Development of Neganov-Luke light detectors for a rare event experiment

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Low Temperature Detector Development and Physics

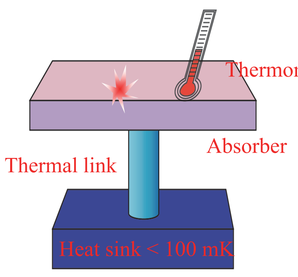
#104

| Abstract

We report a progress of a light detector development with Neganov-Luke (NL) phonon amplification. Double comb-like electrodes were fabricated on an intrinsic Si wafer to apply an electric field. A metallic magnetic calorimeter was used for a sensitive measurement of the temperature increase originating from light absorption in the wafer and NL phonon amplification. The NL light detector was applied to a simultaneous detection of heat and light signals from a ZnWO4 scintillating crystal. Clear amplification in light signals was obtained in various voltages applied to the electrodes while no change on the heat signals was found. The voltage dependence of the measured gain was investigated with a few efficiency parameters such as a saturation voltage to suppress recombination of electron-hole pairs and a heat generation efficiency of the NL effect.

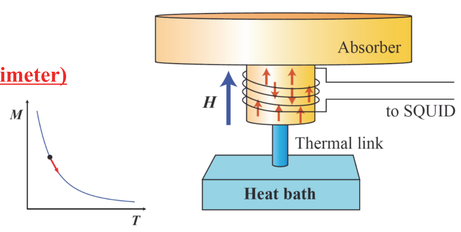
|| Low temperature detectors

"Calorimetric measurement of heat signals at mK temperatures"



Energy absorption ➔ Temperature

Thermistors (NTD Ge)
TES (Transition Edge Sensor)
MMC (Metallic Magnetic Calorimeter)
KID (Kinetic Inductance Device)
etc.



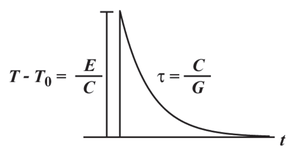
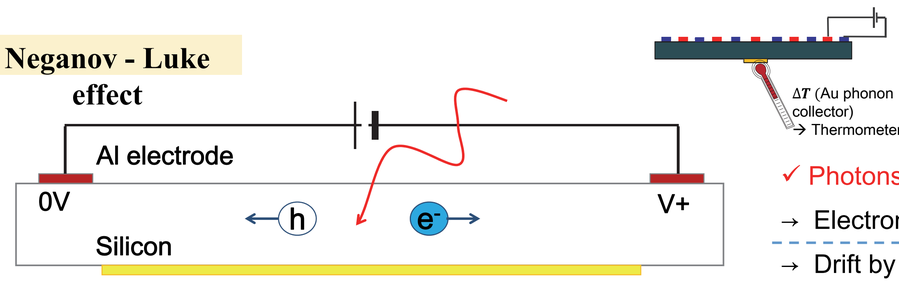


fig. from GB Kim et al CALOR2016

- ✓ Paramagnetic alloy (Au:Er or Ag:Er) in a magnetic field
  → Magnetization variation with temperature
- ✓ Readout: SQUID (Superconducting Quantum Interference Device)
- ✓ High energy resolution, Good linearity, Large dynamic range, No bias heating, Absorber friendly, Relatively fast
- ✓ More wires & materials needed for SQUIDs and MMCs

|| Phonon amplification in scintillation detection

Neganov - Luke effect



- ✓ Photons from scintillation
- → Electron - hole pairs
- → Drift by applied voltage (V)
- → Additional phonons (E_{Luke})
- → Amplification

$$\Delta T = \frac{E_0 + E_{NL}}{C} \qquad C = \textit{Heat capacity}$$

$$E_{NL} = \eta_{AE}\eta_{SE}\eta_{NL} \cdot N \cdot e \cdot V$$

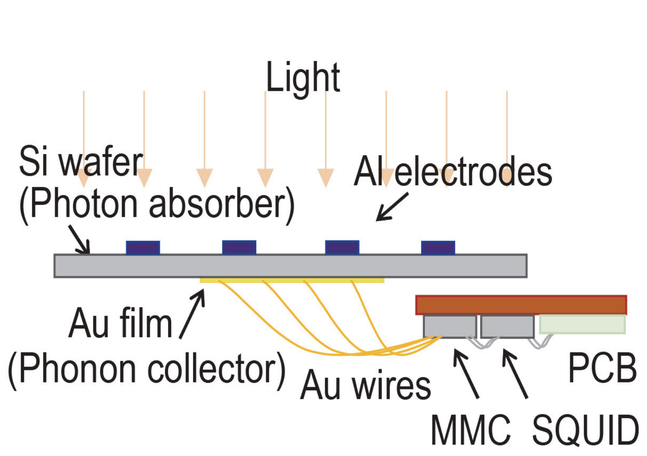
e = the electron charge
V = the applied voltage across the electrodes

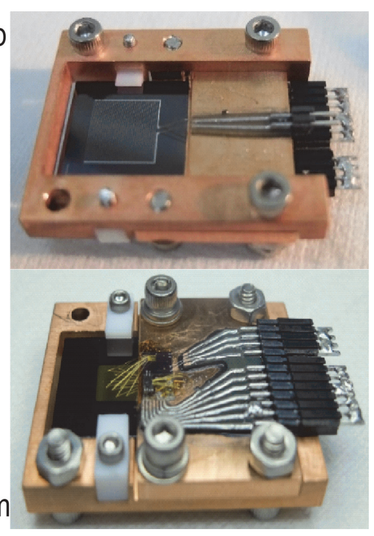
$$G_{NL} = \frac{\Delta T}{\Delta T_{(V=0)}} = 1 + \eta_{IQE}\eta_{AE}\eta_{SE}\eta_{NL}\frac{e}{\varepsilon_\gamma}V = 1 + gV$$

ε_γ *= the average photon energy of the incident light*

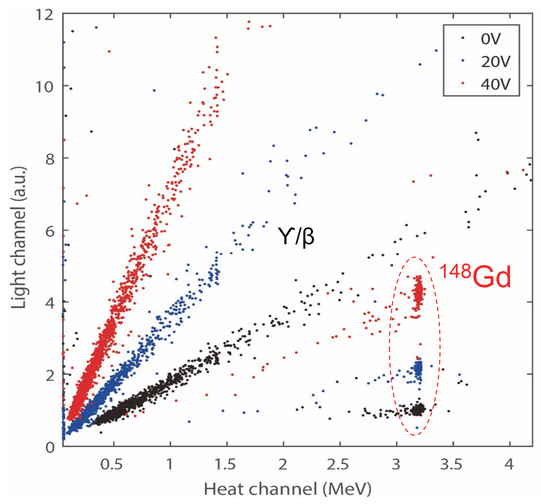
E_0 *= the energy absorbed in the wafer from scintillation light*
E_{NL} *= the amount of thermal energy converted from Luke phonons by the NL effect*
η_{IQE} *= the internal quantum efficiency for an e-p pair creation*
η_{AE} *= the ratio of the active region on the wafer for NL amplification*
η_{SE} *= the suppression efficiency to prevent e-p pair recombination*
(set to function of tanh(1.47V/V_s) : at V_s, where 90 % e-p pair generated by light absorption in Si substrate)
η_{NL} *= the efficiency of heat generation from the NL effect*

|| Simultaneous phonon-scintillation detection

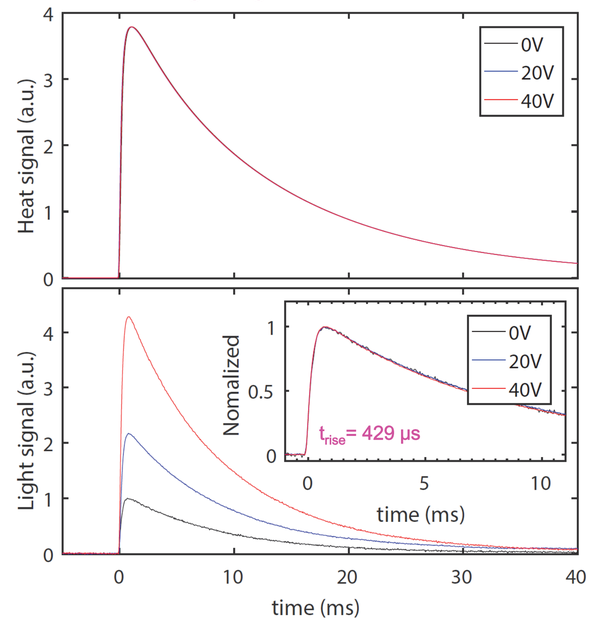




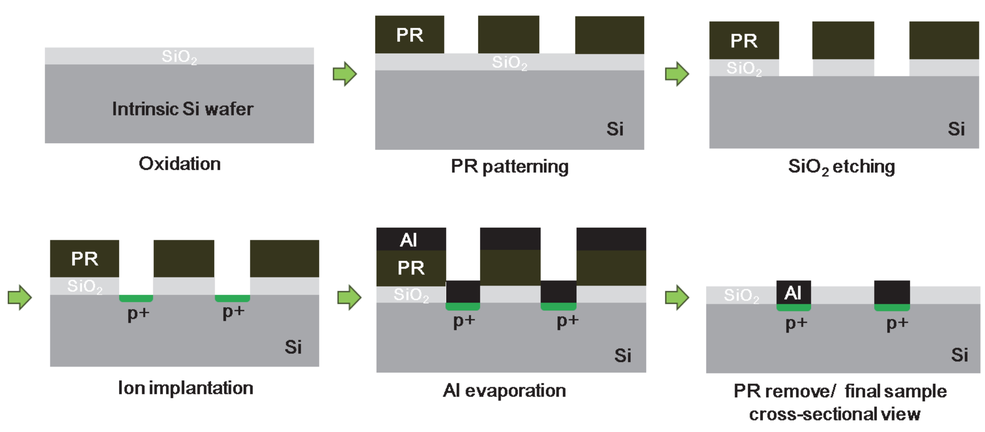
|| Result

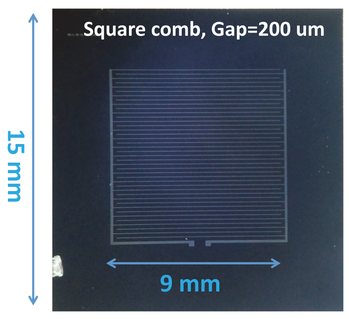


Average signals of ^{148}Gd α events

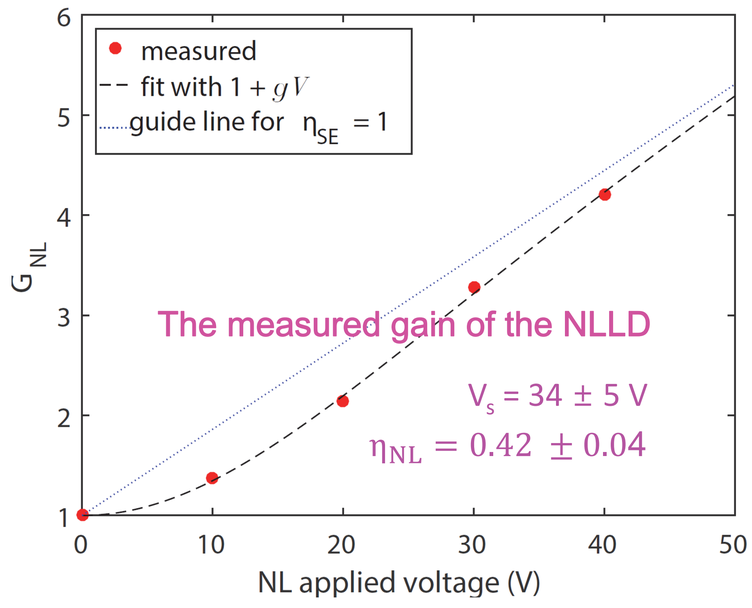


|| Phonon amplified light detector design and fabrication





Fabricated 1cubic photon detector



||| Discussion

The evident phonon amplification in the light detector makes it possible to introduce distinctive efficiency parameters of the NL gain. The double comb-like electrodes with 200 μm gap characterizes a saturation voltage of 44 V for 90% efficiency of recombination suppression.
Moreover, an average of about 45% heat generation is yielded for an unrecombined pair of electron and hole from the full amplification of the NL effect. These parameters indicate that an NLLD prepared in the present method is expected to measure a 40-eV equivalent signal from a single photon absorption in the substrate with an NL voltage of 100 V.
Combined with a sensitive calorimetric sensor, it is possible to compose a detector with a single photon sensitivity. Moreover, this kine low-thereshold can be applied to probe nuclear recoils in the target such as low-mass DM detection or neutrino coherent scatterings.

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