Transmitted Small Angle X-Ray Scattering Intensity Enhancement with a Designed Grating

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Abstract

Transmission SAXS (tSAXS) has been identified as a potential solution for measuring critical dimensions (CDs) of nanoscale features, such as pitch, pitch variations, side wall angle, line edge roughness, line width roughness and so forth.

tSAXS has mostly been performed using a synchrotron X-ray source for its high beam flux or high brilliance which enables tSAXS measurements of CDs with a minuscule scattering volume. However, they are simply too large and too expensive for daily industrial deployment. In this article, a technique is proposed to provide enhancements in the X-ray scattering intensity from a target CD (the structures of interests). The enhancement of X-ray scattering intensity can lead to an increase in measurement speed as well as an improvement in signal quality.

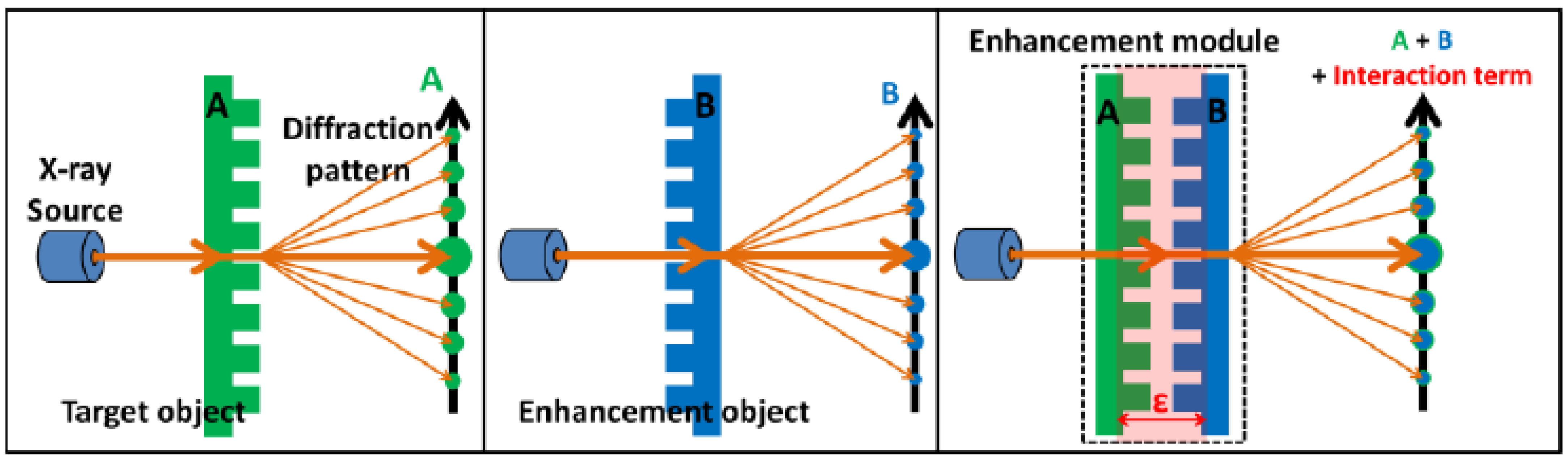

Fig. 1. Illustration of transmission Small Angle X-Ray Scattering.

Target grating: $I \propto \Delta b_1^{\,2} F_1^{\,2}(q)$

Target grating + enhancement object: $I \propto |\Delta b_1 F_1(q_x) + \Delta b_2 F_2\,(q_x)|^2$

$$I(q_x) = \Delta b_1^{\,2} F_1^{\,2}(q_x) + \Delta b_2^{\,2} F_2^{\,2}(q_x) + 2\,\Delta b_1\,\Delta b_2 \cos(q_x \eta)|F_1(q_x) F_2(q_x)|$$

Table. I. Dimensions of target (Si) and enhancement (Al) gratings

Gratings	Pitch (nm)	Width (nm)	Height (nm)
Al	200	100	200
Si	200	100	20

Area of grating pattern: 500 x 500 μm^2
X-ray beam-line condition: photon energy = 18 keV,
energy resolution: ΔE/E ~ 2 x 10^{-4}
(Si (111) double crystal monochromator)
Flux (0.5 x 0.6 mm^2) ~ 10^{10} photons/sec

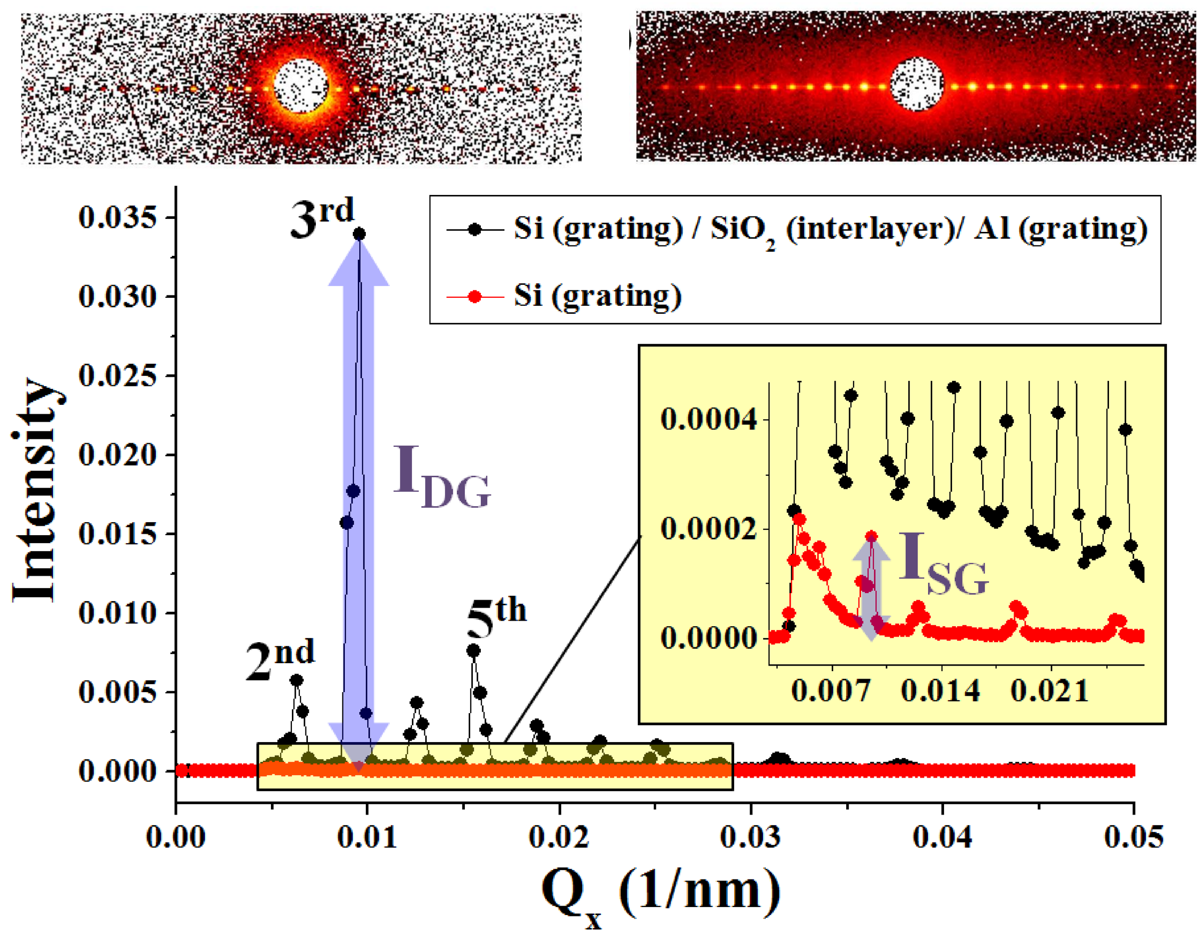

Fig. 2. The scattering intensity of the target grating Si (red line) and enhancement grating (black line)

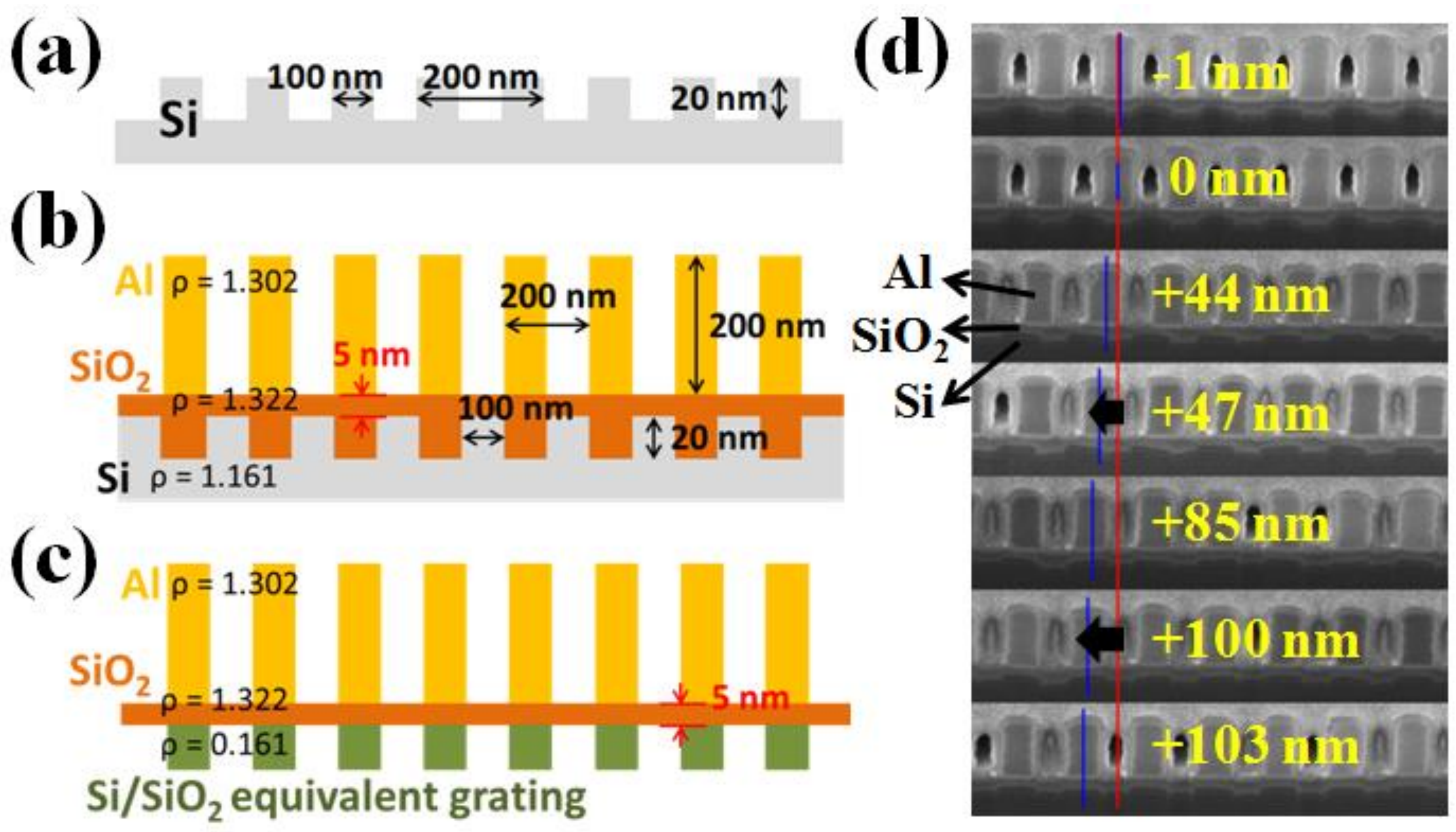

Fig. 3. The illustrations of (a) Si grating, and (b) Si grating + enhancement grating, (c) the equivalent structures of (b), and the cross-sectional SEM image of displacement η.

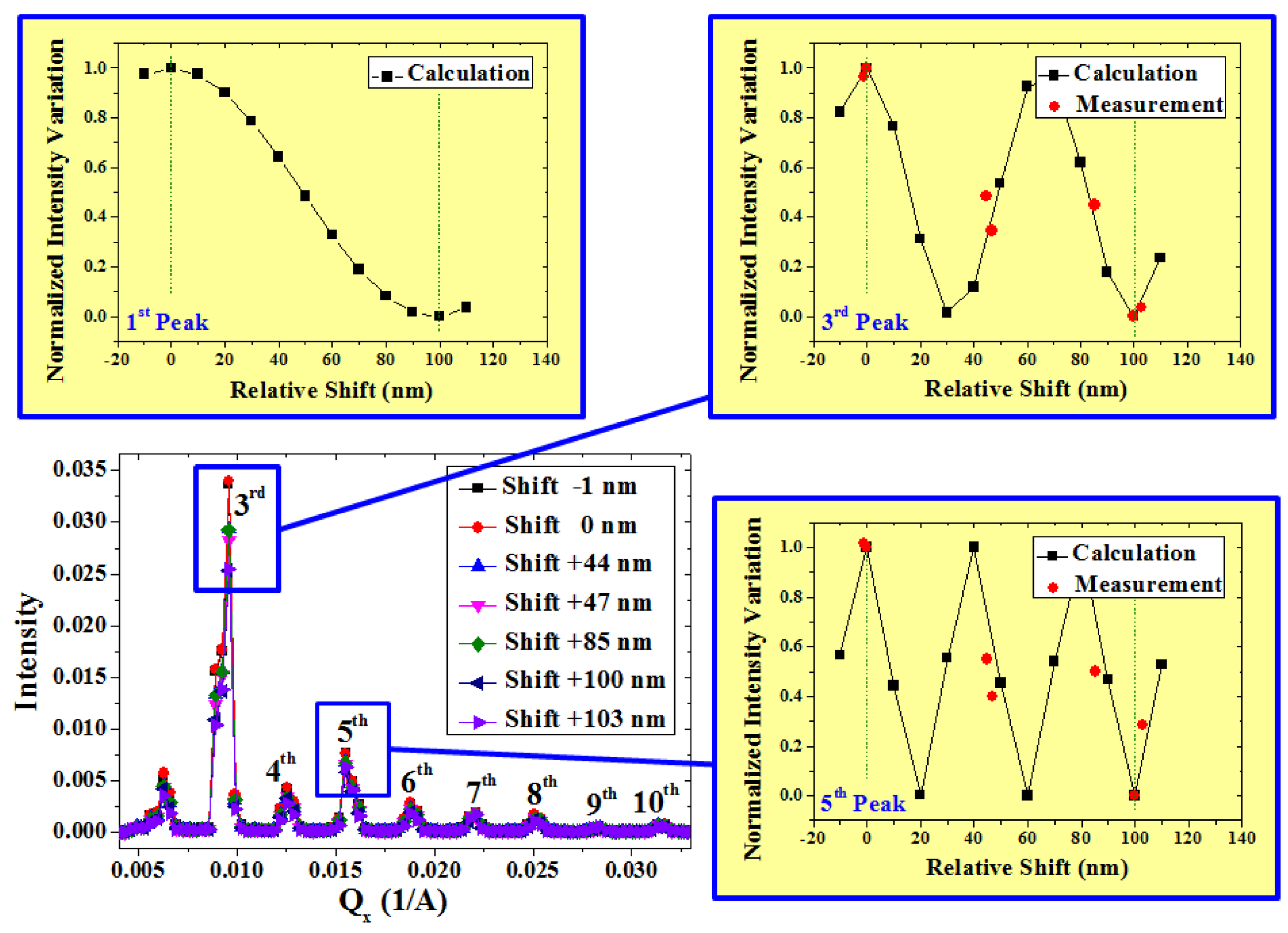

Fig. 4. The peak intensities of the enhancement structure varied significantly depending on the shifts (η) of the Al grating with respect to the Si grating.

Conclusions

A simple technique was proposed to amplify the scattering intensities from a target grating in transmission small angle X-ray scattering measurements. The amplification depending strongly on the alignment of the enhancement grating (Al grating) with respect to the target Si grating was being described theoretically and demonstrated experimentally. This scheme of intensity amplification holds the promise to facilitate the use of tSAXS in semiconductor industries. In addition, the results presented in this work demonstrate that tSAXS can also be used as an high precision overlay metrology.