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Development of superconducting tunnel junction array detectors with three-dimensional structure to exceed 1000-pixel array

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X-ray detectors based on superconducting tunnel junctions (STJs) have demonstrated excellent energy resolution, high detection efficiency, and high counting rate in the soft X-ray range. Our soft X-ray detector using 100-pixel array of Nb/Al/AlOx/Al/Nb STJs with 100 μm square has a mean energy resolution of 12 eV, relatively large detection area of 1 mm2, and a counting rate of several 100 k cps, which are suitable for synchrotron radiation facilities. A X-ray absorption fine structure (XAFS) instrument with our STJ array detector was installed in the synchrotron radiation beam line, and has been opened to users for routine analyses. It is possible to obtain XAFS spectra of light trace elements such as nitrogen dopants of 300 ppm in a SiC compound semiconductor.[1] In order to achieve a high throughput analysis for trace elements such as dopants in structural or functional materials, the detection area of the STJ array detectors should be further increased up to several 10 mm2 which is several 10 times larger. In order to achieve a large detection area, it is necessary to increase the pixel number of the array detectors because enlargement of STJ pixel size tends to degrade the energy resolution due to the increase of the system noise. In order to integrate a large STJ-pixel number more than 1000 within a 10 mm square compact chip, which is the maximum loading size in our XAFS instrument, we have introduced three-dimensional (3D) structure by embedding a wiring layer in a SiO2 (base SiO2) layer underneath a electrode layer of STJs. Conventional way of making close-packed STJ arrangement is situating the wiring leads on the detection area of the STJs. However, two drawback exits with the conventional geometry. One is the decrease of the detection area. The second is making artifact signals generated by the X-ray absorption in the

wiring leads. On the contrary, the 3D structure can solve the two drawback and then is the best solution for realizing close-packed STJ arrangement. In the design using conventional two-dimensional layout, the maximum pixel number of 100 mm-STJs is about 600 on 10 mm square chip. In contrast, in the 3D structure, the maximum pixel number of 100 mm-STJ is more than 3000.[2]

In this work, we have developed the 100-pixel array of the STJs with the 3D structure (3D-STJ) and evaluated performances for X-ray detectors. To make 3D-STJ, our conventional fabrication of STJ arrays was improved by introduced a caldera planarization[3] and TEOS chemical vapor deposition. All fabrication process was performed in the clean room for analog-digital superconductivity (CRAVITY) at AIST[4]. The detail of the fabrication process is described in the literature [2]. The layer structure of the STJs consisted of Nb (100 nm)/Al-AlOx (70 nm)/Al (70 nm)/Nb (300 nm). The critical current density of the STJs was designed about 200 A/cm^2. The STJs with the size of 100 mm squire were situated with an interval of 120 mm, which was 1/2 times smaller than that of conventional STJ array. The 100-pixel 3D-STJ array was cooled to 0.31 K using a helium-3 cryostat, evaluated current-voltage (I-V) and soft X-ray detection characteristics. The typical 3D-STJ showed an I-V curve having subgap current of about 40 nA and an energy gap of 0.44 meV. 93 3D-STJs in 100-pixel showed similar I-V characteristics and can be working as X-ray detectors. It was possible for all working 3D-STJs to be operated by the same bias current of 40 nA at a magnetic field of about 10 mT. 91 3D-STJs of working pixels showed enough energy resolving power to detect soft X-rays. A mean value and a standard deviation of the energy resolution for C-Ka (277 eV) were 12.5 eV and 0.7 eV, respectively. The detection performances are almost same as those of our 100-pixel conventional STJ array. This result indicates that it is possible to achieve excellent performances such as high operation yield of more than 90 % and excellent energy resolution of about 10 eV in 1000-pixel 3D-STJ array.

References

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