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Microscopic X-ray Sources Imaged Using High-Resolution Enlargement Kumakhov Optics

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Abstract—A substantially new direction in X-ray microscopy is developed. X-ray images of a microscopic X-ray source representing a focal spot of a microfocus X-ray tube have been obtained with a spatial resolution on the level of 1 μm. This possibility is provided by a cone-shaped polycapillary high-resolution Kumakhov optical structure. © *2004 MAIK "Nauka/Interperiodica".*

The problem of imaging objects emitting in the X-ray range is still of considerable importance in view of the continuous development of both traditional X-ray sources such as microfocus X-ray tubes and relatively new devices such as laser plasma sources. Previously [1, 2], the focal spot size of an X-ray tube was determined using an image obtained with the aid of a cylindrical Kumakhov X-ray optical structure. However, the accuracy provided by such imaging systems is frequently insufficient for determining the dimensions of focal spots of modern microfocus X-ray tubes, since the error introduced by the usual polycapillary structure is comparable with the anode spot size that is to be determined. Moreover, in the case of micron focal spots, the size of the image of this spot at the exit of the polycapillary column can be smaller than the limiting resolution of a detector system: modern commercial X-ray imaging systems have a resolution on the order of 5–6 μm, whereas the focal spots of microfocus X-ray tubes can be as small as a few microns.

In this situation, it expedient to use the wide possibilities offered by Kumakhov optics in application to the X-ray images [2–7]. Using a high-resolution imaging cone-shaped polycapillary of Kumakhov optical structure, it is possible to lift restrictions related to the detector resolution.

The proposed method is essentially as follows (see Fig. 1). A polycapillary structure with the shape of a truncated cone is brought sufficiently close (at a distance shorter than the focal length) to the X-ray anode, and a detector system is placed at the exit of this capillary structure. The focal length is defined as the point of convergence of the generating lines of the cone. As the detector system for a rapid evaluation of the source size, it is most expedient to use a conventional X-ray imager. The size of the focal spot is determined from the image size upon preliminary calibration of the system.

In the proposed method, the role of the cone-shaped structure is to form an enlarged image of the source. The entrance diameter of the capillary used in the polycapillary structure (i.e., the capillary edge facing the focal spot) must be much smaller than the anode spot size. The exit diameter of the capillary (at the output of the Kumakhov lens) must correspond to the resolution of the imager. In such systems, the capillary optics transfers information about the object size to the detector at an accuracy corresponding to 2–3 entrance diameters of the capillary. Therefore, reaching a resolution of 1 μm requires that the capillary entrance diameter not exceed ~0.5 μm. Naturally, the capillary diameter variation from entrance to exit should be thoroughly controlled so as to avoid distortion of the information transferred. The spatial resolution in the proposed scheme is increased both due to a decrease in the entrance size of the channel and to the cone shape, which provides an increase in the image size.

Using the proposed approach, it is possible to increase the accuracy of spot-size determination using modern X-ray imaging systems up to a level of 1 μm. A disadvantage of this method (as compared to the capillary column technique [1, 2]) is the somewhat more complicated procedure of the adjustment of the cone

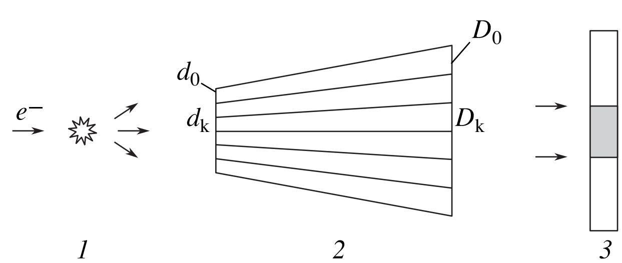

Fig. 1. Schematic diagram of the experimental arrangement: (*1*) focal spot of the X-ray tube; (*2*) cone-shaped polycapillary structure; (*3*) X-ray detector.

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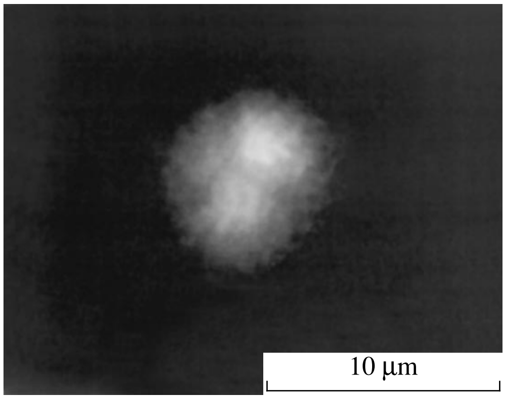

Fig. 2. Typical image of the focal spot of a microfocus X-ray tube obtained using a cone-shaped Kumakhov semilens (the spatial scale is reduced to the anode surface).

relative to the X-ray tube. Additional distortions can be introduced by an imperfectly regular polycapillary structure, which is related to technological difficulties encountered in manufacturing capillaries with decreasing channel size.

The proposed method was implemented using a cone-shaped polycapillary structure (Kumakhov cone semilens) comprised of an assembly of cone-shaped capillaries (hollow glass tubes) with a small entrance diameter that gradually increased toward the exit. The entire assembly had an input diameter of $d_0 = 0.3$ mm and an output diameter of $D_0 = 4.5$ mm (Fig. 1). The capillary channel diameter was approximately 1000 times smaller ($d_k = 0.3$ μm at the entrance and $D_k = 4.5$ μm at the exit).

The polycapillary structure was mounted in a special holder capable of moving in three mutually perpendicular directions, which allowed the collimator to be precisely adjusted relative to the focal spot of the X-ray tube. The minimum step of adjustment was 0.1 μm.

The experiments were performed with an X-ray imager comprising a scintillation screen, a light guide, an electrooptical converter, and a CCD camera whose signal was digitized and fed to a computer for storage and processing. The total resolution of the X-ray imager in the phosphor-coated plane was ~5 μm. A microfocus X-ray tube used in these experiments also had a minimum focal spot size of 5 μm.

Figure 2 shows an example of the typical X-ray image of the focal spot of the microfocus X-ray tube. The image, with a resolution of about 1 μm, was obtained using the method described above. An analysis of this image allows the X-ray tube anode spot size to be determined. The image exhibits dark regions related to the walls of the polycapillary structure. However, these features do not introduce significant image distortions capable of hindering determination of the focal spot size.

Thus, using a cone-shaped Kumakhov semilens, it is possible to obtain images of the focal spots of X-ray tubes with a micron resolution. The proposed method provides high-precision determination of the effective focal spot size of a microfocus X-ray tube.

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