Beam limiting masks for in depth residual stress analyses using the X-ray camera MAXIM

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Residual stresses often play an important role for the mechanical properties and the lifetime of technical components since they have to be superimposed to load stresses [1]. Their assessment, which is often done by means of diffraction methods, is important for many engineering applications. Conventional diffraction methods however yield weighted averages of the present lattice strains within the X-ray penetration depth τ. In case of small variations of the residual stresses over τ, the discrepancies between real space stresses $\sigma(z)$ and the measured ones in Laplace space $\sigma(\tau)$ are negligible. This assumption usually does not hold when determining in depth stress distributions of e.g. surface treated alumina samples where steep stress gradients can often be observed. Hence the stress profiles $\sigma(\tau)$ have to be treated by inversion methods like inverse Laplace transform yielding often erroneous results $\sigma(z)$ in particular for scattering experimental data.

The application of highly absorbing beam limiting masks can be a suitable way to overcome these problems as long as in the irradiated volume, defined by the mask design, no significant change of the residual stress state occurs. The idea for such masks was theoretically described by Predecki [2] in 1993. The practical implementation [3,4], mainly accomplished at DESY during the last years, could demonstrate that the procedure is able to detect X-ray interferences lines from small gauge volumes beneath the sample surface with a spatial resolution down to 6-8 micron and motivates further improvements of the measurement technique.

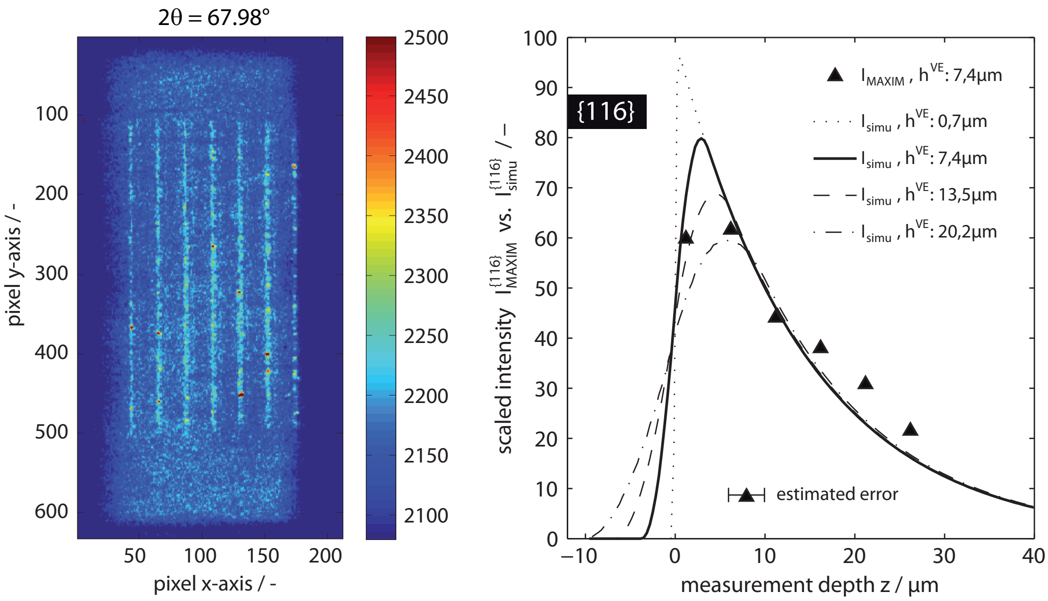

Figure 1: Typical MAXIM image showing diffraction intensities from the gauge volumes (left). Depth dependent integral intensities from MAXIM diffraction pattern compared to simulated distributions for different spatial resolutions (right).

Therefore an accurate sample adjustment could be realised by a 5-axes positioning stage featuring precise micrometer screws and a linear oscillation unit to enhance mainly the number of reflecting crystallites yielding a sufficient grain statistic. For the experiments a deep ground alumina ceramic was used which is well characterised concerning its residual stress state. The measurements were carried out at the HASYLAB beamline G3 using monochromatic synchrotron radiation equivalent to $CoK\alpha_1$. The beamline is equipped with the position sensitive CCD camera MAXIM which applies a multichannel-plate (MCP) for two-dimensional collimation of the diffracted beam [5]. The CCD-MCP-system provides a spatial resolution down 13 micron/pixel which is necessary due to the narrow slits in the masks. The MAXIM images clearly show the slit structure by crystallites which fulfil the Bragg condition (see figure 1, left). The analysis of these images for each 2θ-theta angle and different depth yields among others the integral intensity from the interference profiles. In the diagram of figure 1 (right), the experimental results for the {116} reflection are compared to simulations, where the decrease of intensity clearly correlates with the X-ray attenuation with increasing measurement depth. These results reveal that the method is able to achieve information from defined depths in a sample material.

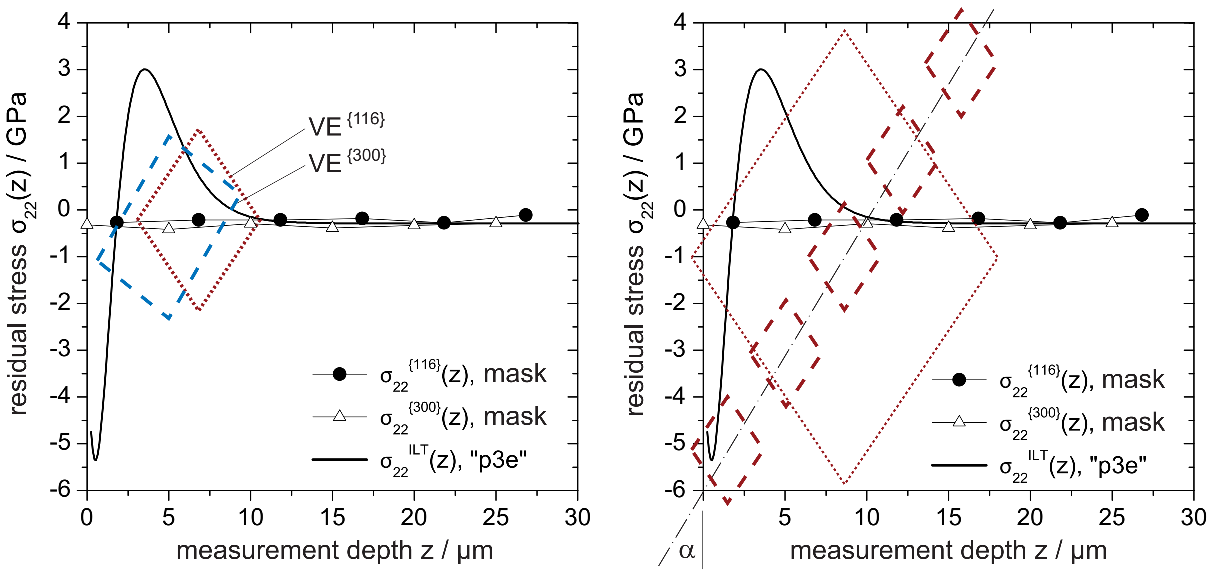

Figure 2: Possible reasons for the discrepancies between residual stress values from Laplace and mask experiments: a) The height of the gauge volumes is to large in contrast to the steep stress gradient. b) Tilt angle errors between mask and sample surface yield different measurement depths of the gauge volumes.

Beside the integral intensities the depth dependent peak positions and thus the strain gradients in the alumina were analysed. The stress results shown in figure 2 were afterwards determined under consideration of the strain free lattice parameter and are compared with the expected real space profiles from inverse Laplace transform. It comes out that the stress is only a weak function of depth since it remains almost constant. This is probably caused by the large height of the used gauge volumes compared to the steepness of the present stress gradient or small tilt angle errors between mask an sample surface [3]. Improvements of the mask alignment and the design of new masks providing higher spatial resolutions and better absorption properties are therefore intended.

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