RESULTS OF THE CRYOGENIC DARK MATTER SEARCH (CDMS) OBTAINED USING A NEW ATHERMAL PHONON MEDIATED DETECTOR

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We present results from the Cryogenic Dark Matter Search (CDMS) collaboration obtained using the newly developed 100 gram silicon FLIP (Fast Large Ionisation and Phonon) detectors. Through the simultaneous measurement of phonons and ionisation, the FLIP detector can discriminate between bulk gamma and nuclear recoil interactions. Backgrounds at the Stanford Underground Facility (SUF) are known to contain large surface electron components that have similar charge to phonon ratio as nuclear recoil events. The new FLIP detector is able to use the rise time of the fast phonon signal to discriminate between surface electron and bulk nuclear recoil events at energies of a few keV. Exposures on the order of one kilogram-day from the silicon FLIP in initial runs at SUF yield upper limits on the WIMP-nucleon cross section that are comparable to much larger exposures of other experiments. Significant improvements in this limit are expected in the next six months from: the transfer of this technology to germanium; an increased number of detectors; and an improved phonon detector design.

1 Introduction

There exists a vast collection of observational evidence indicating that most of the matter in the universe is not only “dark,” [1] but is non-baryonic, weakly interacting and “cold.”[2] The Cryogenic Dark Matter Search (CDMS) experiment attempts to detect these weakly-interacting massive particles (WIMPs) directly, as they pass through cryogenic detectors on Earth.

Expected event rates of these particles in terrestrial detectors are very low, between 0.001 and 1 event per kilogram per day.[4] The primary experimental challenge clearly is to reduce background rates from radioactive contamination to far below this expected WIMP rate. A powerful technique used to

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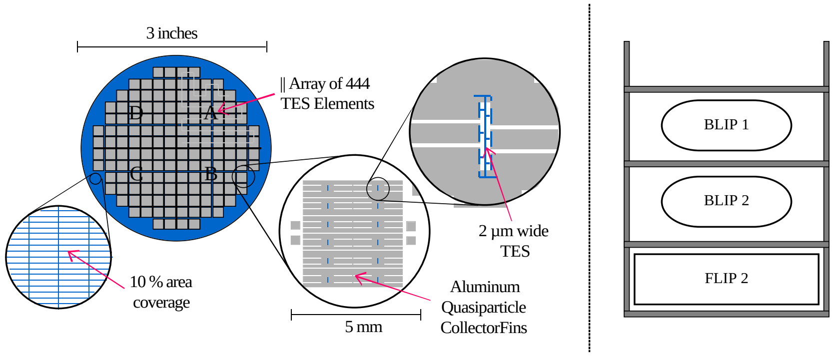

Figure 1. A diagram of the phonon sensor for the 100 g Si FLIP detector. The central item depicts the basic layout of the W/Al QET phonon sensors into four quadrants. Each sensor consists of a parallel array of 444 QET elements covering the top surface of the silicon and providing the ground electrode for the charge measurement. On the right is a sketch of the recent run configuration with two NTD based detectors mounted above the Si FLIP.

accomplish this is event by event background rejection. The CDMS experiment has long used the partitioning of energy between charge to phonons in semiconductors to allow the discrimination of bulk electron recoils and nuclear recoils[5]. A large component of irreducible backgrounds, however, has been found to be low energy betas[6]. These interact in a thin ($\sim$20 μm) surface "dead layer" which traps the generated charge pairs.

A new type of cryogenic dark matter detector[7], using QET[8] (Quasiparticle-trap-assisted Electrothermal-feedback Transition-edge-sensor) technology has shown the ability to discriminate between surface events and bulk events using the rise time of the phonon signal.

2 Description of the Experiment

The CDMS experiment attempts to measure the small energy ($\sim$1 keV) depositions of a WIMP scattering with the nucleus of a semiconductor (silicon or germanium) in the form of phonons and ionization. The ionization measurement is made using conventional charge amplifier technology. The energy deposited directly in the form of heat (phonons) is measured with two different phonon technologies. One, based on eutecticly bonded NTD[9] (Neutron Transmutation Doped) thermistors, and the other based on athermal phonon QET technology.

When a particle event occurs in the 20 mK silicon absorber mass of a

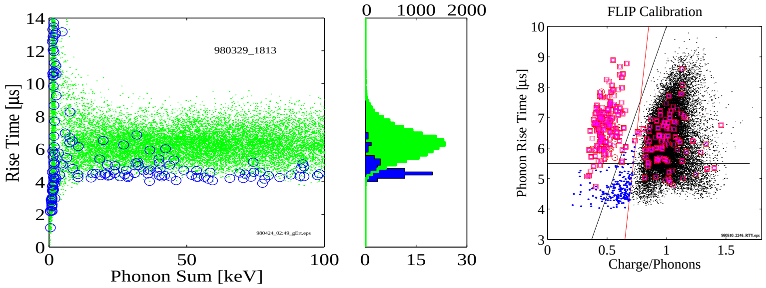

Figure 2. Phonon rise time discrimination. Left: a plot of phonon rise time vs. phonon energy during ^{60}Co calibration for events with large (small dots) and small (large circles) charge to phonon ratios. Middle: a histogram of the two populations. Right: a plot of phonon rise time vs. charge/phonons for ^{60}Co gammas (small dots) and ^{252}Cf neutrons (large squares) in the 30-40 keV energy range.

QET-based detector athermal phonons are detected rapidly ($\sim 2\mu$s rise time) before they thermalize. Recently, new advances in sensor design have lead to an order of magnitude increase in energy collection efficiency QET sensors and enabled the discovery of new surface phonon generation phenomena.

The detectors are mounted on the bottom of copper support “towers” designed to block 4K radiation and to provide a low microphonic electrical connection. This assembly is placed inside a copper cylinder that is separated by 2 m from the Oxford 400 dilution refrigerator that cools to ≈20mK. Shielding the detectors are 1 cm of old lead inside the chamber, and outside is 25 cm of polyethylene, 15 cm of lead and scintillator paddles that provide the active muon veto.[10]

3 Detector Performance and Calibration

The capability of this detector to discriminate between background (photons and electrons) and signal candidate (nuclear recoil) events is calibrated *insitu* using external ^{60}Co gamma and ^{252}Cf neutron sources. Figure 2 shows the response of the QET-based detector to these calibration sources. The low charge collection events during the ^{60}Co calibration were attributed to electrons striking the surface of the detector. As can be seen in Figure 2 (right and middle) the low charge collection events had a significantly faster phonon

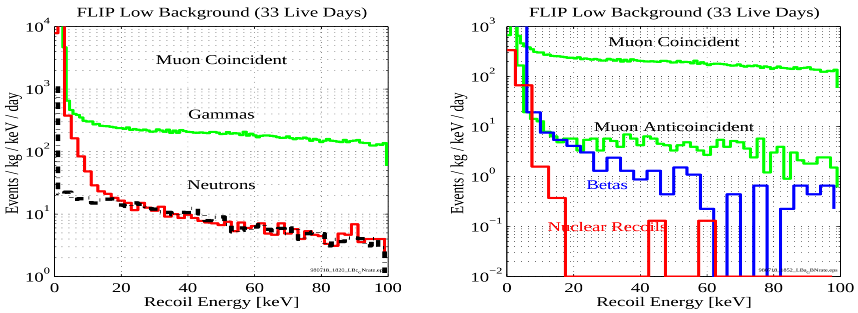

Figure 3. Background spectra in the Si FLIP detector at SUF. On the left are shown the rate of gammas and neutrons coincident with the muon shield. The black dotted line is the neutron rate predicted by Monte Carlo. On the right are gammas, betas (surface events) and neutrons anticoincident with muons.

rise time than bulk events. Nuclear recoil events Figure 2 (right) had the rise time distribution of bulk gamma events. A calibration of this detector with an electron source is being conducted at the time of publication. Preliminary data suggests better than 99% rejection capability down to 20 keV. The noise in the summed phonon channel during calibration and background running (see Sec.4) was stable at 700 eV (FWHM) (Note: this implies 350 eV for a single sensor). The inner charge channel had a noise of 1.2 keV (FWHM) and the outer 1 keV.

4 Results

The 100 g silicon FLIP detector was operated continuously in SUF for a period of several months accumulating 33 total live days of data. An electronics threshold of ~3 keV was maintained throughout the course of background running, although the charge noise and the failure of the rise time cut caused a large increase in backgrounds below ~ 20 keV. The active muon shield was measured to be over 99.993% efficient for muons passing through the detector.

4.1 Muon Coincident

The measured gamma rate coincident with muons passing through the active veto was ~200 dru (see Fig. 3). When a cut on charge yield was applied (conventional discrimination), the neutron rate was measured to be ~10 dru at 30 keV. This constant production of neutrons by muons was a very useful

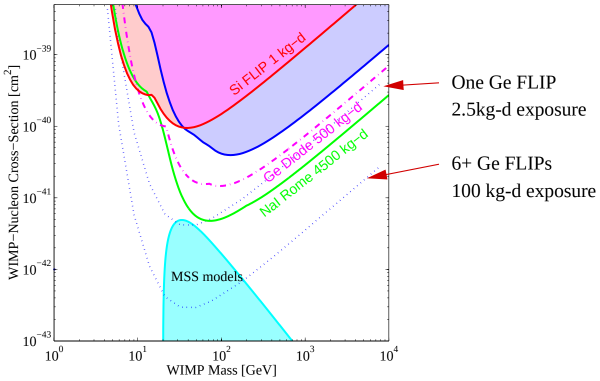

Figure 4. Upper limits on WIMP-nucleon cross section vs. WIMP mass. Upper shaded region is excluded by rates in the Si FLIP detector. Lower shaded region is excluded by the NTD-based germanium detectors. Dotted curves are: the projected limit from an identical FLIP detector fabricated out of germanium; germanium FLIPs with 100 kg-d exposure.

continuous calibration of detector performance and cut efficiencies. Both the coincident rate of gammas and neutrons was consistent with the rate predicted by Monte Carlos. The deviation of the measured neutron rate from the Monte Carlo at low energies was due to contamination by gammas allowed by poor discrimination.

4.2 Muon Anticoincident

When an anticoincidence cut on the muon veto was applied the raw gamma event rate dropped by more than a factor of 40 to ∼5 dru. When a charge yield cut is applied, we can see a persistant surface background of very similar rates to those seen in the NTD-based detectors[9]. These events have significantly faster rise times (4-5mus) than bulk events (7-8mus) and clearly do not represent an unexpected neutron backgound. When a rise time cut is applied (6.25mus) two events survive above ∼18 keV.

This final rate is used to calculate upper limits on the WIMP-nucleon cross section, following Smith and Lewin[4], for spin-independent couplings. Figure 4 shows the limit versus WIMP mass. Although the silicon FLIP detector is a factor of 10 less sensitive than the equivalent mass germanium detector, the limit is still competitive with that of the NTD-based detector (which lacks rise time discrimination) and other experiments with much larger exposures.

5 Future Improvements

Quasiparticle loss in the aluminum fins is now known to account for more than a factor of five signal loss. The bad placement of a cryogenic shunt resistor accounts for a factor of two unnecessary noise. Design improvements will be implemented shortly addressing both these issues and hopefully leading to a dramatically improved threshold. The QET technology is rapidly being transfered to germanium which has ten times as great a sensitivity to WIMPs as silicon for a given detector volume.

6 Conclusion

A new type of Dark Matter Detector based on QET technology has demonstrated a powerfull new discrimination technique for reducing surface backgrounds. The transfer of this technology to germanium will rapidly allow CDMS to achieve orders of magnitude higher sensitivity to WIMP signals.

Acknowledgments

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