次世代赤外線天文衛星 SPICA 搭載用遠赤外線観測装置 SAFARI

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SPICA: space mission for mid- & far-IR astronomy

- **Telescope:** 2.5 m & <8 K
  - Natural background limited Infrared (IR) observations
  - Need **ultra-sensitive** IR detectors

- **IR instruments**
  - SMI (12-37 µm)
  - SAFARI (34-210 µm)
  - Three-band grating spectrometers with **TES bolometer** arrays
Noise Equivalent Power (NEP) required by SPICA/SAFARI

Minimum detectable input power to have S/N=1 with $T_{\text{int}}=0.5$ sec

Higher sensitivity = Lower NEP

ISO-Herschel era
~$10^{-16}$ - $10^{-17}$ W/√Hz

SPICA/SAFARI
$2 \times 10^{-19}$ W/√Hz

100-1000 times!!
Transition Edge Sensors (TESs)

\[ \Delta P \rightarrow \Delta T \rightarrow \Delta R \]

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Typical TES pixel for SAFARI/S-band

Intrinsic noise = phonon noise
→ Noise Equivalent Power (NEP_{ph}) \propto \sqrt{G}
Long-standing questions (1)

SRON-TESs fabricated by KOH wet-etching

SiN legs
- Width (W) = 1 µm
- Thickness (T) = 0.5 µm
- Length (L) = 400 µm

\[ G_{\text{meas}} = 330 \text{ fW/K} \]

\[ \text{NEP}_{\text{meas}} = 4.2 \times 10^{-19} \text{ W/\sqrt{Hz (best)}} \]

→ Deep Reactive Ion Etching (DRIE)

Q1. Can we achieve lower \( G \) and thus NEP values by making narrower and thinner SiN legs??
Long-standing questions (2)

Excess noises

1) Extra-phonon noise \((f > \sim 10\text{Hz})\)
   \(C_{\text{tes}} \sim C_{\text{island}} \& C_{\text{legs}}\)

2) Photon noise

Q2. Can we reduce the extra-phonon noise by making lighter SiN island and SiN legs??

Q3. How dark is our setup??

NEP_{\text{meas}}/\text{NEP}_{\text{ph}} \sim 2-3 \text{ (typ.)}

Khosropanah, Hijmering+ 09,10,11,12

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New TESs fabricated by DRIE

- Deep Reactive Ion Etching (DRIE) process success
- Narrow SiN legs ~0.5-0.7 µm
- Thin SiN legs and island ~0.2 µm

Fabricated by Marcel Ridder (SRON)
Do not blow a puff of air, please!!
AC measurement setup

- **SQUIDs**
- **LC resonators**
- **TES array chip**

**FDM assembly**

**Stray-light absorber**

**FDM bracket + Nb tube**
FDM readout

10pix-FDM system
1-3 MHz resonators
df=100 kHz

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Measured thermal conductance

Khosropanah, Hijmering+ 2012

G (fW/K)

WT/L (µm)
Measured NEPs

- Measured NEPs:
  - Large island: $T_c = 93 \text{ mK}$, $P = 2.0 \text{ fW} @ 50 \text{ mK}$, $G = 60 \text{ fW/K}$
  - Small island: $T_c = 94 \text{ mK}$, $P = 1 \text{ fW} @ 50 \text{ mK}$, $G = 30 \text{ fW/K}$

- NEPs:
  - $1.1 \times 10^{-19} \text{ W/√Hz}$
  - $1.5 \times 10^{-19} \text{ W/√Hz}$

- Meet the SAFARI requirement

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Measured NEPs

Achieved phonon noise level \((f<\sim 100\text{Hz})\)

- **Small island**
  - \(T_c=94\ \text{mK}\)
  - \(P = 1\ \text{fW} \ @ 50\text{mK}\)
  - \(G = 30\ \text{fW/K}\)

- **Large island**
  - \(T_c=93\ \text{mK}\)
  - \(P = 2.0\ \text{fW} \ @ 50\text{mK}\)
  - \(G = 60\ \text{fW/K}\)
NEP-evolution track of SRON TESs

Dark NEP (x10^{-19} W/√Hz)


This work!!
Excess noise

Frequency (Hz)

Normalized NEP

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Darkness of current setup

Similar TES properties, but with and without absorbers

NEP$_{\text{photons}}$ $\sim 5 \times 10^{-19}$ W/√Hz

Need a stray-light free setup

With absorber:

$T_c = 87$ mK, 
$G = 58$ fW/K 
$P_{\text{sat}} = 1.9$ fW@50mK

No absorber:

$T_c = 93$ mK, 
$G = 63$ fW/K 
$P_{\text{sat}} = 2.0$ fW@50mK

NEP$_{\text{dark}}$ (x10-19 W/√Hz)
Summary

Ultra-low $G$ TESs were fabricated by DRIE

- **Without** an absorber
  
  We measured an electrical NEP as low as $1.1 \times 10^{-19}$ W/√Hz, which achieved the *phonon noise limit*, and also a reasonable response speed (<1 msec).

- **With** an absorber
  
  We confirmed a higher NEP ($\sim 5 \times 10^{-19}$) due to stray light.