The dependence of x-ray speckle contrast on focusing optics

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Introduction

Speckles are produced by scattering of coherent light from a disordered system. Until recently, mainly pinhole setups have been used in x-ray speckle experiments. The full-width at half-maximum (FWHM) size of a speckle is inversely proportional to the diameter of the illuminated spot *D* on the sample [1]. Using focusing optics (e.g., a zone plate), *D* can be decreased to submicron size. In this work, we compared the dependence of the speckle size and contrast on *D* for the common pinhole setup [2, 3–11] with a focusing setup using a zone plate [12].

Methods and Materials

The experiments were performed on the SRI-CAT beamline 2-ID-B [13, 14]. We used the two different scattering geometries shown in Figure 1.

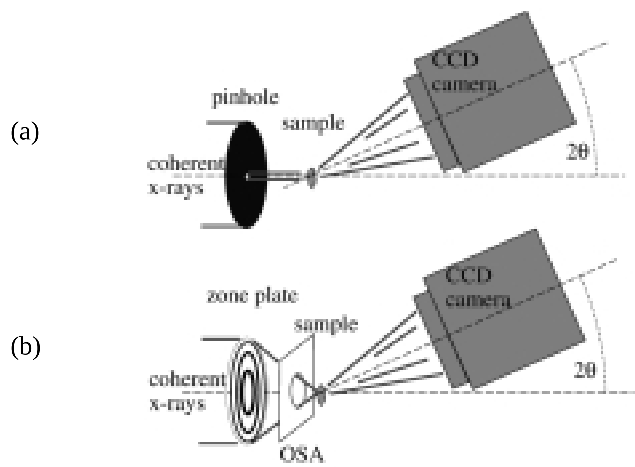

Figure 1: Experimental geometries investigated: (a) the pinhole setup and (b) the zone plate setup.

Figure 1a shows the setup with a 5 µm-diameter pinhole ~5 mm upstream of the sample. The zone plate of the setup in Figure 1b had a diameter of 77 µm and a focal length of 11.3 mm. A 20 µm-diameter order-sorting aperture (OSA) selected the first-order focused beam behind the zone plate. In both setups, a guard slit (not shown) directly in front of the sample allowed us to block parasitic scattering from components upstream of the sample. The detector was a thinned, directly backside-illuminated CCD camera located 517 mm downstream of the sample. We used a photon energy of 1820 eV, which resulted in a calculated transverse coherence length of 66 µm in diameter at the experiment [15]. The sample consisted of dried 266 nm-diameter polystyrene latex spheres.

Results and Discussion

Figure 2 shows the speckle width and contrast measured in both setups.

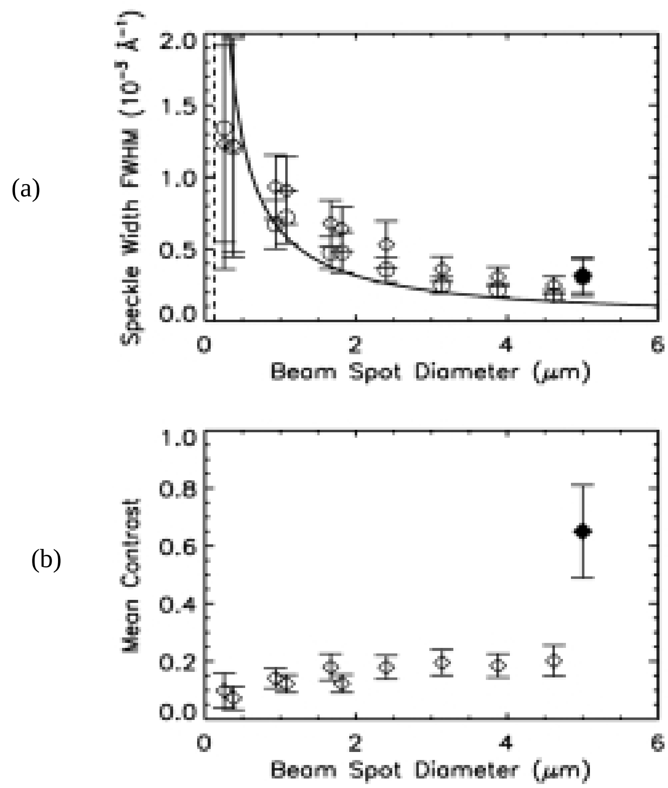

Figure 2: (a) Speckle widths and (b) contrast versus beam spot diameter on the sample. The filled and open symbols represent data obtained for the pinhole setup and the zone plate setup, respectively. (a) The azimuthal speckle FWHM in *q*-space is shown with circles, the radial speckle with diamonds. The beam spot diameter at the focus of the zone plate is indicated by the vertical, dashed line. The solid line represents the calculation according to [12].

Each data point is an average over a *q*-region of one speckle pattern (0.005 Å^{-1} ≤ q ≤ 0.017 Å^{-1}); any *q*-dependence is therefore reflected in the error bars shown. The actual beam spot diameter *D* in the zone plate setup was calculated from FWHM of the intensity distribution in the vicinity of the focus of a lens. Since the illumination of the zone plate was not fully coherent, *D* may have been slightly larger than shown at the smallest values. The solid line in Figure 2a describes the predicted inverse dependence on *D* [2, 12], which fits the data nicely.

Remarkably, the high divergence introduced by the zone plate does not increase the speckle widths. Accounting for this divergence (6.8 x 10^{-3} rad) in the same way as for the source divergence in a pinhole setup [2], speckle sizes smeared out to about 9 x 10^{-3} Å^{-1} would be expected, independent of the distance between the zone plate focus and the sample. This was clearly not observed.

The fact that the radial speckle width was consistently larger than the azimuthal speckle width could not be attributed to limited monochromaticity as in references [2, 3–11]. In our case, the monochromaticity was high enough not to result in any significant radial broadening. The small differences between the radial and the azimuthal widths may be due to the radial nature of the zone plate focusing.

The significant difference in contrast (Figure 2b) for both setups is probably due to the difference in the degree of coherence of the illumination of the 5 µm pinhole and the 77 µm zone plate, respectively. Here, we follow the definition of contrast given in [2]. The contrast did not decrease for small speckle widths (large beam spots) in the zone plate setup, which is further evidence that the divergence introduced by zone plate focusing did not affect the speckles. Toward small D, the contrast decreased probably due the extreme aspect ratio of sample thickness to D, which was about 100:1 for the smallest spot size we investigated.

Conclusion

The observed speckle size or contrast was not affected by the divergence introduced through zone plate focusing. Using a zone plate setup, the size of the speckles can be controlled over a wide range by adjusting the distance between zone plate focus and sample. Thus, sample areas of various sizes can be targeted and the required sample to detector distance for a given spatial resolution can be decreased. Consequently, for a fixed detector the accessible momentum transfer q can be extended. In addition, the zone plate setup can increase the flux per speckle by focusing the beam. This may be important in time-correlation experiments. The pinhole setup, on the other hand, provides better q-resolution, in our experiment, $\Delta q \approx 6.16 \times 10^{-4}$ Å^{-1} with a 5 µm pinhole.

Acknowledgments

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