A Calibrated Large-area X-Ray Source for Plasma Spectroscopy

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Dedicated to Professor Dieter Pfirsch on his 60th Birthday

A large-area (10×30 cm^2) X-ray source for relative and absolute calibration of double-crystal monochromators for plasma soft X-ray spectroscopy was developed. For a voltage of 20 kV and a current of 1 mA uniform and reproducible emission is achieved at a level of about 30 mW/(m$^2 \cdot$ sr) for K_α line emission in the photon energy range from 1 keV to about 8 keV, while the L_α line emission increases with photon energy from 10 to 20 mW/(m$^2 \cdot$ sr).

1. Introduction

The transport of energy and particles in magnetically confined plasmas is one of the most important physics problems in fusion research [1]. Special attention is paid to transport of impurities, which can lead to intolerable radiation losses [2]. Identification of impurities in the plasma and measurement of their concentrations, their spatial distributions and their fractional abundances as functions of time are made possible by soft X-ray spectroscopy. Continuous scanning of a wide spectral range can be made by applying a double-crystal monochromator device and, moreover, continuous spatial scanning of spectral lines is allowed if the crystal which is closer to the plasma is rotated additionally around the axis parallel to the X-ray beam between the two crystals [3].

Determination of impurity concentrations calls for absolute X-ray line intensity measurements. The sensitivity (throughput) of a double-crystal monochromator and its distribution within the scanning range depend on the crystal reflectivities and rocking curve widths, the detector efficiency and the solid angle. Although the crystal properties were measured [4] and the detector efficiency [5] as well as the dispersion [6] and solid angle properties were determined separately, it is desirable to have direct absolute calibration of the double-crystal monochromator – at least relative calibration of the spatial-scan version. Since the plasma is an extended volume X-ray source, the calibration device must be a large-area X-ray source. The main condition of such a source is to achieve reproducible and uniform high emission across the entire area of the source seen by the monochromator. This emission should be absolutely calibrated over a wide spectral range.

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2. The Large-area X-Ray Source

The calibration source consists of a rectangular vacuum vessel which can be attached to the monochromators. The anode is a solid metal plate (Al, Ti, Cr, Cu, Zn, …) with an area of 10×30 cm^2 and a thickness of 1.5 cm [7]. At a distance of 2 cm above its surface five thin gold-covered tungsten wires 100 μm in diameter are stretched parallel to the long side of the anode at equal distances of 1.5 cm. The wires are kept under tension by separate metal springs. A grid at cathode potential about 1 cm above the cathode wires gives a well-defined potential distribution in the source vessel, thus avoiding additional X-ray emission by secondary electron emission.

The anode (as well as the cathode) can easily be exchanged to achieve different K_α or L_α line emission.

3. Results

For reproducible operation of the large-area X-ray source it turned out to be necessary to apply sufficient mechanical tension to the cathode wires in order to avoid their sagging during heating.

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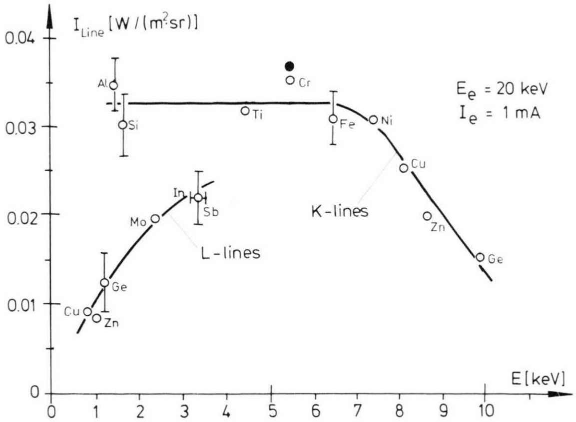

Fig. 1. The line intensities emitted from the large-area X-ray source for different anode materials versus photon energy E calibrated with the Si(Li) detector (open circles) and the ^{55}Fe source (full circle).

Moreover, the pressure in the vacuum vessel should be below about 10^{-3} Pa (10^{-5} mbar). After replacement of the anode plate or the cathode wires it was necessary to heat the wires at a pressure of less than 10^{-3} Pa for about a quarter of an hour in order to reach the stable and reproducible emission characteristics. For normal operation at a voltage of 20 kV and an electron current of 1 mA the X-ray emission was found to be constant within 4% (statistical error of the radiation measurement with a time constant of 120 s), if the voltage and current were both stabilized within a margin of 1%. At these parameters the source can be operated for hours.

The emission of this large-area X-ray source shows excellent homogeneity over a length of about 24 cm, which is nearly the entire anode plate length [7]. This is an important condition for relative calibration of the spatial-scan double-crystal monochromator. A pinhole device was used to measure this relative X-ray intensity distribution [7].

The emission was found to be proportional to the electron current within a relatively wide range (from at least 0.01 mA to 2 mA).

For absolute calibration of the large-area X-ray source two different methods were applied: The source was compared with a calibrated ^{55}Fe source (which emits MnK$_\alpha$) at exactly the same solid angle and aperture area as CrK$_\alpha$ was emitted from the source. The intensity ratio is then obtained from the detector count rate ratio on the assumption that the detector sensitivity is the same for the nearby lines MnK$_\alpha$ (5.898 keV) and CrK$_\alpha$ (5.414 keV). This condition is fulfilled for the applied Si(Li) detector [8]. The other method for absolute source calibration is to measure the count rate of the Si(Li) detector and determine the solid angle and aperture area, taking the spectral efficiency of the Si(Li) detector into account [8].

The absolute calibration measurements were done with several different materials (mostly metals) as anode plates, in some cases (such as Si, Ge, InSb, ...) as inserts in an aluminium anode plate surface.

The results of the measurements at an anode voltage of 20 kV and an electron current of 1 mA are plotted in the figure. It turned out that in the photon energy range from about 0.9 to about 8 keV the (total) intensity of the respective K$_\alpha$ (plus K$_\beta$) lines is about 30 mW/(m^2 · sr). It decreases monotonically with increasing atomic number of the anode elements above about 8 keV. The L$_\alpha$ line intensities are somewhat smaller. They slightly increase with the atomic number. For photon energies below about 3.5 keV the Si(Li) detector efficiency correction of Müller et al. [8] had to be taken into account. Although the reproducibility of the intensity measurements seems relatively high, the error bars reflect the uncertainties of the solid angle and aperture area determination.

Further measurements seem to indicate that the sum of the K$_\alpha$ line intensities of alloys as anode plate materials is also of the order of 30 mW/(m^2 · sr).

4. Conclusions

The large-area X-ray source operated at 20 kV and 1 mA can be applied for relative and absolute calibration of double-crystal monochromators in plasma spectroscopy. It shows excellent homogeneity of K$_\alpha$ line emission over nearly the entire anode length and reproducibility at a level of about 30 mW/(m^2 · sr). The wavelength can be varied by anode plate exchange.

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