Pop-Up Bolometer Optimization for SHARC2

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Goal: Calculate noise terms for pop-up bolometer (including 1/f) and optimize bolometer design for SHARC2.

Assumptions
Most of the noise expressions and notation are from Mather (1982). In the bolometer tabulations, the following abbreviations appear:

RL	load resistance
T0	base operating temperature
R0, delta	R = R0 exp(sqrt(delta/T))
G0, beta	G = G0 T^beta
Q	radiation power on bolometer
L0, m, d	terms for electrical nonlinearity (ignored)
Vol(bol.)	volume of bolometer thermistor
Vol(load)	volume of doped load resistor
frequency	radiation modulation frequency
en	amplifier voltage noise
in	FET current noise
Vbias	bias voltage across load resistor and bolometer
Vg=V	voltage across bolometer
I	current
R	bolometer resistance (V/I)
Z	bolometer dynamic impedance (dV/dI)
T	bolometer temperature
S	responsivity (dV/dQ)
G	dynamic thermal conductance (dP/dT)
R(T0)	bolometer resistance at T0
NEP	*electrical* noise equivalent power

Electrical nonlinearity (Mather 1984b) is ignored. The calculation of 1/f noise is based on Han et al. (1998). Perfect coupling of the electrons and lattice is assumed, i.e., $T_{electron} = T$. Han et al. find empirically that:

$$(\sigma R/R)^2$$
$$= 0.034\ (\mathrm{delta}/1\ \mathrm{K})^{2.453}\ (T/0.15\ \mathrm{K})^{-(5.2\ +\ 0.9\ \log(\mathrm{delta}))}\ /\ (3.5\times10^{18}\ \mathrm{cm}^{-3}\ V\ f).$$

The resistance fluctuation is converted to a voltage fluctuation by:

$\sigma V = [VZ/(Z+R_L)]\ (\sigma(R_L)/R_L)$ (load resistor 1/f)

$\sigma V = [VR_L(R+Z)/(2R(Z+R_L))]\ (\sigma(R)/R)$ (bolometer 1/f)

(Could anyone verify these equations?)

SHARC1 example

As a starting point, consider the SHARC1 bolometers, which have 0.20 mm (long) x 0.40 (wide) x 0.3 μm doped thermistors with delta = 33 K and four 12 μm x 14 μm x 2 mm silicon legs (partially doped). The properties of the bolometers have been measured by Wang et al. (1996). An optical power of 50 pW is assumed.

The bolometer parameters are calculated in Table 1. For SHARC1, the expected electrical NEP is 2.46×10^{-16} W $s^{1/2}$, within a factor of 2 of what is observed (which is not well documented). Interestingly, the 1/f noise could be the dominant contributor to the detector noise (excluding photon noise) at 4 Hz, although this has not been confirmed experimentally.

To compare with SHARC2, we compute dS/dQ (the change in responsivity with change in atmospheric opacity):

$(dS/dQ) = 7.1 \times 10^5$ V/W/pW
$(dS/dQ)/(S/Q) = 0.37$

SHARC2 optimization

The SHARC2 optimization assumes a bolometer thermistor area of 1mm x 1mm and a load resistor which has 3 times the area of the bolometer. For effective use of an AC-biased readout, a modulation frequency of 0.1 Hz is assumed. For the SHARC2 bolometers, an optical power Q = 60 pW is assumed. (HAWC is anticipating 60-80 pW/pixel.) An operating temperature of 0.320 K is assumed.

When the NEP is optimized by adjusting the design parameters {RL, R0, delta, G0}, the impedances become ridiculously high. Therefore, the bolometer impedance is constrained to R < 10 MΩ. An impedance near this value is preferred for AC biasing so that RC electrical time constants do not become too large. A limitation of RL = 100 MΩ was applied.

For the first optimization, only G0, R0, and RL are adjusted from the SHARC1 values. The best value (Table 2) of G0 is 4.0×10^{-9}, a factor of 8 lower than in SHARC1. The bolometer warms up to 0.57 K, which reduces its 1/f noise. For this bolometer:

NEP = 1.68×10^{-16} W $s^{1/2}$
$(dS/dQ) = 1.7 \times 10^6$ V/W/pW

$(dS/dQ)/(S/Q) = 0.82$

For comparison, the expected photon NEP is $3.0\text{-}3.5\times10^{-16}$ W $s^{1/2}$. The change in responsivity with changing atmospheric conditions is greater, but this can be calibrated. Basically, this will just result in a larger constant relating $\tau_{225\ \mathrm{GHz}}$ and log(Jy/mV).

If delta is increased (meaning a lower doping concentration), the NEP can be improved. For example, if delta = 50 K, and R0 and G0 are optimized (Table 3):

NEP = 1.53×10^{-16} W $s^{1/2}$
$(dS/dQ) = 2.2\times10^{6}$ V/W/pW
$(dS/dQ)/(S/Q) = 0.92$

<u>Effect of 4K metal film load resistors</u>
Now reconsider the case with delta the same as SHARC1, and let the load resistors be fixed metal film devices (100 MΩ) at 4.0 K. A small noise penalty results (NEP = 1.77×10^{-16} W $s^{1/2}$ instead of 1.68×10^{-16} W $s^{1/2}$; Table 4), but an advantage of a fixed load resistance is gained.

<u>Summary</u>
NEP's can be improved over the SHARC1 value, even at the lower frequency of 0.1 Hz, by lowering the thermal conductance G0 nearly an order of magnitude and optimizing R0 accordingly. Further improvment can be obtained by decreasing the doping (increasing delta). Using fixed, large load resistors at 4K is an acceptable configuration.

<u>References</u>
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