background limited antenna coupled MKID arrays for ground based imaging

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Outline

- A-MKID
- Photon noise limited performance
- Hybrid antenna coupled MKID
- Test chip noise performance – effect of Al and interfaces
- A-MKID system tests
**A-MKID**

- 2 color imaging instrument for APEX, 870 µm and 350 µm
- 15 arcmin FOV, 1 Fλ pixel spacing
- 2 separate arrays of 4 sub-arrays in the FP, polarizer to select band
  - 870 µm
  - 350 µm
  - # pixels: 20,000 pixels
  - 3.200 pixels
  - goal sensitivities: 34 mJy s$^{0.5}$
  - 59 mJy s$^{0.5}$
  - goal pixel NEP: 2.7e-15 W/Hz$^{0.5}$
  - 1.4e-14 W/Hz$^{0.5}$
A-MKID :: Read-Out Concept

- Phase readout due to low Q of the devices (20,000) due to loading
- MPIfR developed readout (full IQ)
- Bandwidth 1.25 GHz
- 32,768 bins (76 kHz resolution)
- 8 ENOB (expected)
A-MKID - readout

- Phase readout due to low Q of the devices (20,000) due to loading
- MPIfR developed readout (full IQ)
  - Bandwidth 2.5 GHz
  - 32768 bins (76 kHz resolution)
  - 8 ENOB (expected)
  - based upon E2V 10AQ 190 ADC, 4×1.25 Gsample/sec
  - and analog devices AD9739 DAC
Photon noise limited performance

- Random arrival rate of photons creates a white noise in quasiparticle number rolled off at the lifetime

- On top of this there is recombination noise from the random recombination of excess quasiparticles

- If all quasiparticles are due to photon absorption:

\[
S = (S_{G-R} + S_{\text{photon}}) \approx \left( \frac{2N_{qp,p} \tau_{qp}}{1 + (\omega \tau_{qp})^2} + \frac{2N_{qp,p} \tau_{qp} \eta \hbar \nu / \Delta}{1 + (\omega \tau_{qp})^2} \right) \cdot \left[ \frac{\delta(A, \theta)}{\delta N_{qp}} \right]^2
\]
Photon noise limited performance

- Photon noise level $\propto \nu$ and independent of radiation power!

- Photon noise level not much above the G-R noise
  - Not easy to reach
  - Carefull material selection required

- Photon noise limited KIDs have always a contribution due to qp recombination
  - $S_{\text{photon}} + S_{\text{G-R}} = S_{\text{photon}} (1+0.85)$ at 350 GHz for Al

<table>
<thead>
<tr>
<th>Noise PSD</th>
<th>Quasiparticle recombination</th>
<th>Photon arrival</th>
<th>KID responsivity</th>
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<tbody>
<tr>
<td>$S = (S_{G-R} + S_{\text{photon}}) \sim \left( \frac{2N_{qp,p} \tau_{qp}}{1 + (\omega \tau_{qp})^2} + \frac{2N_{qp,p} \tau_{qp} \eta \nu / \Delta}{1 + (\omega \tau_{qp})^2} \right) \cdot \left[ \frac{\delta(A, \theta)}{\delta N_{qp}} \right]^2$</td>
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</table>
Hybrid antenna coupled MKID
Hybrid antenna coupled MKID
NbTiN as MKID material

- Lower frequency noise
- 1.2 THz gap frequency
- Very good readout power handling

Rami Barends, Ph.D. Thesis (Deft University) 2009
Hybrid antenna coupled MKID
Al to detect quasiparticles

- Al on sapphire (see P. de Visser) has shown generation-recombination noise
- Using Al to absorb the radiation should allow us to reach the photon noise limit

Hybrid antenna coupled MKID
Antenna – lens to absorb radiation

- Lens array
  - creates space for KIDs
  - High filling fraction
  - Focussing of radiation to antenna
- Si lens array + Parylene-C $\lambda/4$ AR coating
CST modelling + measurements
Fabrication – Hybrid KIDs on Si

1. KID pattern in NbTiN (white)
   - Dry etch 300 nm NbTiN
   - 13.5 sccm SF$_6$
   - 20 sccm O$_2$
   - 65 ° slopes

2. Al resonator part (blue)
   - 50 nm Al sputter depo
   - Wet etch of excess Al or Lift-off process

3. Metal air bridges (red)
   - 250 nm Al sputter depo
   - On sacrificial resist layer
   - Wet etch to define bridges
Fabrication: Al lift-off vs wet etching

- Lift-off process (until recent)
  - Hard to reproduce
- Wet etch process
Result
Hybrid KIDs with lift-off process

- Photon noise limited performance
- High optical efficiency
- But.... 1/f noise
  - Use amplitude readout -> too stringent requirements digital electronics
  - Reduce phase noise at low frequencies

Test chip

- CPW resonators 3-2-3 μm wide
- Change the length of the Al section
- Also HW devices (without interface)

Green = substrate
Blue = Al on substrate
Red = Al on NbTiN
White = NbTiN
Test chip performance
Lift-off devices

1 min Ar+ RF cleaning prior to Al deposition, definition with lift-off

- No effect of interfaces
- Frequency noise determined solely by Al
  - Widening NbTiN section has no influence
  - Noise scales with Al length
- Noise spectra with much Al have $1/F$ below 100 Hz
  - $F^{-0.7}$ for 100% Al on Si resonators

H15 batch made with lift-off

Expected for NbTiN

Much wider resonators

Same – no interface effect

At optimum power

Quarter wave
Half wave
expected level Gao et al
8x9 array

$S_{F/F_0}$ at $P=40$dBm and 1 kHz

$F^{-1}$

$F^{-0.5}$
Test chip performance
wet – etch devices

No Ar+ etch prior to Al deposition, but buffered HF dip, definition wet etch

- Frequency noise only weak function of Al length
- Noise level higher for pure NbTiN resonators
- Hybrid frequency noise low, especially at low F: – 10 dB at 1 Hz

H20 batch made with lift-off
System test for A-MKID test camera

He7 test cryostat

- Detector array
- BP filter @ 0.3 K
- LP filter 0.4 THz @ 1K
- LP filter 0.6 THz @ 4K
- LP filter 0.8 THz @ 77K
- Goretex @ 300K
System test for A-MKID test camera
H20 with etching full system measurement

- 1/f significantly reduced
- 1/f noise is now from the system and can be (partly) removed
**F spacing**

- 4±2 MHz dF
- Q=20,000
- Only for large arrays!
Conclusions

- We are developing large arrays for the A-MKID camera and NIKA
  - Noise properties differ from 1 layer KIDs, especially at low F
  - NbTiN-Al interface does not play a role
- Devices are photon noise limited at high modulation frequencies
- Approach BLIP in band of operation
Results
H10 with lift off measured with cryogenic BB

- Photon noise limite performance
- 1/F from the device dominates below 10 Hz