# DEVELOPMENT OF A NEW HIGHLY BRIGHT X-RAY GENERATOR

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*Abstract*

A new type of rotating anticathode X-ray generator has been developed, in which the electron beam irradiates the inner surface of a U-shaped anticathode. We have achieved emission of X-rays 10 times more brilliant than can be attained by a conventional rotating anticathode. The development is still in progress. New results are reported in details.

## INTRODUCTION

The U-shaped rotating anticathode X-ray generator has achieved highly brightness by means of using heat of fusion. The electron beams are focused so strong that anticathode material, cupper, is being melted in operation [1]. A high-flux electron beam is focused on the inner surface by optimizing the shape of the bending magnet [2, 3]. In order to minimize the sizes of the X-ray source, the electron beam is focused in a short distance by the bending magnet which is small and is close to the rotating anticathode. The power of the electron beam can be increased over the melting point, because a strong centrifugal force fixes the melting part on the inner surface not to be splashed.

## SOUCE SIZE AND RESOLUTION

### *Electron Beam Focus Size*

The electron beam focus size on the U-shaped rotating anticathode was measured using a 10 mm-diameter Au pinhole and a chilled CCD camera with fluorescent film.

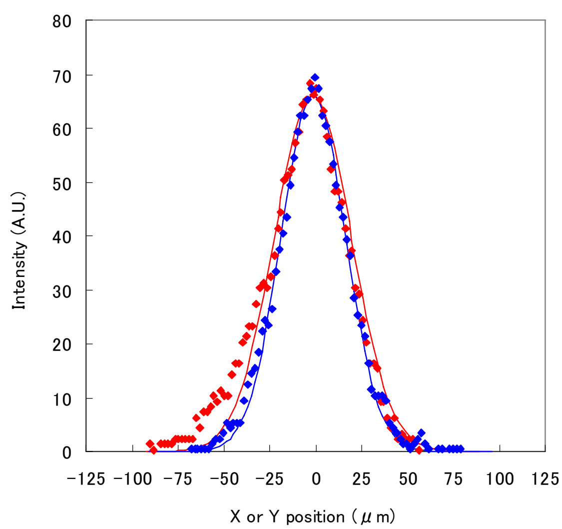


Figure 1: X-ray source distribution on the anticathode.

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Figure 1 shows a typical example of the focused electron distribution observed at the takeout angle of 6 degrees from the rotation surface. Each distribution in x and y directions has a FWHM size less than 50μm.

### *Resolution*

In order to estimate resolution, we took an X-ray enlarged picture of a MFT chart, of which line numbers and width are listed in Table 1. Figure 2 shows an example with a magnifying power of 4.7.

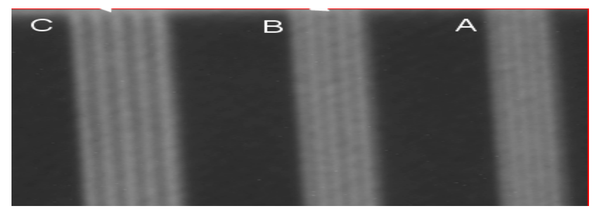


Figure 2: X-ray figure of a MTF chart.

Table 1: MFT chart parameter

| Type | Line density | Line width (μm) |
|---|---|---|
| A | 20 line pairs/mm | 25 μm |
| B | 16 line pairs/mm | 31 μm |
| C | 12.5 line pairs/mm | 40 μm |

## BRIGHTNESS AND CURRENT

### *Achieved Brightness*

Figure.3 presents examples of the achieved brightness

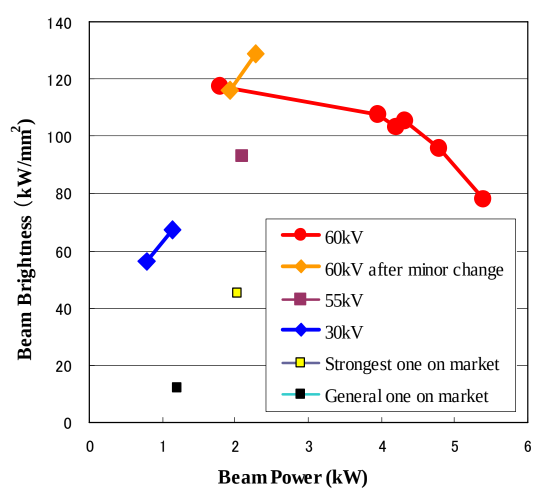


Figure 3: Beam power dependence of brightness.

by the new X-ray generator. Two values of other systems seen in the figure. It would be one of the major subjects to improve ability in the high energy region.

### *Current Dependence of Source Size*

The measured source sizes are plotted in Fig. 4, which correspond to the data shown in Fig. 4. The focus sizes obviously increases linearly or more rapidly in high current region. This is the reason why the brightness decreases in the high power region in Fig. 3. It would be necessary to improve the final focusing.

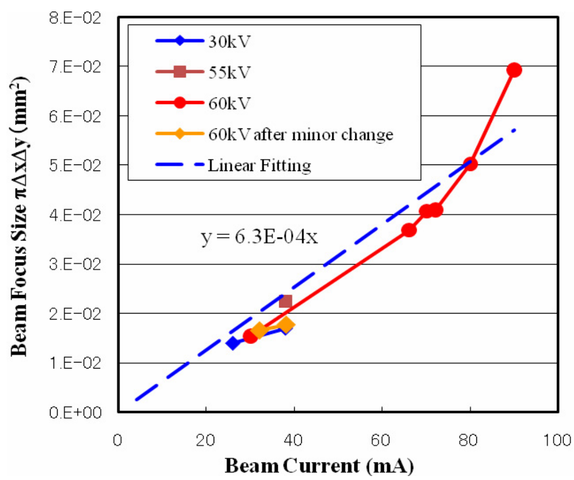


Figure 4: Current dependence of focus size.

## TEMPERATURE OF ANTITARGET

### *The Temperature of the Irradiated Area*

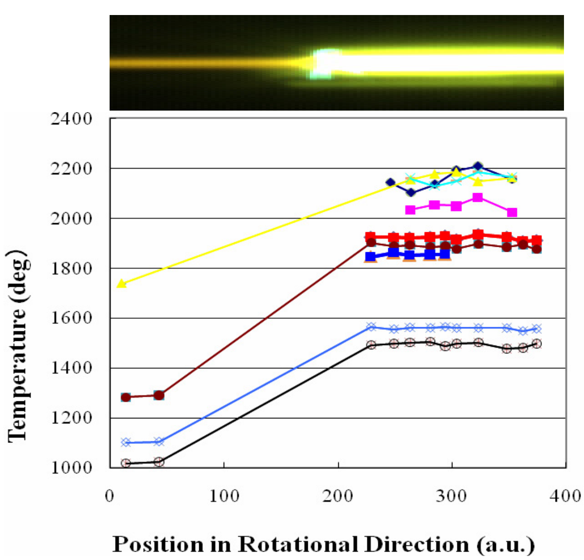


Figure 5: Temperature distribution of the target in rotational direction before and after irradiation.

The temperature near the irradiation area was observed by a two-colour type thermometer. The light for the measurement was taken out through a hole whose visible area on the target is 4.6mm x 6.5mm. The center of the visible area is the irradiation point and the takeout angle of the light is 65 degrees from the rotating surface. The antitarget of 10cm in diameter rotates with 6000RPM. Figure 6 shows examples of temperature distribution on the irradiated area. A visual picture near the irradiation area is shown on the top in Fig. 5.

## ENERGY DEPENDENCE

### *Effect of Heat of Fusion*

Cupper has large heat of fusion, which is very useful for suppressing the surface temperature raise caused by electron irradiation. This is one of features of our system in which high brilliant X-rays are safely generated in the range of the temperature over melting point.

In the case that the electron beam power would be fully used to melt the cupper surface, the temperature would be kept at melting point, where vapour pressure is negligibly small. Electrons with energy near the range of 50keV can, however, penetrate into the cupper in short distance; some micrometers. Therefore electrons can directly melt very limited volume near the surface.

In order to suppress the temperature raise, rotating antitargets are generally and widely adopted. The irradiated portion on the surface passes the electron beam cross section with a speed of rotation. Let us think the case that the antitarget is solid state before entering into the electron beam cross section, and in the middle of the passing period, the irradiated area has completely melted. But irradiation still continues. It would make the temperature easily higher to dangerous region since specific heat is too small to suppress.

It is obviously important to well utilize the phenomena, heat of fusion, for developing highly brighter X-ray generator. We have made an experiment to examine the energy dependence of temperature.

### *Energy Dependence of the Temperature*

The rotating antitarget temperature would be thought to depend only on a rotating speed and the electron- beam power density. In our system, however, the electron energy has an important role, as having being pointed out from early stage by one of authors, N. Sakabe.

The penetrating depth of electron depends on the energy of electrons: higher the energy, deeper the depth. Then the higher-energy electrons can make larger volume melt, and more energy is absorbed for melting. As a result, it is expected that the temperature relatively goes down.

Figure 6 shows energy dependence of the temperature near the irradiated area of the rotating antitarget. The average temperature was measured by a thermometer of two-colour type in a region about 2mm apart from the beam center. This means that the data was taken in about 0.07μs after irradiation. Each connected set of data corresponds to a constant beam current. Energy dependence is obvious from the figure: higher the energy, lower the temperature, even if the beam power increases.

Each data set has a dotted line which was calculated by Eq. 4 with experimental parameters. They have a remarkable agreement.

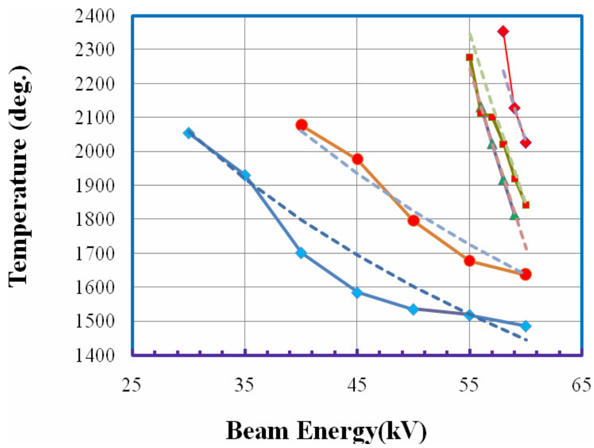


Figure 6: Energy dependence of the temperature at the irradiated area of the rotating antitarget.

## *Adiabatic Approximation*

We can observe the antitarget area near irradiation from -4mm to +4mm in the rotational direction, which corresponds to the time range of 0.1ms before or after irradiation. In such a short time, heat conduction becomes negligibly small, so small that dissipated heat exists only in the area electrons reached. Therefore adiabatic approximation becomes useful. Let us think a case that electron energy increases by a tiny value of $\Delta E$ , which is defined here to be measured in unit of Volt. From the energy conservation law we have

$$I\Delta E = L\rho\Delta x r\omega\Delta z + J\rho\Delta x r\omega z\Delta T \ , \qquad (1)$$

where $I, L, \rho, \Delta x, r\omega, and, J$ are the electron beam current, heat of fusion, density, the beam spot size in the axial direction of rotation, and work correspondent of heat, respectively.

In the right side of Eq.1, the first term represents an increase of heat of fusion in a deeper region of $\Delta z$ . Second term corresponds to amount of power increase which is used to raise temperature by a small value of $\Delta T$ .

As for the electron penetrating range we assume the following empirical formula.

$$z = \alpha E^{\beta} \qquad (2)$$

Then we have the following equation.

$$\frac{dT}{dE} = -\frac{L\beta}{JC}\frac{1}{E} + \frac{I}{J\rho C\Delta x r\omega z} \qquad (3)$$

This gives us the relation, as follows.

$$T - T_0 = -\frac{L\beta}{JC}\log\frac{E}{E_0} + \frac{I}{J\rho C(\beta - 1)\Delta x r\omega}\left(\frac{E}{z} - \frac{E_0}{z_0}\right) \qquad (4)$$

As for the right side terms, the first term comes from the cooling effect due to heat of fusion, and the second term corresponds to a temperature change in the power dissipating area due to the volume change. As our case of $\beta > 1$, the right side terms have both the same sign. Therefore both terms contribute to decrease temperature with energy up.

We should take attention to the following two facts: The first term contributes only when material melts by irradiation, and the second term depends on $I/\Delta x r\omega$ so that for small $\Delta x$ the second term becomes dominant as is the case of rapidly changing data in Fig. 6. Fortunately we have a free parameter such as $r\omega$ , which is the rotating speed of anticathode. Others are all characteristic values of matter. By means of enlarging the value of $r\omega$ , we would be able to suppress the second term's effect.

From Eq. 4, higher energy beams are obviously advantageous from a view of temperature.

## *Energy Dependence of X-ray Strength*

We also measured the X-ray strength shown in Fig. 7. It increases rapidly as is expected from a formula for radiation. As for the characteristic X-rays, however, other consideration would be necessary.

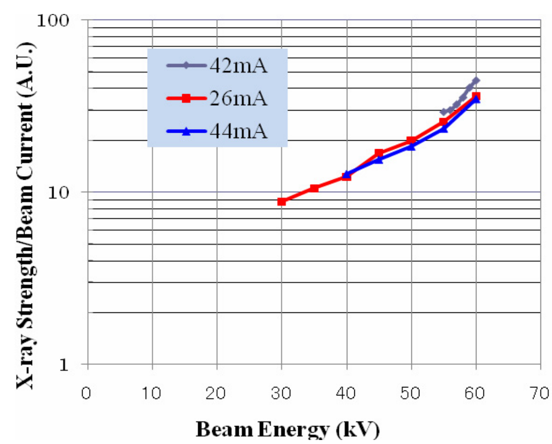


Figure 7: Energy dependence of X-ray strength.

## REFERENCES

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