MKID Focal Plane Array for LiteBIRD

Yutaro Sekimoto Advanced Technology Center National Astronomical Observatory of Japan National Institutes of Natural Sciences



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MKID at NAOJ

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 - Focal plane design

Microwave Kinetic Inductance Detector (MKID) P. Day et al. 2003 Nature J. Zmuidzinas 2012 ARCMP

J. Baselmans 2012 JLTP



600 pixels MKID



- 1. Nitta T et al. 2014 "Close-Packed Silicon Lens Antennas for Millimeter-Wave MKID Camera." J Low Temp 176(5-6):684–90.
- Sekimoto Y et al. 2014 "Developments of wide field submillimeter optics and lens antenna-coupled MKID cameras" SPIE 91532P
- 3. Mitsui K, et al. 2015 JATIS "Fabrication of 721-pixel silicon lens array of a microwave kinetic inductance detector camera 1(2):025001

- Aluminum on Si substrate
- 1/4 λ CPW resonators
- 220 GHz double slot antenna
- machined Si lens array



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MKID

- Cooper pair breaking detector
 - Millimeter-wave to X-ray
- Oynamic Range ~ 10^5
- Frequency Multiplexing with a LNA
- Without bias circuit

material	Tc [K]	fg [GHz]	Tbath [K]
Al	1.2	88	0.24
Nb	9.3	678	1.9
Ti	0.4	29	0.08
NbTiN	14	1026	2.8
TiN	(0.5) - 4.5	330	0.9

$$f_g = \frac{2\Delta}{h} = 74 \text{ GHz} \times \frac{T_c}{1 \text{ K}}$$



MKID noise and beam measurements at NAOJ



NEP 2 x 10⁽⁻¹⁸⁾ W/rHz (Karatsu + 2015 LTD)





220 GHz beam pattern T. Nitta + 2013 IEEE TST 3, 56

M. Naruse+2013 IEEE TST 3, 180

Cryogenic (0.1K) Optics





F#1 – F#6 Cryogenic optics Nested baffle reduces stray light 0.1 K was demonstrated S. Sekiguchi et al. 2015 IEEE TST 5, 49 T. Tsuzuki et al. 2015 JATIS 1, 025002

Cryogenic test

150 mm window (~7 W at 300K) Taiyo Nissan dillution 20 μ W @ 0.1 K Tbath = 88 mK





600 pixels MKID

Vield :







MKID readout



H. Kiuchi et al. 2015 IEEE TST 5, 456

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700 pixel Si Lens array

Before Anti-Reflection (AR) Coating

After Mixed Epoxy AR





220 GHz

NAOJ ATC machine shop

LiteBIRD focal plane requirements

- 1. Optical Quality of feeds
 - 1. Each polarization
 - 1. beam shape (ellipticity, far & near side lobes)
 - 2. polarization alignment
 - 3. Cross polarization
 - 2. Differential Beam
 - 1. Differential beam pointing (beam squint)
 - 2. Differential gain (Main & Side lobes)
- 2. Sensitivity
 - 1. Map-noise
 - 1. <10 uK-arcmin (< 100 GHz))
 - 2. <5 uK-arcmin (100 200 GHz)
 - 3. <10 uK-arcmin (>200 GHz)
 - 2. Dynamic range for calibration
 - 3. Stability (1/f knee)
- 3. Environment
 - 1. Power Consumption (0.1K, 4K, 20K)
 - 2. Microphonic
 - 3. Cosmic ray
 - 4. Weight
 - 5. Volume





Sensors

Feeds

Cryogenic Amplifiers

Readout Circuits

Direct machined corrugated horn array

1)Larger effective area than platelet/stacked horn without fixing bolts
 2)Lighter weight by carving unnecessary part
 3)Low standing wave with chamfer
 4)Superconducting electro-magnetic shield



Planar OMT with circular waveguide

G. Engargiola & R. Plambeck 2003 RSI 74, 1380
Fundamental Mode: TE11(Odd mode)
Higher Modes: TM01 TE21 TE01 TM11 (Even modes)
are cancelled with 180° Hybrid
P. Grimes + 2007 Electron Lett 43(21):1146.

CIRCULAR WAVEGUIDE I 80 DEG HYBRID OR BALUN POL 2 OUT I 80 DEG HYBRID OR BALUN POL 1 OUT



David Pozer Microwave engineering

Broadband OMT (80 - 160 GHz) J. McMahon + 2012 JLTP 167, 879 R. Datta + 2014 JLTP 176, 670





A Prototype

- 4 pixels x two bands (90 and 140 GHz) x dual polarization
- Frequency : 80 160 GHz
- Directly machined corrugated Horn : AI 6063-T5
- OMT/filters : Nb
- AI MKID on SOI wafer
- Light tight
- Light weight





MKID focal plane for LiteBIRD

Mizuguchi-Dragone F#2.5 antenna

	Pixel	Pixel	module	detector	low	high	BW
	[mm]	Num	Num	Num	GHz	GHz	%
Low	24	36	5	360	55	77	33%
				360	78	108	32%
Mid	10	61	4	488	80	113	34%
	10			488	117	160	31%
High	8	271	1	542	165	227	32%
				542	233	330	34%



Total weight ~ 8 kg

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Challenges

- Low frequency MKID: 50 90 GHz
 - Ti/Al bilayer (Catalano + arxiv1504.00281)
 - TiN/Ti multilayer (Hubmayr + 2015 apl 106, 073505; Bueno + 2014 apl 105, 192601)
 - AIMn [D. Moore 2012]
 - Al/Cu bilayer (A. Dominjon + 2015: Poster)
- 1/f noise
 - knee 0.01 Hz
- Space qualified readout
- Mitigation of cosmic rays
 - D'Addabbo + arxiv1505.01647
- High optical efficiency
 - Horn-planar OMT/bandpass filters
 - For TES; Datta + 2014 JLTP 176, 670

Summary

MKID focal plane for LiteBIRD

 Corrugated horn array
 Planar OMT-MKID



Collaborators

- National Astronomical Observatory of Japan
 - T. Noguchi, W. L. Shan, A. Dominjon, H. Kiuchi, M. Sugimoto, H. Matsuo, N. Okada, M. Fukushima, Y. Obuchi, K. Mitsui
- Department of Astronomy, University of Tokyo
 - M. Sekine, S. Sekiguchi, S. Shu
- Institute of Physics, University of Tsukuba
 - T. Nitta, N. Nakai, N. Kuno, M. Nagai, H. Imada, Y. Yamada, S. Hisamatsu
- Graduate School of Science and Technology, Saitama University
 - M. Naruse, H. Myoren, T. Taino
- Institute of Space and Aeronautical Science (ISAS), JAXA
 - A. Miyachi, M. Mita, S. Kawasaki, T. Matsumura
- **RIKEN**
 - C. Otani, S. Mima
- KEK
 - M. Hazumi, O. Tajima, S. Oguri
- Kavli IPMU, University of Tokyo
 - N. Katayama, H. Sugai
- Okayama University
 - H. Ishino, A. Kibayashi