Transition Edge X-ray Sensors for Industrial Applications

K. Tanaka [a,1], T. Morooka [a], R. Fujimoto [b], Y. Ishisaki [c], Y. Takei [b], U. Morita [c], N. Iyomoto [b], T. Oshima [b], S. Nakayama [a], N. Yamasaki [c], M. Koyanagi [d], K. Mitsuda [b], T. Ohashi [c], K. Chinone [a]

[a] *Seiko Instruments Inc., Chiba 270-2222, Japan*
[b] *The Institute of Space and Astronautical Science, Kanagawa 229-8510, Japan*
[c] *Tokyo Metropolitan University, Tokyo 192-0397, Japan*
[d] *National Institute of Advanced Industrial Science and Technology, Ibaraki 305-8510, Japan*

Abstract

We present the performance of Transition Edge Sensors (TES) using Au/ Ti bilayer (operating temperature 69 mK) with fast decay time for industrial applications. The energy resolution was 11.4 eV for Mn Kα1 (designed value 3.7 eV) and the decay time 219 μs, yielding the count rate 760 cps (count per sec.). We found that the energy resolution was limited by excess noise. The excess noise increased in proportion to the inverse of TES resistance as decreasing the TES resistance from normal resistance. The source of excess noise might exist in the TES.

Key words: Transition Edge Sensor; energy resolution; count rate; excess noise

1. Introduction

Transition edge sensors (TES) are promising as x-ray detector that can rapidly measure a wide range of x-ray energy with high-energy resolution. For industrial application, the energy resolution should be under 10 eV because the chemical bonding of the material can be measured. Furthermore the count rate should be the same (2 k–3 k cps: count per sec.) as that for conventional silicon detector commonly used in the X-ray fluorescence analysis. Using bulk micromachine technique, we previously developed TES structure [1], in which the support substrate of Silicon On Insulator (SOI) wafer remains if part of silicon under the membrane is etched. This structure increases the mechanical strength of the wafer. When this structure is used, the count rate of the system can be increased by arranging a lot of TES on the same wafer without degrading the mechanical strength of the wafer. In this study, we developed TES whose design energy resolution was 3.7 eV and designed count rate was 2 kcps for single TES. We achieved the energy resolution 11.4 eV for Mn Kα1 and the decay time 219 μs, yielding the count rate 760 cps.

2. Experimental set up

Figure 1 shows the photograph of the TES. The Bilayer and absorber were fabricated on 1 μm-thick SiN_X membrane. Each bilayer was Au (110 nm thickness)/ Ti (40 nm thickness) and was 0.5 mm×0.5 mm. Each absorber was Au (300 nm thick) was 0.3 mm×0.3 mm. Table 1 lists TES parameters; τ_0 is the intrinsic decay time (C/G) where C is the heat capacitance and G is the thermal conductance, $\alpha \equiv d\ln R/d\ln T$ is the sensitivity of TES. The SQUID amplifier was fabricated for the amplifier of TES and driven by using FLL technique [2]. The intrinsic designed energy resolution was 2.8 eV. When the SQUID amplifier noise was 18 pA/$\sqrt{\mathrm{Hz}}$, the total energy resolution was 3.7 eV. The sample and shunt resistance were installed at the 20mK

[1] E-mail:keiichi.tanaka@sii.co.jp

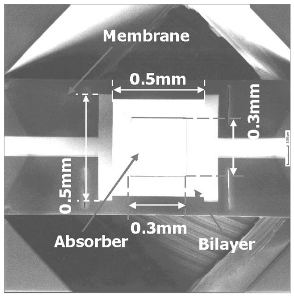

Fig. 1. Photograph of TES

Table 1
TES parameters

Normal resistance	89 mΩ
Heat capacitance	0.7 pJ/K
Tc	68.5 mK
Bath temp.	20 mK
Thermal conductance	0.6 nW/K
τ_0	1.28 ms
α	11
ΔE (eV) design value	2.8 eV
ΔE (eV) (+SQUID noise) design value	3.7 eV

stage in a dilution refrigerator and the SQUID amplifier was mounted on the 1.5 K stage. A DC voltage supply was used for the source of bias current.

3. Results and discussion

Figure 2 shows the energy spectrum for ^{55}Fe x-rays. The energy resolution was 11.4 eV for Mn Kα1 x-ray at 5.9 keV. The base line width that reflects the total noise level and the signal to noise ratio was 6.8 eV. The pulse decay time was 219 μs, yielding the count rate 760 cps. The difference between the energy resolution and base line width was caused by the scattering of thermalization in the TES. The difference between the base line width and designed energy resolution had two possible causes: the degradation of sensitivity α and excess noise. The degradation problem would be overcome by adopting the bank structure [3].

To investigate the cause of excess noise, we studied the dependence of noise current on TES parameters (shunt resistance, TES current, TES resistance). The noise current was measured at the 4 kHz where phonon noise was negligible. Figure 3 shows the noise current versus TES resistance curves for two TES normal resistance (89 mΩ and 126 mΩ). The noise current is in proportion to the inverse of TES resistance with decreasing the TES resistance from the normal resistance. The noise current did not depend on the shunt resistance and TES current. If the cause of excess noise is the DC

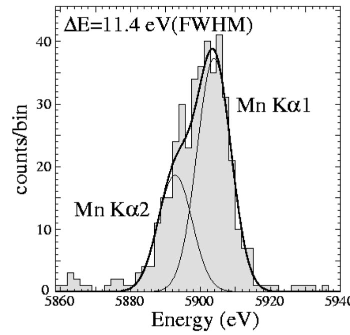

Fig. 2. Energy spectrum for ^{55}Fe x-rays. The energy resolution is 11.4 eV for Mn Kα x-ray at 5.9 keV

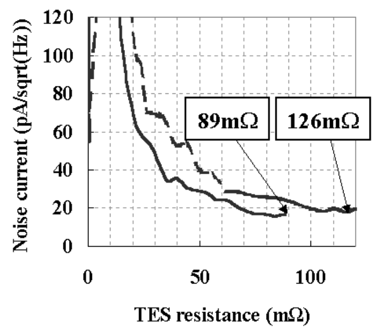

Fig. 3. The noise current vs. TES resistance curves of (a) normal resistance 89 mΩ (solid line) and (b) 126 mΩ (dashed line)

voltage supply, the excess noise would depend on the shunt resistance. Therefore the source of excess noise is not the DC voltage supply but might be exist in the TES. Based on these results, the source of excess noise might be voltage fluctuation that depend on the TES normal resistance and might be in the TES.

4. Conclusion

We fabricated the TES to achieve energy resolution under 10 eV for industrial application. The energy resolution was 11.4 eV and the count rate 760 cps. The energy resolution was caused by the existence of excess noise, which only depended on the TES resistance.

References

[1] K. Tanaka *et. al.*, Appl. Phys. Lett. **77**, (2000) 4196.

[2] T. Morooka in this volume.

[3] G. C. Hilton *et. al.*, IEEE Trans. Appl. Supercond **11**, (2001) 739.