4.2 Annular Illumination – An Experimental Demonstration

This section reports on an experimental demonstration in which an on-axis hole was imaged by means of a lens with an annular aperture [68].

4.2.1 Experimental Results

Using annular illumination the intensity distribution in the vicinity of the focus point has been theoretically discussed in Section (2.3.3). Equations (2.21) and (2.22) give the intensity distributions in the focal plane and on the optical axis, respectively. The optimum case with regard to the resolution is when the obstruction ratio (ϵ) tends to unity. In this case the $FWHM$ of the first-order Bessel beam is 1.6 times smaller than the $FWHM$ of the Airy pattern obtained by means of a clear aperture. However, a thin annular filter introduces a serious light loss into the system. The filter blocks ϵ^2 of the incoming intensity, therefore the efficiency is $1 - \epsilon^2$. During the experiment the obstruction ratio of the filter was 0.85, which is a trade-off between resolution enhancement and light loss. The light loss introduced by the filter was ϵ^2=72% while the filter remained appropriately narrow to reduce the resolusion. The experimental arrangement can be

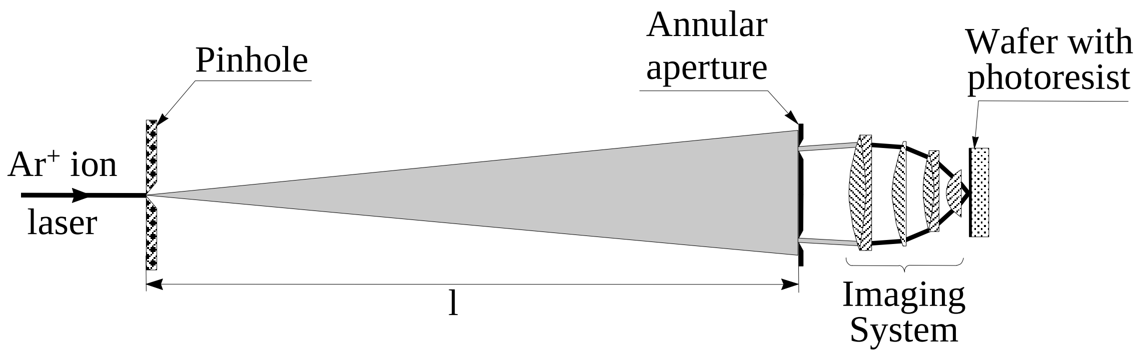

Figure 4.5: Schematic diagram of the experimental arrangement.

seen in Fig. 4.5. An Ar^+ ion laser operated at 457 nm, illuminates a pinhole of 50 μm in diameter (D). Several other illumination arrangements (beam-expander, a single microscope objective and lens) were proposed and used to illuminate the aperture, however only a pinhole could produce appropriately homogeneous illumination. The distance between the pinhole and the annular aperture (l) was chosen so that the radius of the first bright diffraction spot be larger than the radius of the aperture ($l \cdot \lambda/D \approx 3R$). The outer and inner radii of the annular aperture were 4.75 mm and 4 mm, respectively, corresponding to an obstruction ratio of $\epsilon = r/R \approx 0.85$. The projection optics consisted of a simple microscope objective ($M = 40, NA = 0.65$). During the experiment only 74% of the NA was used, so thus the effective numerical aperture (NA') was 0.48. Therefore, the theoretically predicted hole diameter without annular aperture was 0.58 μm. If an above-defined annular aperture is used the predicted hole diameter is larger than 0.36 μm. However, due to the nonlinearity of the resist, the diameter of the hole could in fact be further decreased by 36%.

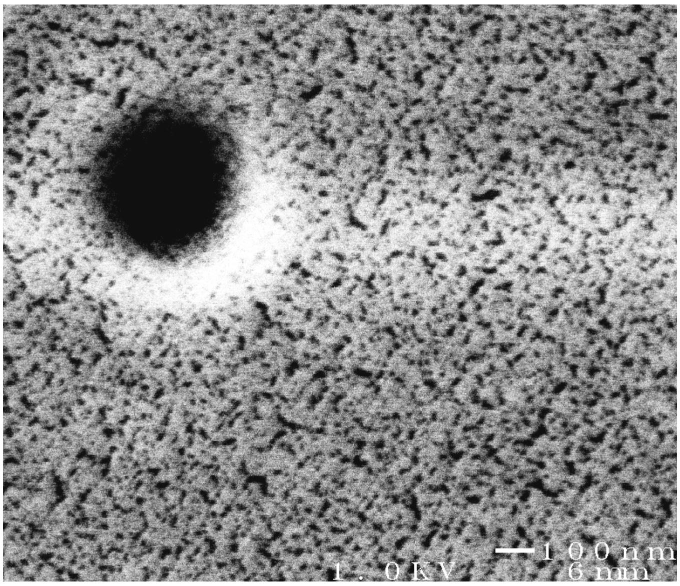

Figure 4.6: SEM picture of a 0.28 μm contact hole exposed in photoresist

The main issue of the exposure procedure was the exact alignment of the resist into the focal plane of the imaging system. Insertion of the wafer with a 1μm thin photoresist into the focal plane is practically impossible without a special alignment device. In the absence of this kind of tool, the image was exposed to the photo-resist using different wafer positions and evaluated by means of a scanning electron microscope (SEM). Fig. 4.6 depicts a 0.28 μm contact hole exposed in photoresist (Shipley XP 94314).