U.S.A.*

7. Emerging Detector Technology Accomplishments

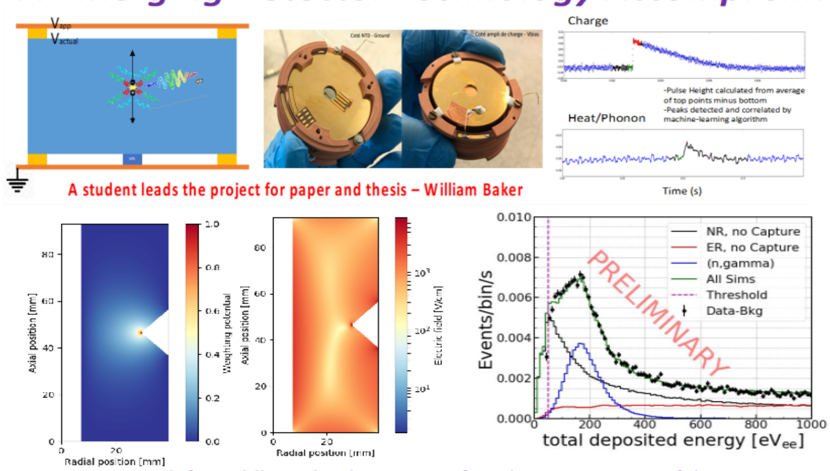


Figure 6: Upper left, middle and right: Contact free detector concept, fabrication, and performance; Lower left: The field calculation for a ring contact detector; Lower right: A preliminary results from the low-energy nuclear recoil measurements.

During the first two years, the search for dark matter and neutrinoless double-beta decay has evolved and new detector technologies and new knowledge on the detector response to nuclear recoils have been proposed. PIRE-GEMADARC has paid a close attention to the new demands which has motivated us to develop two new technologies and a new low-energy nuclear recoil measurement. The contact free SuperCDMS-type detector has been developed at TAMU with a new partner in France. This detector aims to address the low leakage current and electrical breakdown issues observed with the current SuperCDMS-type detectors. A ring contact detector proposed by David Radford at ORNL aims to develop large-size Ge detectors (> 6 kg) for ton-scale neutrinoless double-beta decay to further reduce background by reducing cables and small parts. A student at UNC has presented the field calculation and the design ideas in the APS DNP meeting in 2018. Si and Ge detectors response to low-energy nuclear recoils below 1 keV are important knowledge in searching for low-mass dark matter in sub-GeV. UMN has started low-energy nuclear recoil measurements using high-energy gamma rays produced by thermal neutron captures. Figure 6 exhibits some work-in-progress for emerging detector technology. *---Written by Prof. Dongming Mei from the University of South Dakota in the U.S.A.*

UPCOMING EVENTS

1. NSF Reverse Site Visit: February 28, 2020
2. PIRE-GEMADARC 2020 Sumer School and Collaboration Meeting, May 20 - 30, 2020, Taiwan

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