Electronic and optical moiré interference with microchannel plates: artifacts and benefits

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The spatial resolution of position-sensitive detectors that use stacks of microchannel plates (MCP's) with high-resolution anodes can be better than 20-μm FWHM [Proc. SPIE 3114, 283–294 (1997)]. At this level of accuracy, channel misalignments of the MCP's in the stack can cause observable moiré interference patterns. We show that the flat-field detector response can have moiré beat pattern modulations of as great as ±27% with periods from as small as a few channel diameters to as great as the size of a MCP multifiber. These modulations, however, may be essentially eliminated by rotation of the MCP's or by a mismatch of the channel sizes. We also discuss how the modulation phenomena can be a useful tool for mapping the metric nonlinearities of MCP detector readout systems. Employing the optical moiré effect, we demonstrate a simple, but effective, technique for evaluation of geometrical deformations simultaneously over a large MCP area. For a typical MCP, with a 60-channel-wide multifiber, we can obtain accuracies of 1.2 mrad for multifiber rotations and twists and 35°(L/p) mrad for channel-long axis distortions (where L/p is MCP thickness to interchannel distance ratio). This technique may be used for the development of MCP x-ray optics, which impose tight limitations on geometrical distortions, which in turn are not otherwise easily measurable with high accuracy. © 1999 Optical Society of America

1. Introduction
The term moiré effect generally refers to a geometrical optical interference formed when two periodic two-dimensional meshes of a similar pattern overlap. This phenomenon has been applied as a technique for metrology, topography, and strain analysis and has been well described in the literature.1–3 In many applications, however, moiré patterns are problematic, because they degrade the quality and complicate the analysis of measured data.4–6 In this paper we discuss the specific moiré fringes formed electronically by a stack of microchannel plates (MCP's) commonly used as electron multipliers in imaging detectors.7,8 MCP's are composed of a large array of small (5–25-μm diameter) glass capillaries.9 Generally, these capillaries (channels or pores) are arranged into multifiber bundles that are hexagonal and 60 channels wide. The multifiber bundles are fused together and then sliced into wafers to make MCP's of whatever geometry is required (usually round, square, or rectangular; see Fig. 1). Typical MCP's have pores of 10-μm diameter and 12-μm spacing, with an effective open area of 60–70% (Fig. 1). The channel length-to-diameter ratio (L/D) is usually in the 40:1–120:1 range, depending on the application. Larger L/D ratios are difficult to make, owing to problems in etching out the core glass (in the capillaries) that is used in the manufacturing process. Several MCP's are usually stacked together to achieve the gain and pulse-amplitude distribution performance desired for imaging detector systems.7,8 In such a stack it is clear that individual channels would be almost impossible to coalign precisely, even if the channel array were perfect. Channel misalignments due to MCP rotations will produce moiré interference when channels in one MCP intersect the interstitial areas (web) of the next MCP in the stack. Since each MCP multiplies the electronic signal, partial obstruction of channels can reduce the overall stack gain and also produce spatial shifts of the charge distribution. Depending on the MCP arrangement and on the readout method, this can result in image distortions, modulations, and variations in relative efficiency (see Section 2).
Therefore it is important to understand this problem and find ways to reduce or eliminate it.

In the field of x-ray optics for x-ray astronomy, x-ray lithography, and x-ray fluorescence microanalysis\textsuperscript{10,11} there has recently been considerable interest in square-pore MCP’s as optical collecting and focusing elements. The performance of such optics is mainly limited by the geometrical distortions of the plate structure as determined by the manufacturing process. Issues include the straightness and parallelity of the channels, the roughness of the channel walls and twists, and the rotations and parallelity of the multifibers. Measurement of these parameters can be difficult (optical or electron microscopy of channels) and time consuming, and the accuracies needed (<10 mrad) are not easily achievable. We found that optical moiré interferometry techniques applied to MCP’s allow for some of these deformations to be measured with high accuracy. Imperfections in the MCP structure (multifiber twists and rotations, and long-axis channel misalignments) will distort the moiré interference pattern. In Section 3 we demonstrate how these relatively easily measurable distortions correspond to the MCP geometrical imperfections.

2. Moiré Interference in Microchannel Plate Detectors

Many detectors that utilize MCP’s employ a stack of several straight-channel MCP’s to achieve high amplification levels without ion-feedback effects.\textsuperscript{7,8} Typical configurations are pairs and triplets (Z stacks) where the bias angles (usually 6°–15° to the MCP axis) of the pores are alternated to obstruct ions from traveling back up the MCP stack. Gains for these configurations are of the order $10^5$–$10^7$, with pulse-amplitude distributions of 100% to <20% FWHM. An alternative configuration for low ion feedback is the single, curved-channel, MCP that has a gain of $>10^6$. Osterman et al.\textsuperscript{12} showed that the image distortions with individual curved-channel MCP vary and are of the order of the pore size. This is due to nonuniformity of the MCP itself and is a result of the manufacturing process. Straight-pore plates are largely free of channel displacement distortions. Image uniformity of a straight-channel MCP stack may be degraded by the presence of moiré patterns formed at the interfaces between MCP’s. This usually does not happen if the MCP stack has gaps between the individual MCP’s. However, moiré can be a problem for back-to-back contact MCP stacks, which are often used to provide high uniform gain and tight pulse-amplitude distribution. The output electron cloud from the first MCP may be partially blocked by the interchannel web of the second MCP, thus reducing the overall gain of the event. If the gain of these events falls below the amplitude threshold of the readout electronics, this may cause loss of events. For the ideal case of two identical perfectly flat plates positioned in direct contact the ratio of the blocked to the total charge $Q_{\text{total}}$ from a particular pore can vary between 0 (channels on two plates perfectly overlap) and $A_{\text{blocked}} = Q_{\text{blocked max}}/Q_{\text{total}}$. 

\begin{figure}[h]
  \centering
  \includegraphics[width=0.5\textwidth]{MCP_transmission}
  \caption{MCP transmission photo showing pores and multifibers.}
\end{figure}
\[ Q_{\text{total}} \] depending on the relative translational shift and rotation of the MCPs. Assuming that the distribution of the electron cloud over the pore output area is uniform, the maximum absorbed charge portion is

\[ A_{\text{blocked}}^{\text{circ}} = 1 - \frac{6 \arccos \left( \frac{p}{\sqrt{3}d} \right) d - \frac{p}{\sqrt{3}} \left( 1 - \frac{p^2}{3d^2} \right)^{1/2}}{\pi d} \]  

for a circular pore on a hexagonal packed array and

\[ A_{\text{blocked}}^{\text{sq}} = 1 - \frac{(2d - p)^2}{d^2} \]  

for square-pore plates, where \( d \) is the pore size and \( p \) is the distance between pore centers. For a standard 12.5-\( \mu \)m pore on 15-\( \mu \)m-center MCPs these values are \( A_{\text{blocked}}^{\text{circ}} = 0.42 \) and \( A_{\text{blocked}}^{\text{sq}} = 0.36 \). This blocked charge fraction is the maximum local gain loss, since the gain of MCP stacks in the saturated mode is not simply linearly proportional to the charge output of the top MCP.\[^{13}\] There will also be a displacement of the charge cloud centroid, owing to the charge obscuration at the interface of the first and the second MCPs. At the output of the second MCP in three MCP stacks, the event charge cloud is spread over a number of channels. Thus the charge obscuration is averaged over several webs and probably does not result in a large gain modulation or position displacement.

The gain losses due to moiré interference can produce periodic modulations of the detector flat-field image. For sensors with which the image readout intensity is proportional to the gain of the events, or with which events fall below the electronic acceptance threshold, the moiré will result in a periodic (beat) pattern of darker areas in the flat-field intensity image. At the same time there will be a similar pattern of darker areas in the flat-field gain map image. The position resolution of signal-to-noise limited readout systems will also be degraded in the low-gain areas. However, in photon-counting image readout systems with gain-independent (or gain-tolerant) imaging there will be little or no moiré gain effect. There will still be a pattern of darker areas in the flat-field gain map image, but the overall position resolution will not be affected. Shifts of the event charge cloud centroid will produce modulations of the flat-field intensity images and distortions of the images along with the gain map modulations.

A. Moiré Modulation Artifacts

The beat pattern disappears quickly with the increase of the interplate gap. Electron clouds spread out between the MCPs,\[^{14}\] activating a larger surface area on the second multiplication stage. \( A_{\text{blocked}} \) then averaged over a larger MCP surface area, thus causing the reduction of its range of variation. At a certain active area width at the second MCP, the value of \( A_{\text{blocked}} \) becomes a constant over the surface, and moiré pattern no longer exists. Therefore one of the possible ways to avoid image degradation in MCP detectors due to moiré effect is to provide this surface integration with a proper selection of the interplate gap distance and bias, though it can lead to the degradation of the pulse-height distribution of the detector.

In the case of direct stacking of identical plates the relative angular displacement of MCPs has to be set up properly. The spatial frequency of the beat pattern is determined by that angle, which can be chosen so that the moiré period has a small value. The modulation then may be completely smoothed by the detector readout. The dark solid curve in Figure 2 shows the variation of the moiré period with angular displacement between the identical MCPs. We calculated the moiré period by finding the minimums of the pulse-height distributions of the MCPs due to moiré effect is the provided this surface integration with a proper selection of the interplate gap distance and bias, though it can lead to the degradation of the pulse-height distribution of the detector.

A stack of three back-to-back circular-pore Galileo MCP's (80:1 \( L/D \), 10-\( \mu \)m pore on 12-\( \mu \)m centers, 13° bias angle, 36 mm in diameter, resistance 25 M\( \Omega \)) was used for direct moiré modulation measurements. The readout of the detector was a cross delay line anode,\[^{15}\] and a mercury vapor UV lamp (2537 Å) was used for illumination. An accelerating bias of 3200 V was applied across the MCP stack. The detector gain was \(~1.8 \times 10^7\) with a pulse-height distribution FWHM value of 80%. First, a pinhole mask with 10-\( \mu \)m-diameter holes positioned 0.5 mm apart was installed on the front surface of the MCP stack to determine the spatial resolution, which was measured to be 40- and 50-\( \mu \)m FWHM in X and Y dimensions, respectively. The detector was then reassembled without the pinhole mask but with the front MCP rotated by 180° relative to the middle plate. The angle of rotation \( \delta \) was changed, and measured for each detector assembly, with a CCD...
camera image. The detector response to a flat-field illumination was then obtained for each rotation angle (Fig. 3). Strong modulation over the whole active area was observed at small relative angular displacements, whereas the beat phenomenon completely disappeared from the image when the front MCP was rotated by $180^\circ + 25^\circ$ relative to the middle MCP. The rotation angle can be easily controlled in the case of a chevron stack by observation of the period of the direct moiré pattern when the MCP’s are backilluminated with an ordinary visible light source, as discussed in Section 3. This may be possible if the detector body can be demated from the readout anode. The variation of the period of the beat pattern does agree with the calculated values (solid curve in Fig. 2, with $p1$ and $p2$ being equal), although the presence of many different periods due to multifiber rotations makes precise comparison difficult.

In some cases the relative rotation of the plates is restricted by their shape, e.g., rectangular MCP’s, and can be changed only by $90^\circ$ (square MCP’s$^{16}$) or even $180^\circ$ (rectangular MCP’s$^{17}$) increments. A distinct moiré flat field image modulation was observed when three identical plates positioned in direct contact were used in the Far Ultraviolet Spectrographic Explorer detector during early testing.$^{17}$ Another possible method for reducing moiré modulation is to use MCP’s with different pitch sizes, as was implemented in the Far Ultraviolet Spectrographic Explorer flight detectors. MCP’s with 12.5-$\mu$m pores on 15-$\mu$m centers (and 10-$\mu$m pores on 12-$\mu$m centers) were combined together in a Z stack. Figure 2 shows the predicted variation of the moiré period with angular displacement between two MCP’s with different pitch sizes $p1$ and $p2$. Increase of the ratio $p2/p1$ quasi exponentially reduces the value of $T_{\text{moiré}}$ at small angular displacements.

B. Application of Moiré Modulation

Along with all the complications it causes, moiré modulation can also be beneficial during detector development and testing. First, the beat pattern can be a good supplement to pinhole image masks for tests of the detector readout. The distance $T_{\text{moiré}}$ between the maxima can be continuously adjusted by the relative angular displacements of the MCP’s. Thus $T_{\text{moiré}}$ can be chosen such that it corresponds to the expected detector resolution, with values of $T_{\text{moiré}}$ as small as several channel diameters. In addition, the entire active area of the detector is subject to moiré modulation, thus providing a possibility to qualitively test the resolution and linearity of the entire surface of the readout scheme and to localize any possible distortions. The microscale response of the MCP’s (for example, localized electric-field distortions) determines the output image and therefore may be evaluated with the above tests. The optical moiré interference (Section 3) can be used thereafter as a reference image undistorted by the electric-field artifacts. Thus the presence of the moiré pattern makes the flat-field detector response somewhat more informative, adding microscale features to it. The detector may be reassembled after all these measurements in order to eliminate the beat pattern.

The flatness of a back-to-back channel plate stack can also be tested at the scale of several pore diameters with the help of moiré modulation. Variation of the interplate gap distance causes gain variations. As the electron cloud spreads in the gap, more active channels become involved in the multiplication process. As mentioned in Subsection 2.A, this leads to local disappearance of the moiré pattern, as is observed with the detector response shown in Fig. 3(c). A good contact between the MCP’s is also important for the thermal stability of a Z stack with three low-resistance MCP’s, which have better count rate capabilities compared with high-resistance plates.$^{18}$ In this case the middle MCP is conductively cooled, and therefore insufficient local contact may result in thermal runaway.

3. Microchannel Plate Metrology: Angular Deviations inside a Microchannel Plate

Multiple capillary arrays have attracted considerable interest in x-ray optics. The recent progress in the development of both policaillaries, known as Kuma-kho lenses,$^{19}$ and MCP x-ray optics$^{20,21}$ substantially improves the quality of available optical systems. The possibility of producing MCP’s slumped into a spherical geometry provides a basis for an implementation of the so-called lobster-eye telescope,$^{22,23}$ an attractive option for an all-sky x-ray monitor instrument. Profiled MCP’s have proven to be effective soft-x-ray collimators that may be used in x-ray lithography and other applications.$^{11}$ The performance of such optics is limited by the distortions in the MCP structure that occur during the manufacturing process.$^9$ Initially glass tubes are made and then have a glass rod inserted into the core. The glass fibers are drawn in a vertical oven and then stacked and fused together to form a multifiber. These multifibers, in turn, are drawn and fused together to make a cylinder several centimeters in diameter, depending on the size of MCP to be manufactured. Finally, this block is sliced, and the core glass is etched from the interior of the channels. The deviations of the plate geometry from the ideal, and the pore surface roughness, have to be minimized to achieve the best optical characteristics. Therefore the quantitative evaluation of these imperfections becomes important for the selection of MCP’s and for the control and the improvement of the manufacturing process. According to Peele et al.,$^{21}$ the optical performance of Schott Fiber Optics square-pore channel plates (200-$\mu$m pore size on 240-$\mu$m centers, 30:1 $L/D$ ratio) was limited mainly by the channel rotations and twists and also by the surface roughness. The Monte Carlo model of Brunton et al.,$^{24}$ with parameters taken from experimental data on x-ray focusing with a planar, square-pore Galileo MCP (85-$\mu$m pore size on 122-$\mu$m centers, 56:1 $L/D$ ratio), and optical, scanning electron, and atomic force microscopy, showed that the main contributions to the
focal spot broadening were pincushion and long-axis misalignment. Channel rotations and twists were the second largest factors determining the intensity of the focal spot.

A number of measurement techniques can be used to qualify the structural imperfections in channel plates. Optical and scanning electron microscope images can be used to evaluate the interchannel and the intermultifiber rotation angles, which have been measured to be of the order of 15 mrad\textsuperscript{24} (20 mrad\textsuperscript{21})
and 23 mrad (35 mrad) rms for Galileo and Schott Fiber Optics MCP's, respectively. A disadvantage of this method is its localized nature; therefore a large number of images have to be analyzed to examine the whole area of the channel plate with the required accuracy. We suggest another simple method for evaluating the structural imperfections of the MCP over a large area, in particular, multifiber rotation, twist, and long-axis misalignment (Fig. 4).

A. Optical Moiré Pattern with Microchannel Plates

The moiré pattern that occurs when two identical channel plates overlap is sensitive to their relative angular rotation. The period of the beat pattern reduces rapidly with increase of the rotation angle. Thus the angular fluctuations of multifiber position rotations inside a MCP can be evaluated by variation of the pattern period $T_{\text{moire}}$. The accuracy of this data depends on the value of $T_{\text{moire}}$, which is limited by the size of the multifibers. The moiré period should be at least two times smaller than the size of multifiber, so that at least two maxima are present inside each multifiber and thus the value of $T_{\text{moire}}$ can be measured in each multifiber.

For hexagonal packing of circular pore channel plates the pore centers $r_{mn}$ are given by

$$r_{mn} = (x, y)_{mn} = p \left( \frac{\sqrt{3}}{2} m, n + \frac{l}{2} \right),$$

where $p$ is the pitch size and $m$ and $n$ are integers. The moiré pattern from two such identical MCP's rotated by angles $(\alpha/2)$ and $-(\alpha/2)$, correspondingly, has centers of the beat pattern maxima with coordinates $R_{MN}$ given by

$$R_{MN} = \frac{p}{2 \sin(\alpha/2)} \left\{ M + \frac{1}{p} \left[ \delta_x \sin \left( \frac{\alpha}{2} \right) + \delta_y \cos \left( \frac{\alpha}{2} \right) \right] 
+ \frac{\sqrt{3}}{2} N + \frac{1}{p} \left[ \delta_x \sin \left( \frac{\alpha}{2} \right) - \delta_y \cos \left( \frac{\alpha}{2} \right) \right] \right\},$$

where $(\delta_x, \delta_y)$ are translational shifts of the plate rotated by $-(\alpha/2)$ relative to the coordinate center and $M$ and $N$ are integers. In case of square-pore geometry, Eq. (4) becomes

$$R_{MN} = \frac{p}{2 \sin(\alpha/2)} \left\{ M + \frac{1}{p} \left[ \delta_x \sin \left( \frac{\alpha}{2} \right) + \delta_y \cos \left( \frac{\alpha}{2} \right) \right] 
+ \frac{1}{p} \left[ \delta_x \sin \left( \frac{\alpha}{2} \right) - \delta_y \cos \left( \frac{\alpha}{2} \right) \right] \right\}.$$

For constant values of $\delta_x$ and $\delta_y$ over some plate area the moiré pattern period is then given by

$$T_{\text{moire}} = \frac{p}{2 \sin(\alpha/2)}.$$

Fig. 3. Variation of moiré modulation with relative angle between MCP’s. Images were obtained with full-field uniform UV illumination and contain approximately $10^8$ counts. Front MCP was rotated by $180 + (a) 0.9°$, (b) 1.5°, (c) 1.8°, and (d) $-25°$ relative to the middle MCP. The contrast on the images was enhanced to highlight the moiré pattern.

Fig. 4. Schematic diagram of (a) multifiber rotation, (b) twist, and (c) long-axis misalignment inside a MCP.
B. Multifiber Rotations

A moiré pattern formed by two perfect MCP's will have a single frequency, depending on the relative angular displacement. In practice MCP's generate a pattern with a number of beat frequencies (e.g., Fig. 3). Equation (6) indicates that we can evaluate the relative angular displacements between multifibers [Fig. 4(a)] by measuring the variation of the value $T_{\text{moire}}$ over the MCP surface. We can accomplish this either by overlapping two MCP’s or by taking a digital image of one MCP and then overlapping it with its rotated copy or with a corresponding digital image mask. In the former case the angular displacements of two MCP’s determine the variation of the moiré pattern, whereas in the latter case only one test MCP is examined, although it requires much better imaging resolution. The accuracy of the measurements of the angular displacement $\alpha$ from Eq. (6) is given by

$$\Delta \alpha = -\frac{2}{T_{\text{moire}}/p[4(T_{\text{moire}}/p)^2 - 1]^{1/2}} \Delta(T_{\text{moire}}/p). \quad (7)$$

Figure 5 shows variation of angle $\alpha$ and the accuracy of its measurement with $(T_{\text{moire}}/p)$. For standard production MCP’s with a 60-pore-wide multifiber, the ratio $T_{\text{moire}}/p$ can be $\sim 29$ (half the multifiber size), and the value $\alpha$ can thus be measured with an accuracy of $\sim 1.19$ mrad. This is approximately 1 order of magnitude smaller than the rms angular displacements of MCP’s available at the moment$^{21,24}$ and will be better for a larger number of channels in one multifiber. Figure 6 shows the moiré beat pattern obtained with two Philips MCP’s (80:1 channel $L/D$ ratio, 12.5-μm pores on 15-μm centers, 0° bias, 60-pore multifiber size) backilluminated with white light. Digital imaging was performed with a PULNIX TM-7CN CCD camera. Resolution of the CCD camera was only $640 \times 480$ pixels; therefore a number of translationally shifted images were obtained and then mosaicked together. Analysis of these data reveals that the angular displacements between the multifibers of these two plates vary between 0 and 53 mrad. The strong localized nature of multifiber angular deviations is clearly seen in the image (Fig. 6).

Brunton et al.$^{24}$ reported that the interchannel rotation angle and the intermultifiber rotation angle were measured to be in the ratio of 0.67:1.0. Therefore the single-channel rotations can be also evaluated by moiré interference despite the fact that they cannot be obtained explicitly.

C. Multifiber Twists

The multifiber twists [Fig. 4(b)] can also be estimated by the moiré technique. To accomplish this, both front and rear surfaces of a single plate should be imaged with a relatively high resolution ($\sim 10$ image pixels per pore). Superposition of these two images, aligned with marks visible on both sides (e.g., plugged pores$^{25}$), with one inverted, forms a moiré pattern from which the multifiber twists can be measured. Variation of the value $T_{\text{moire}}$ over the MCP surface provides information on the multifiber twists within a single MCP. Figure 7 shows the beat pattern formed by overlapping of the front and the back surfaces of one of the MCP’s described above. Figure 7(a) corresponds to the aligned case, in which only multifiber twists determine the variation of $T_{\text{moire}}$. Figure 7(b) represents the case in which the front and the back images were deliberately misaligned by 2° so that both twists and rotations contribute to the for-
The moiré pattern is analyzed to determine angular displacements between multifibers. For this particular MCP, angular displacements range between 0 and 45 mrad, corresponding to a variation of $T_{\text{moiré}}$ $\gamma$ between 13 and 32, whereas the twists are less than 5 mrad.

D. Long-Axis Rotations

Long-axis misalignments $\gamma$ inside MCP's (Fig. 4(c)) are the angular deviations of the channel's long axis, and they are not measurable in a straightforward way. However, these can be measured explicitly through the combination of MCP x-ray focusing experiments and simulation as suggested by Brunton et al. $T_{\text{moiré}}$ may be measured with an accuracy of 1 pitch size; triangles, $T_{\text{moiré}}$ can be measured with an accuracy of 3 pitch sizes.

Fig. 7. Moiré beat pattern from the two surfaces of the same MCP. Images of the front and the rear sides were taken separately and then digitally superposed. (a) Both sides are aligned such that the front image positionally matches the back. Multifiber rotations do not contribute to the pattern distortions. (b) Back (inverted vertically) and rear images are misaligned by 180°. Angular rotations between the multifibers determine the visible variation of pattern period. Vertical shear line in (a) is an artifact of the images' superposition.

Angular rotations between the multifibers determine the visible variation of pattern period. Vertical shear line in (a) is an artifact of the images' superposition.

Fig. 8. Variation of long-axis intermultifiber rotation $\gamma$ with $T_{\text{moiré}}/p$. Diamonds, $T_{\text{moiré}}$ can be measured with an accuracy of 1 pitch size; triangles, $T_{\text{moiré}}$ can be measured with an accuracy of 3 pitch sizes.

For a 60-pore-wide multifiber the lowest measurable value $\gamma$ is only 0.12 mrad. Although the sensitivity of this method is not always sufficient for qualitative tests of MCP optical performance, it can be used by the manufacturers for the evaluation of long-axis rotations.

where $L$ is the MCP thickness. The accuracy of these measurements, again, depends on the number of channels in one multifiber, which limits the maximum value $T_{\text{moiré}}$. Figure 8 shows variation of the value $\gamma$ with $T_{\text{moiré}}/p$ for a $L/p = 300:1$ channel plate. For a 60-pore-wide multifiber the lowest measurable value $\gamma$ is only 0.12 mrad. Although the sensitivity of this method is not always sufficient for qualitative tests of MCP optical performance, it can be used by the manufacturers for the evaluation of long-axis rotations.
misalignment inside the glass boule from which channel plates are cut. We can do this by imaging both sides of the boule before or after it is cut. In that case the value of \( L \) can be substantially larger, and therefore the angles \( \gamma \) can be measured with a much better accuracy, provided that the contribution of multifiber twist distortions is negligible.

4. Conclusions

We have shown that moiré interference in microchannel plate (MCP) detectors may lead to a significant modulation of detected images, and we have discussed precautions that should be taken into account during detector assembly in order to avoid these modulation effects. In some cases, though, the beat pattern can be useful in detector testing and calibration, providing the capability of examining the full active area in one measurement. In addition, optical moiré interference can be used as a rather straightforward technique for measuring the MCP geometrical distortions that can limit the performance of MCP x-ray optics. The main advantage of this method is its simplicity and ability to simultaneously localize a number of geometrical imperfections over a large surface area.

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