Hybrid NbTiN-Al MKIDs

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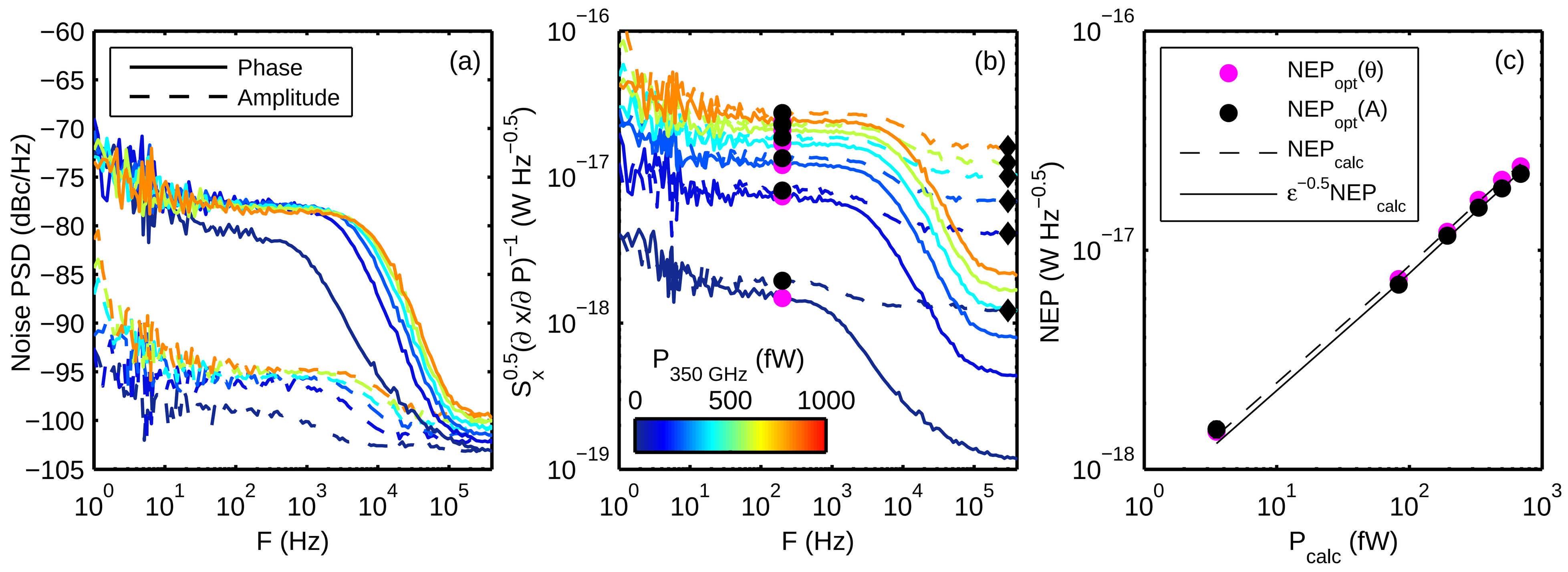
Introduction

Lens-antenna coupled hybrid NbTiN-Al Microwave Kinetic Inductance Detectors (MKIDs) [1] are a detector candidate for large format sub-mm camera's and spectrometers developed in the next decade. For large array development electrical and thermal tests are preferred as initial tests over a full optical evaluation, which requires a time-consuming measurement and a dedicated setup with a controlled illumination source. Based on a simplified model analysis Gao et al. [4] have argued that the change in complex conductivity due to thermally and optically excited quasiparticles is equivalent.

We test the performance of NbTiN-Al MKIDs as well as test the equivalence between their optical and thermal response.

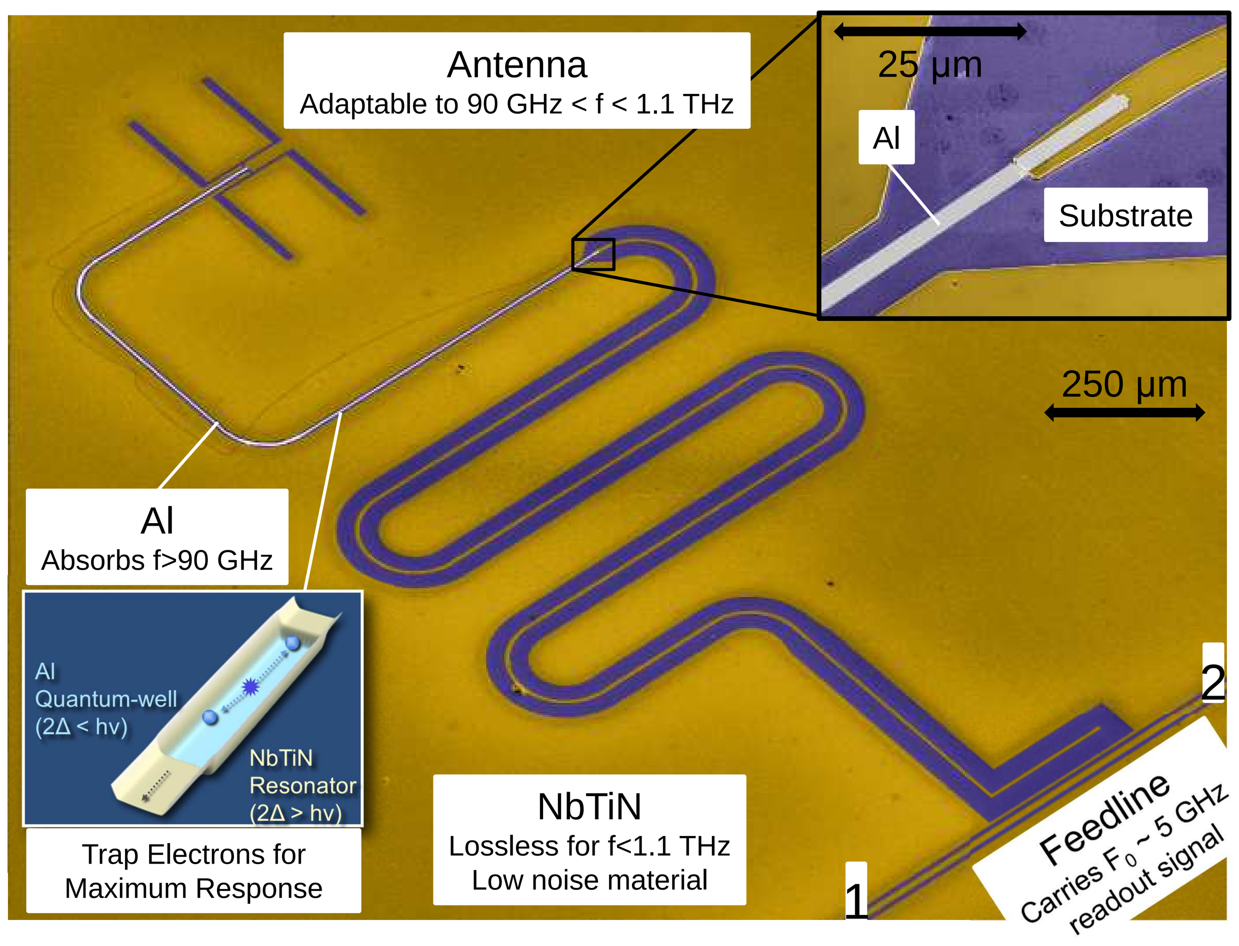
Photon Noise Limited Performance

The antenna coupled NbTiN – Al MKIDs show photon noise show photon noise limited performance down to 100 fW [1]. Photon noise limited operation can be used to accurately (uncertainty ~5%) determine the optical power absorbed by the MKID and thus verifying its optical reception properties.



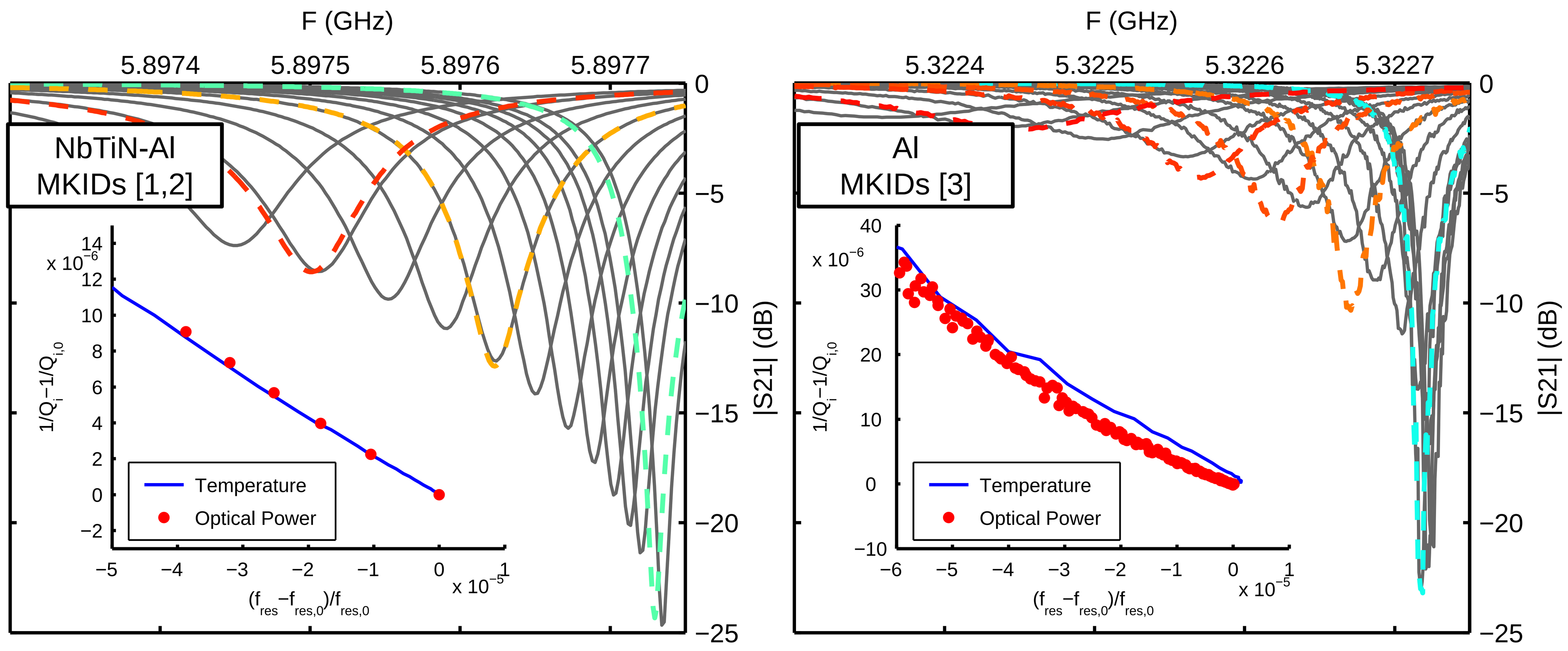
NbTiN-Al MKID Design

The antenna coupled NbTiN – Al MKID design [1] aims to simultaneously **maximize the MKID response** and **minimize the detector noise**.



MKID Response: Optical versus Thermal

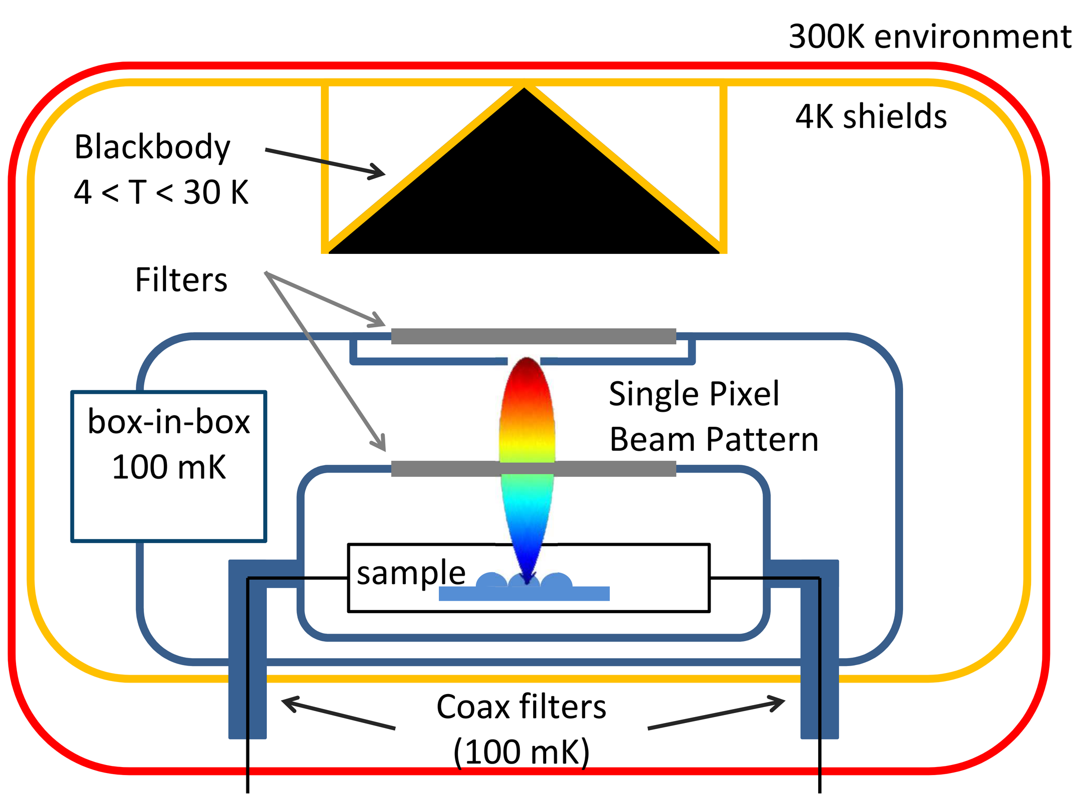
The evolution of the resonance curve as a function of increasing temperature (grey) and increasing optical loading (color).



NbTiN-Al MKIDs: for every optical loading a bath temperature can be found, which produces an identical resonance curve.

Fully Al MKIDs: radiation induces less losses than temperature for the same frequency change.

Experimental Method



KID No. 1	Optical	Electrical
dθ/dP	(4.75 ± 2.0)	(35.5 ± 6.3)
dA/dP	(-4.59 ± 0.29)	(-4.29 ± 0.70)
KID No. 2	**Optical**	**Electrical**
dθ/dP	(32.7 ± 3.5)	(20.3 ± 3.6)
dA/dP	(-3.39 ± 0.37)	(-2.41 ± 0.43)

Optical and electrical (dark) responsivity for two representative NbTiN-Al MKIDs. Values have been divide by 10^{12} for clarity.

In our experiment we use a bath temperatue T_0=100 mK and blackbody temperature $T_{bb,0}$=4.2 K as initial conditions for both our optical and thermal measurement. Starting from $(T_{bb,0},T_0)$ we change either T_{bb} or T in the optical or thermal measurement, respectively.

We determine the optical responsivity from a linear fit between the measured change in phase (x=θ) and amplitude (x=A) as a function of the absorbed optical power (P_{opt}).

We determine the electrical (dark) responsivity from the measured temperature responsivity, quasiparticle recombination time, pair breaking efficiency and the superconducting transition temperature [2].

$$\frac{\delta x}{\delta P_{dark}} = \frac{\eta_{pb}\tau_{qp}(T)}{\Delta(0,T_c)}\frac{\delta x}{\delta N_{qp}(T,T_c)}$$

We derive Δ from the well-known BCS relation and determine N_{qp} using an integral over the fermi-dirac energy distribution and the BCS density of states.

Conclusions

We have shown that [1,2]:

- Hybrid NbTiN-Al MKIDs are photon noise limited down to 100 fW.
- Thermal and optical excitations have an equivalent effect on the resonance feature of hybrid MKIDs.
- The electrical (dark) responsivity is within a factor of two of the optical responsivity.

We attribute this to the unique geometry of the hybrid NbTiN-Al MKIDs, which integrate a 1 mm long Al absorber in a NbTiN resonator. In different MKID embodiments the equivalence between optical and electrical response is not a priori justified.

In addition, we show that the Optical efficiency can be more accurately be determined from the photon noise (uncertainty ~ 5%) than by comparing the optical and electrical NEP (uncertainty ~15%).

References:

[1] Janssen et al., Appl. Phys. Lett. (2013)
[2] Janssen et al., Appl. Phys. Lett. (2014)
[3] de Visser et al., Nat. Commun. (2014)
[4] Gao et al., J. Low Temp. Phys. (2008)

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