Study on Defects of Square Capillary X-ray Lenses or Slices

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Abstract. X-ray imaging method as a non-destructive, in-situ, and effective analytical tool plays an important role in material analysis and application. The Square Capillary X-ray Lenses or Slices (SCXLS) as the key optics in X-ray imaging are being studied and reported more and more. In this work, we presented the main defects of SCXLS in the manufacturing process, and gave the corresponding solutions to these defects, which finally enables SCXLS to better enter imaging application for material analysis.

Introduction

Capillary optics as the friendly optical devices are being used widely in laboratories. Based on the different manufacture steps and final structures, there are divided into mono-capillary X-ray optics and poly-capillary X-ray optics\cite{1,2}. There are hundreds of thousands of glass tubes in a poly-capillary X-ray optics, and each tube has its own contour curve equation. These tubes transmit and control X-ray beams well under the principle of total external reflection\cite{3}. Combined the poly-capillary structure and the principle, the poly-capillary lens can control a laboratory X-ray source to a focus beam or a parallel beam. Therefore, this kind of X-ray optics has been widely used in X-ray diffraction analysis, X-ray fluorescence analysis or other experiments\cite{4,5}\cite{6}.

In the field of X-ray imaging, Pawel Korecki et al. had applied the poly-capillary X-ray lens for coded aperture imaging\cite{7,8}. However, in fact that round glass tubes contribute the hexagonal arrangement of the lens. This kind of hexagonal structure is not conducive to X-ray transmission due to the existence of triangular voids, nor can it be adapted to Charge Coupled Device (CCD) well\cite{9}. Therefore, a model of SCXLS has been proposed\cite{10}, and the simulation and manufacturing has been reported\cite{9,11}. During the manufacturing process, the glass tube misalignments and drawing temperature fluctuations may cause the structural defects of the lens. In this work, we will present and discuss known defects of the SCXLS. In section 2, the classification of defects are specifically introduced. The discussion is presented in section 3, and conclusions are given in section 4.

Classification of Defects in SCXLS

In the manufacturing process, the square core rod was first filled into a square glass tube to form a square glass tube preform, and drawing it into monofilament fiber with a drawing machine. Then the monofilament fibers were arranged in a rectangular shape to form a monofilament array perform. The preform need to be placed in the drawing machine again to form multifilament fibers. Finally, a multifilament array preform in which the multifilament fibers are arranged was drawn again to obtain a SCXLS\cite{11}. Due to the complexity of the process, defects have arisen. The main defects are shown as follows.

Multifilament Fiber Gap Defect

The gap between the square multifilament fibers contributes the multifilament fiber gap defect. This
defect not only caused cracks in the SCXLS, but also caused severe transmitted X-ray in optical experiments. As shown in Fig. 1, under the X-ray imaging results, it can be found that the square lens slice has a significant gap. This defect was mainly due to the fact that during the drawing process, the softening temperature of the multifilament array preform was insufficient. Therefore, it is impossible to form an effective adhesion between the fibers.

![Figure 1. The X-ray image of the multifilament fiber gap defect.](image)

**Axis Deviation Defect**

In the stage of drawing the monofilament fiber, due to the difference in thermal expansion coefficients of the square core material and the square glass tube, local defect of the monofilament was caused, which lead to the bent of the fiber. For the multifilament fiber, defects would occurred due to uneven heating in the drawing machine or the used of monofilament fibers containing a local defect, which eventually caused the square lens to deviate from the theoretical optical axis.

![Figure 2. Schematic of square array axis deviation defect (a) Single direction deviation; (b) Multi-directional deviation.](image)

**Multifilament Fiber Distortion**

Multifilament fiber distortion means that the microchannel profile was no longer square, but was extruded into other various defect shapes. In the process of drawing a square lens, this defect was caused by excessive heat or uneven heating of the multifilament fiber. Figure. 3 showed this kind of distortion. This kind of distortion cannot be observed during the drawing process, it can only be found by slicing the finished square lens and then placing it under a microscope. Therefore, in the drawing of the square multifilament preform, the drawing temperature should be controlled strictly, and the actual drawing temperature can be lowered to effectively reduce the proportion of distortion defects.
Multifilament Fiber Dislocation

Dislocation refers to the case where the microchannel of a square lens deviates from the theoretical position, showing a situation in which the columns and columns are staggered. As shown in Fig. 4 red area, the horizontal two rows of microchannels showed this kind of dislocation. In X-ray capillary optics, the material for producing the lens is mainly silicate glass, and its outer wall is extremely smooth. Therefore, when arranging filaments of monofilament or multifilament array preforms, slippage is likely to occur, resulting in dislocations.

Twisted Fiber Defect

When the preform was drawn into the drawing machine, if the axis of the preform deviated from the center of the furnace, the preform will cause a difference in radial pull due to uneven heating, so the preform would rotate along the center line. This rotation phenomenon exists in any preform, no matter of the monofilament fiber preform or others. There are two kinds of twisted schematic diagram shown in Fig. 5. Figure 5(a) is the twisted process of normal glass fiber and the Fig. 5(b) is that of twisted multifilament preform or lens.

Discussion of the Defects

In the second section, there are five major defects in the manufacture of X-ray imaging square lenses. In addition, the environmental fluctuations of the drawing machine could also affect the manufacturing performance, but these factors can be well avoided and dealt with, so no longer make a
statement. With the above main five defects, the most serious defect was the multifilament fiber gap defect. The multifilament fiber gap defect would reduce the mechanical properties of the SCXLS, besides, in actual optical experiments, the transmitted X-ray will be formed to affect the lens performance. Therefore, when actually drawing the multifilament array preform, the setting temperature of the heating furnace cannot be too low, and the drawing speed should be as slow as possible to avoid such a defect. For axis deviation defects, it cannot be effectively evaluated by means of microscopic observation, etc. Evaluation by X-ray optical detection method was also complicated. However, it can be seen from the cause of the axis deviation defect that the strictly controlled drawing process and the high-precision arrangement of fibers can effectively avoid such defects. The multifilament fiber dislocation and distortion can be easily found by the microscopic observation. By the high-precision arrangement of fibers, the dislocation can be avoided well, in actual manufacturing, this step should be checked carefully. Because it can avoid dislocations, and it will also make the preforms have better thermal conductivity and less uneven stress, the strict step of the checking will reduce the generation of distortion defects. What’s more, it is necessary to strictly control the uncertain effects caused by the environmental fluctuations. To achieve this goal, more specialized machine, plant and engineers are needed. Then the twisting fiber defects can also be better avoided. In general, high-performance and practical SCXLS can be put into practical application if these processes are strictly controlled in engineering production.

Summary

In summary, we presented the main defects of the manufacturing the SCXLS: the multifilament fiber gap defect, axis deviation defect, multifilament fiber distortion, multifilament fiber dislocation and twisted fiber defect. Through strict control of the operation process, dislocations, twisted fiber and axis deviation defects can be effectively avoided, and the distortion defects can be reduced. As long as the preform is not overheated and the drawing speed is properly controlled, the distortion defect will be significantly reduced. Then the operating temperature is reduced as much as possible without gap defects, and finally, a SCXLS with excellent performance can be produced.

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References


