Development of Microwave Kinetic Inductance Detectors for IR single photon counting

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Introduction

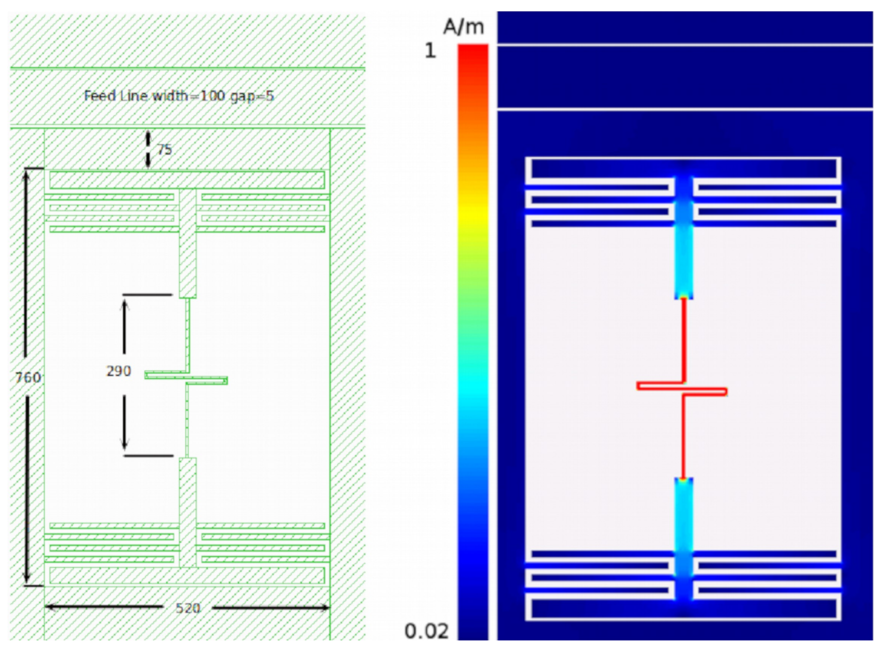
The development of photon number resolving detectors with high sensitivity in the visible-IR range is highly desirable in many research areas which include quantum optics, optical quantum metrology and astrophysics. At 1550 nm Microwave Kinetic Inductance Detectors with single photon number resolving capability has been proved but the energy resolution experimentally demonstrated is still one order of magnitude far from the theoretical limits [1,2]. In order to push for further improvements, we have focused our research on the film material and the resonator layout. In particular we have carried out an extensive investigation [3] on Ti/TiN multilayer films aiming to achieve the control of the superconducting and electrical properties important for MKIDs. In this poster we describe our preliminary results. Although we have not yet optimized its volume, the detector can resolve single photon number and its sensitivity is within a factor of two from the best value published in literature [2].

Fabrication

- The film of our detectors is made of titanium and titanium nitride, deposited in a multi-layer structure Ti/TiN/Ti/TiN.
- Thanks to the proximity effect, we can tune T_c by properly choosing the thickness of the Ti and TiN layers [3]
- We set the Ti and TiN single layer thickness to 10 and 12 nm respectively: the total thickness is 44 nm.
- The film has a normal state resistivity of 131 μΩcm, T_c =1.2 K and the surface kinetic inductance is 34 pH/sq
- Samples have been fabricated by sputter deposition of Ti/TiN films onto p-type, <100>, high resistive FZ, 6" silicon wafers with a resistivity larger than 5000 μΩcm.
- The films were deposited with an Eclipse ® Mark II sputtering system using a titanium target in combination with reactive sputtering with nitrogen.
- All films were deposited at 350 °C. The 10 nm thick Ti layers were deposited in 8 sec with 1 kW RF power applied. The TiN layers were deposited with 6 kW RF power, 200 V bias applied and an argon flow of 30 sccm and an nitrogen flow of 45 sccm

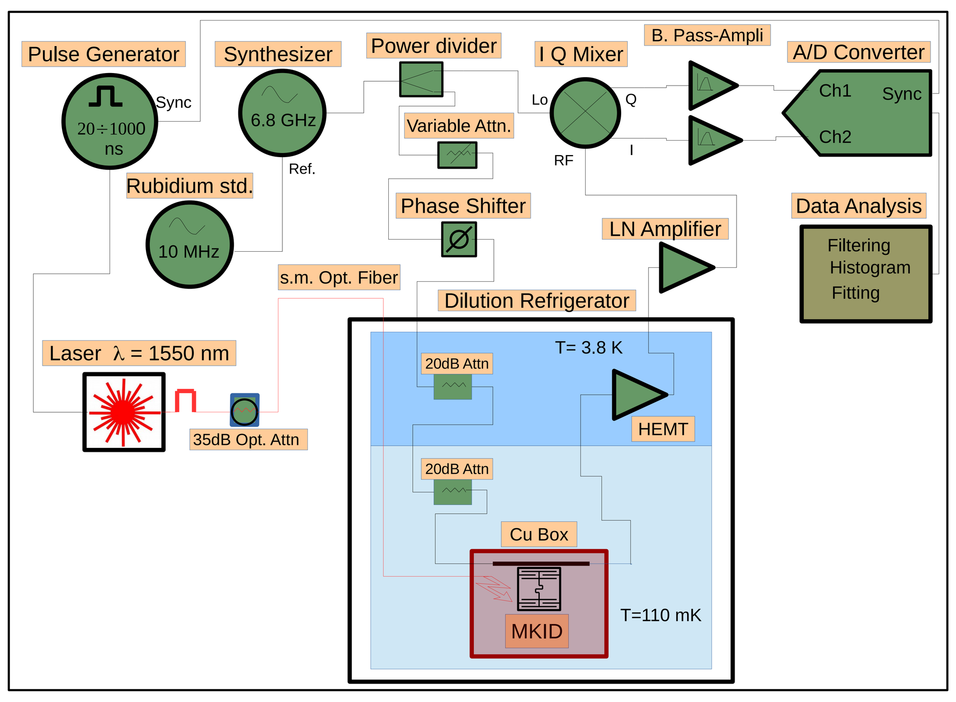
Resonator layout

- the resonator has lumped capacitance *C* and inductance *L*
- at 20 mK the measured resonance frequency is υ_r=6.802 GHz, the internal quality factor is Q_i=125000, the coupling quality factor is Q_c=27170 ; the estimated kinetic inductance fraction is α = 0.86
- the current density simulation (on the right) shows that the most sensitive part is the inductor central part ; its line width is 5 μm and the volume corresponds to 128 μm³



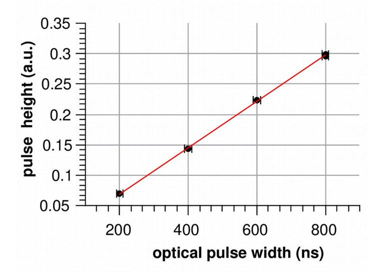
Experimental setup

- the cryogenic HEMT preamplifier has a noise temperature of 4 K and a gain of 33 dB; the overall noise temperature increases to about 6.3 % due to all other room temperature contributions
- the 1550 nm laser diode sends, with a rate of 33 Hz, N_p optical pulses to the resonator ; $10000 \le N_p \le 50000$
- the homodyne scheme is employed to read out the MKID
- a matched filter is applied to the sampled raw data to improve the signal to noise ratio
- a histograms of the amplitude *x* (in Volts) of the reconstructed pulses is produced

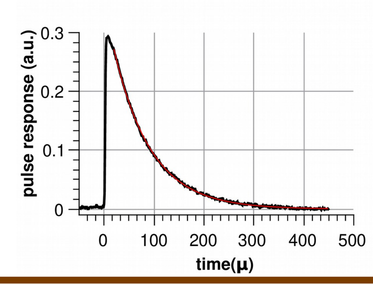


Results

The detector response linearity was tested irradiating the resonator with optical pulses: the time width range corresponds to an average photon number range 0.4 ÷ 1.81



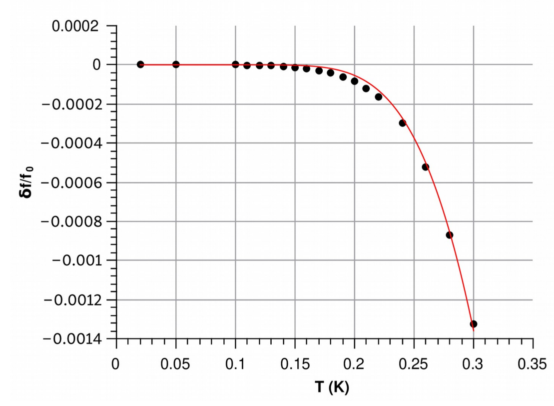
The pulse decay time of the averaged response is 75 μs



Best fit of the equation :

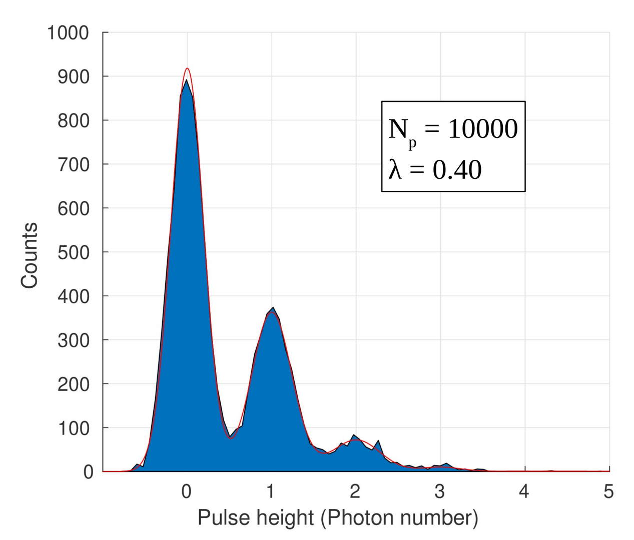
$$\frac{\delta f}{f_0}=\alpha\left(1-\tanh\left(\frac{\Delta_0}{2K_BT}\right)^{-1/2}\right)$$

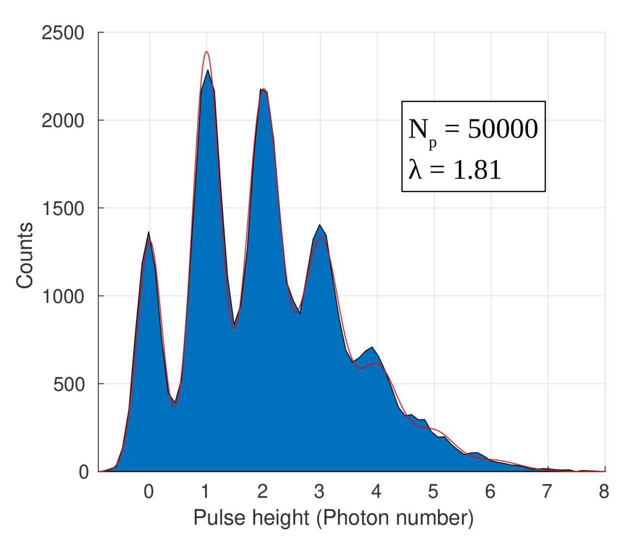
(see ref.[4]) to the temperature dependent frequency response data; we find $\Delta_0/\Delta_{0BCS}=0.91$



A fitting procedure with a proper sum of *N* gaussian functions convolved with a Poisson distribution is employed to estimate the Volt to photon number conversion factor *b*, the mean number of absorbed photon *λ* and the standard deviation of the *n-th* gaussian peak $\sigma_n = \sigma'_n / b$; *a* is a normalization factor

$$\sum_{n=0}^{N} a\frac{\lambda^n}{n!}\exp\left(\frac{(x-nb)^2}{2\sigma'^2_n}\right)$$

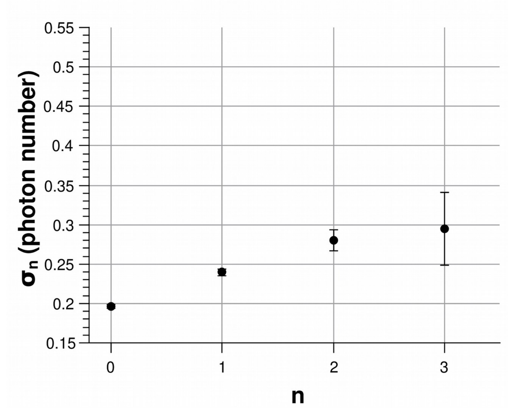


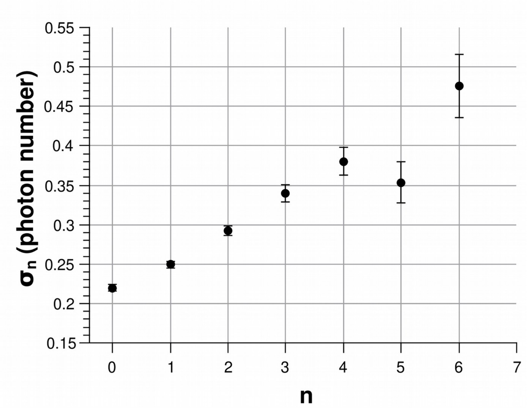


For the 0- and 1-photon peak we obtain a FWHM energy resolution :

ΔE_0= 0.44 eV and **ΔE_1= 0.56 eV**

The standard deviation σ_n increases with *n*. The broadening of peaks with *n*≥1 can be related to the non uniform responsivity of the detector absorbing area [2]. In this case, we expect a broadening increasing linearly with *n*.





Conclusions

We have employed the Ti/TiN multilayer film technology to develop MKIDs capable to resolve single photons at 1550nm. As proved in ref. [2] the energy resolution improves by reducing the volume of the resonator inductor. Therefore in the next design we aim at a further improvement by reducing the inductor volume by about a factor of 10.

References

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