Dose Rates at the Surfaces of the Irradiated Materials in Neutron Transmutation Doping Service of HANARO

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1. Introduction

Neutron transmutation doping (NTD) for producing N-type silicon is based on the conversion of the Si-30 isotope into phosphorus atom by the absorption of neutron. This method can produce silicon semiconductors with extremely uniform dopant distributions [1]. The NTD is one of the rare cases in the research reactor utilization providing direct industrial applications.

HANARO, a 30 MW research reactor, has two vertical holes in the heavy water reflector region for the NTD - NTD1 and NTD2 of which the diameters are 22 and 18 cm, respectively. It has been confirmed that the two holes are very good for the NTD from the viewpoints of neutron quality and size [2]. The commercial NTD service for 5 in. silicon ingot has been going on at the NTD2 hole, and an additional 6 in. irradiation device at the NTD2 and a 6 and 8 in. irradiation facility using the NTD1 hole are under development.

In the several procedures of NTD service, the workers are occupationally exposed by radiation, mainly, gamma-rays. In this work, gamma-ray dose rates at the surfaces of the irradiated materials in NTD service are investigated in order to predict the dose rate of the NTD workers.

2. Calculation and Experimental Methods

In NTD procedure, the important irradiated materials are silicon ingot for doping, activation sample for neutron fluence measurement and aluminum tape for fixing the sample. The variations of the specific radioactivities of the irradiated materials in various irradiation conditions and cooling time were calculated by using the balance equation of each isotope [3]. The dose rates at the surfaces of materials irradiated at a condition were measured with the calibrated dose rate meter 6150ADT manufactured by Automess. By using the measurements, the dose rates in the various conditions were predicted.

There are three isotopes of Si-28(92.23%), Si-29(4.67%) and Si-30(3.10%) in natural silicon. Among them, only Si-30 is transformed to phosphorus atom by neutron absorption through β-decay with the half-life of 2.62 hours. In this process, 1266 keV gamma-rays and some β-particles are emitted from irradiated silicon ingot. This residual radioactivity, the specific radioactivity of irradiated silicon must be below the exemption limit from radioactive material [4]. The calculations of dose rates were performed for the 5 inch silicon ingots with a 30 cm length at the reactor power of 30 MW.

The zirconium foils with a thickness of 0.127 mm and mass of 10~50 mg were used at the NTD in order to measure the neutron fluence. Generally, three zirconium foils are attached and fixed on the surface of silicon ingot by using the aluminum tape. The induced activities of the zirconium by a neutron irradiation are Zr-95, Zr-97 and their daughters such as Nb-95 and Nb-97 [5]. In calculation, the mass of zirconium was set to be 50 mg.

The aluminum tape is composed of aluminum film and adhesive materials. From the detection of gamma-rays emitted from irradiated aluminum tape with HPGe detector, it is confirmed that the main component of adhesive materials is bromine. Among the two natural isotopes of bromine, the radiative capture of Br-79(50.69%) is negligible because of the short half-life of Br-80. Therefore, the Br-82, the product of capture reaction of Br-81, is the main source of radiation of the aluminum tape. In the calculation, the mass ratio of the aluminum and the bromine in the tape is 1:0.42, and the size of the aluminum tape is 5×2.5 cm^2.

3. Results

Figures 1,2,3 shows the variations of the dose rates at the surfaces of the silicon ingot, zirconium sample and aluminum tape as a function of the cooling time, respectively. For the silicon ingot, the main gamma-ray source is Si-31($T_{1/2}$=2.62 h), so, if the cooling time is longer than 2 days, the occupational dose of NTD worker due to silicon ingot is reasonably low.

When the cooling time is 2~3 days, the dominant gamma-ray sources of zirconium sample are Zr-95, Zr-97 and Nb-97. From the figure 2, it is confirmed that the residual dose rate is too big for manipulation and measurement of neutron fluence in the case of above cooling time and the irradiation time over 6 hours. Therefore, in that case, the sample with smaller mass must be used.

Since the half-life of Br-82 which is the main gamma-ray source of aluminum tape is relatively long, and it is difficult to reduce the size of the tape, the main contribution to gamma-ray dose of NTD workers is the aluminum tape.

When the irradiation time is 12 hours which is the maximum irradiation time at HANARO NTD service, the maximum dose rate of the irradiated materials after 2 days cooling is expected to be about 300 μSv/h. This dose rate is not so big for being manipulated by NTD workers.

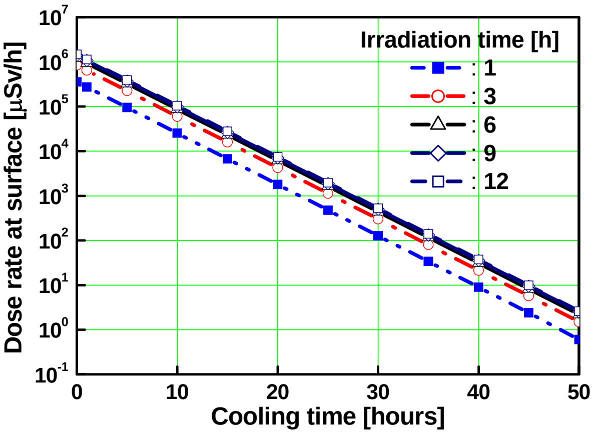

Fig. 1. Dose rates at the surface of the silicon ingot as a function of the cooling time.

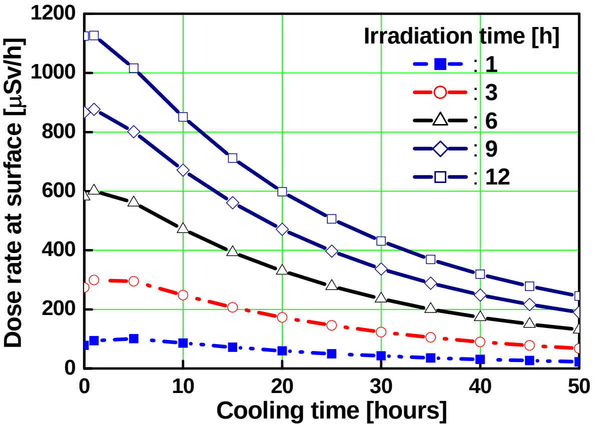

Fig. 2. Dose rates at the surface of the zirconium sample as a function of the cooling time.

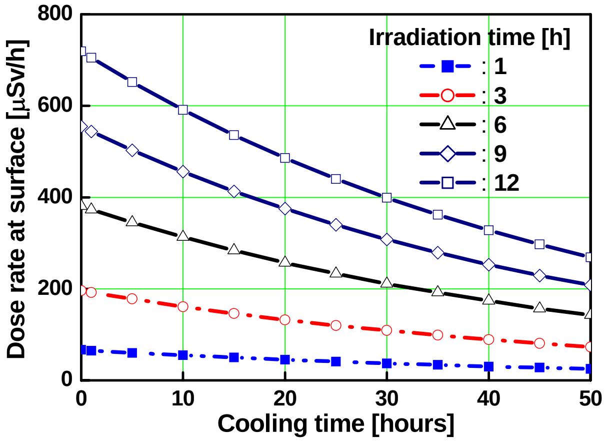

Fig. 3. Dose rates at the surface of the aluminum tape as a function of the cooling time.

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