Development of tender X-ray (1-5 keV) high-order multilayer coated gratings

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High-order multilayer coated blazed gratings (MLBGs) can provide larger angular dispersion and much higher diffraction efficiency compared to the 1st order single-layer-coated grating. To reveal the potential of high-order MLBGs, we designed MLBGs operating in different diffraction orders at 2.5 keV based on our developed analytical approach [1]. By choosing proper structural parameters, those MLBGs meet the criterion of the single-order regime, where only the desired order is effectively amplified. The theoretical diffraction efficiencies are 58%-44% in the 1st order to the 8th order at 2.5 keV. These values are over 40-50 times higher than those of the single layer coated grating (2400 l/mm). The examination of high-order effect is carried out in the context of the common tender X-ray instruments, i.e., the collimated plane grating monochromator (cPGM) and spherical variable-line-spaced (SVLS) grating spectrometer. The instrument transmission of MLBG-based design increases by two orders of magnitude compared to the case with single-layer-coated grating. The energy resolution gradually increases with diffraction order, reaching an ultra-high value of ~9×10^4 using the 8th order. Two MLBGs with 2400 l/mm line density operated at 2nd and 4th order, respectively, were fabricated and characterized in collaboration with the Precision Gratings Department at Helmholtz-Zentrum Berlin and the grating department of National Synchrotron Radiation Laboratory in China. The experimental diffraction efficiency is 12%-34% at 2.5 keV, which is about 10~30 times higher than a typical single-layer-coated grating. And the efficiency can be further improved through higher manufacturing accuracy. The experimental angular dispersion is calculated as 3.75×10^{-4} °/eV of the 1st diffraction order, 6.25×10^{-4} °/eV of the 2nd order, and 8.75×10^{-4} °/eV of the 3rd order, showing a good agreement with theory. The angular dispersion of the 3rd order is 1.6 times larger than that of the 1st order single-layer-coated grating with same line density.

[1] Q. Huang, I. V. Kozhevnikov, A. Sokolov, Y. Zhuang, T. Li, J. Feng, F. Siewert, J. Viefhaus, Z. Zhang, Z. Wang, *Opt. Express* **2020**, *28*, 821.