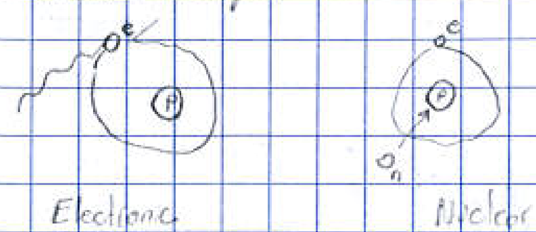
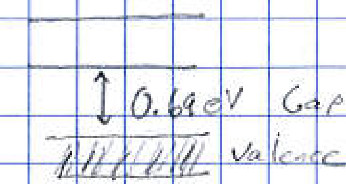
3/12/14 phonon physics – Lindhard Theory

Bands γ's & n's

Atomic: Hydrogen



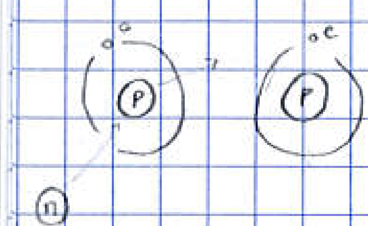
Germanium



Semiconductor → Gap < 3eV

→Because of thermal fluctuations Germanium conducts at room temperatures

For nuclear recoils, when the nucleus begins to move it can either interact with electrons & eject them or interact with other nuclei, and give up some energy to heat (phonons) so there is a quenching factor



$$Q = \frac{E_{nr}}{E_{er}}$$ E_{nr} → energy recoil! less energy given to phonons; E_{er} → energy recoil

So Lindhard derivation tries to separate energy loss to electrons and energy loss to nuclei.

4/16/14 – phonon physics – 1Dimensional lattice

discretize

$$F_s = \sum_n C_n (q_{s+n} - q_s) = m \frac{d^2 q_s}{dt^2}$$

then derive wave eqn.

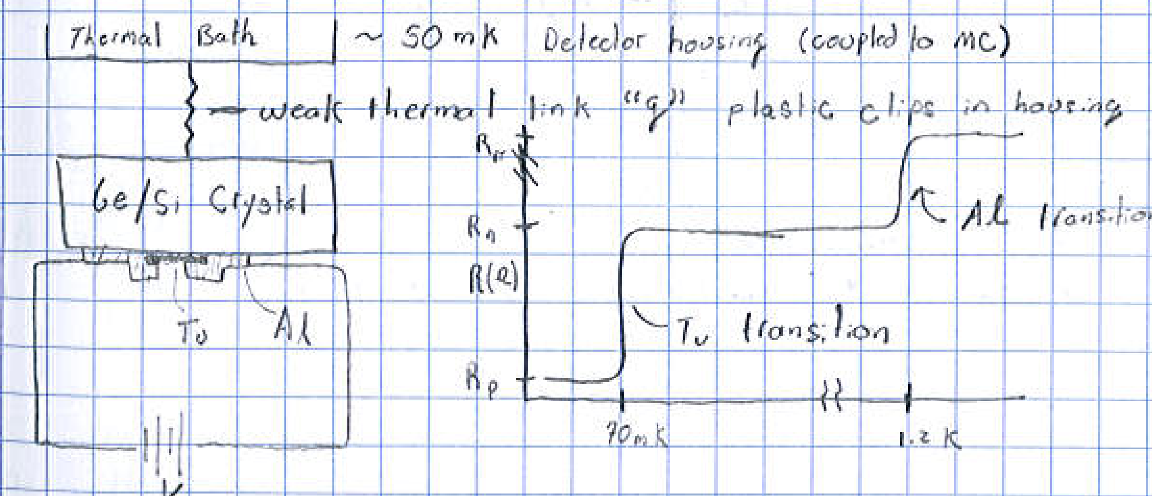
$$\frac{d^2 q}{dt^2} = v^2 \frac{d^2 q}{dx^2} \Rightarrow q \sim A e^{-i\omega(t - \frac{x}{v})}$$

w/ definition $\frac{\omega\lambda}{v} = 2\pi \Rightarrow \frac{\omega}{v} = \frac{2\pi}{\lambda} = k$

$q = Ae^{-i\omega t + ikx}$ → use to get dispersion relation for $\lambda \sim a$

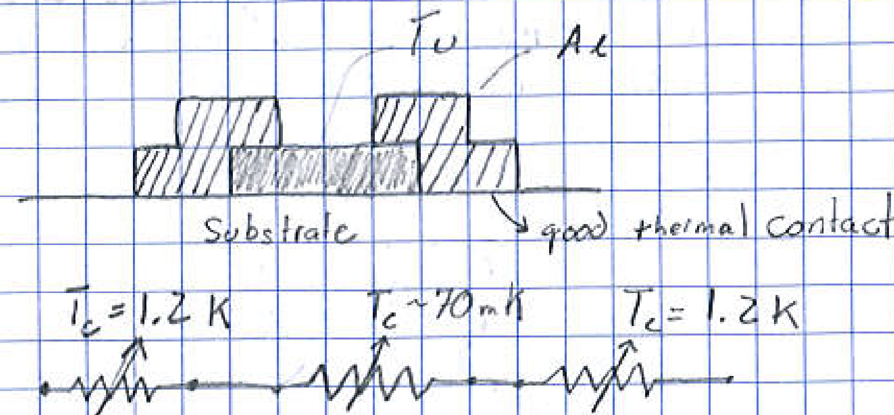
$$\boxed{\omega_k^2 = \frac{2}{m}\sum_{n>0} C_n (1-\cos(nka))}$$

4/23/14 Electrothermal Feedback / TES (My Talk which I postponed)

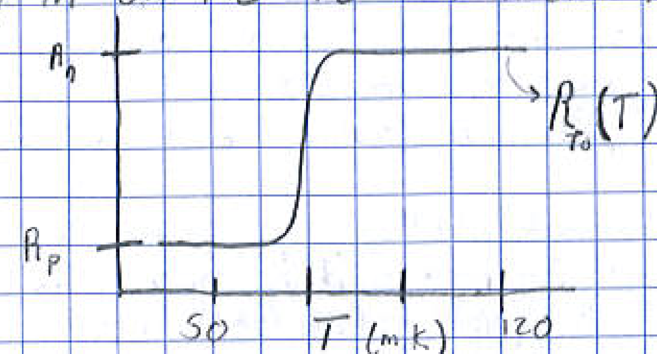


We want to operate at the Tw transition and use the deeply superconducting Al fins as Quasiparticle traps – see Allisons talk.

So the Aluminum/Tungsten structure is called a Transition Edge Sensor (TES). This can be modeled as below



Zooming in on the Tu transition

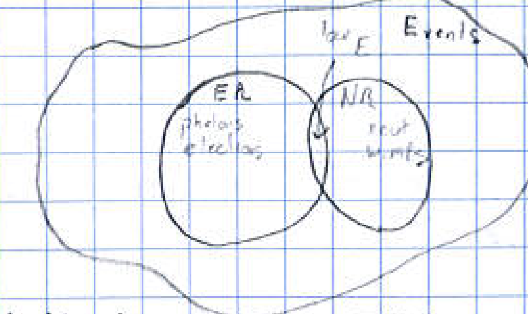


4/30/14 Reference Roland Clarke's thesis 2.13, 2.1.4

ETF/QET presentation

0) Because of nature of DM we want a pure NR sample at low E

1) Hassan has said charge will be quenched wit phonons for NRs ⇒ measure both you might be able to do ER/NR descrim



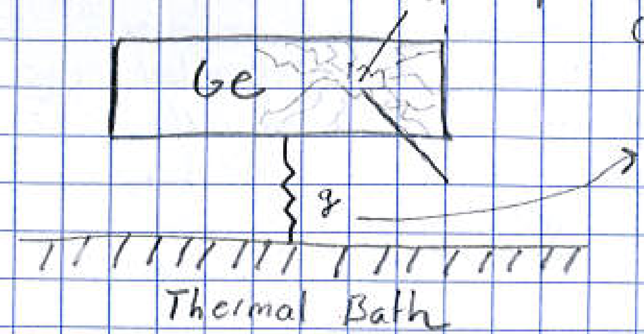
2) Allison talked about TES and absorbing phonons by Quasiparticle trapping - getting quasiparticles (Broken cooper pairs) to dissuse to an active element and stay there making an affect on a measurable bulk property of the element (resistance)

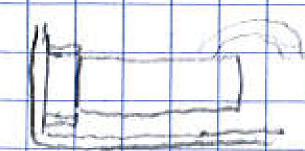
3) Today: how to set it up so that these sensors will be stabily operating to measure 'heat' from a particle event and return to normal.

Review: TES (previous two pages, draw simple substrate not whole detector)

So, need to put these things on a substrate and use them to measure phonons.

K. Irwin Appl Phys Lett Vol 66 No 15 1995
K. Irwin IEEE Trans Appl Supercond 5:2690-3, 1995





To operate a TES on this substrate we must balance power

$$\delta P = (\text{Power dumped electrically}) - \left(\begin{array}{c}\text{Cooling power}\\ \text{through link } g\end{array}\right) + (\text{Signal Power})$$

Suppose we tried current bias: i_b

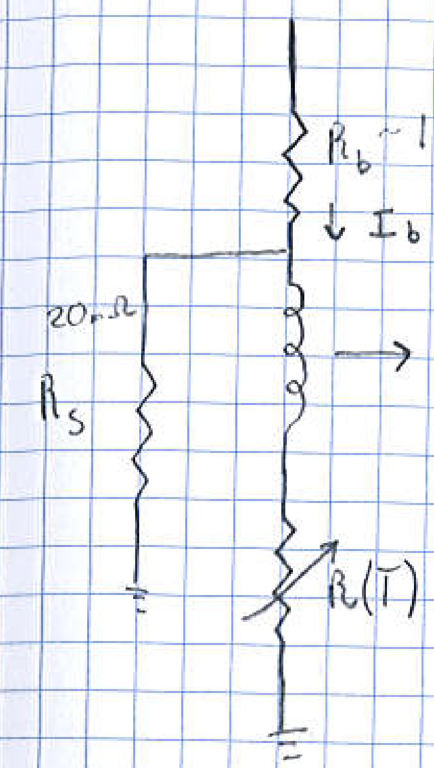
$$C_v \frac{dT}{dt} = \underbrace{\boxed{i_b^2 R(T)}}_{\text{(positive FB)}}^{\text{have control here}} - \overbrace{K(T^n - T_s^n)}^{\text{conduction cooling}} + \underbrace{P(t)}_{\text{signal}}$$

$P_e = IV = I^2 R$

$$C_v \frac{dT}{dt} = \underbrace{\boxed{\frac{V_b^2}{R(T)}}}_{\text{(negative FB)}} - K(T^n - T_s^n) + \underbrace{P(t)}_{\text{Signal}}$$

$P_e = IV = \frac{V^2}{R}$

So, want to use <u>negative</u> ETF



<u>Analyze equation in linearized Approx.</u>

$$C_v \frac{d\delta T}{dt} = -\frac{P_o \alpha}{T}\delta T - g\,\delta T$$

P_o = equilibrium power flowing to substrate

$\alpha = \frac{T}{R}\frac{\partial R}{\partial T}$

$g = nKT^{n-1}$

$n = 5$

$\tau_o = (C_v/g)$ natural conductive time const

The effective time constant of the eqn is:

$$\tau_{ETF} = \frac{\tau_o}{1 + \frac{\alpha}{n}}$$

here we've modeled a pulse as an instantaneous temperature excursion. This is like assuming the events raise the temperature discretely and ETF brings them back. Or the time constants for quasiparticle transport are slower than τ_{ETF}

The energy of the signal is

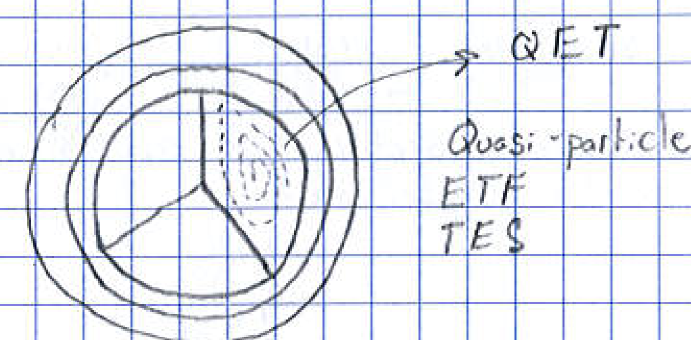
$$E_{TES} = V_b \int SI \, dt$$

and so (see Sunil's thesis App B) for an exponential phonon pulse governed by τ_{ETF} the noise is: including Johnson noise on the sensor and phonon thermal noise (see. K Irwin)

$$\sigma = \sqrt{4 k_b T^2 C_v \underbrace{\left(\sqrt{n/2}/\alpha\right)}_{\text{ETF assistance}}}$$

well, where is T_c? inside α!

So, in practice many TES are connected in parallel and laid out on the substrate



A specific model for $R(T)$ can be used to get more accurate estimates for our noise and specifically the dependence on T_c

possible next topics

1) Full derivation of σ using optimal filter framework

2) specific calculation for reasonable models of $R(T)$ including Johnson noise of all resistors

3) Fixing the above for the ETF cutoff.