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NanoTerasu Soft X-Ray RIXS Beamline Achieves 7.1-meV Resolution Using Blazed Gratings From Inprentus

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Abstract

The 2D-RIXS beamline BL02U at NanoTerasu (Sendai, Japan) recently achieved a record-breaking energy resolution $\Delta E = 7.1$ meV at $E = 710$ eV using a pair of diffraction gratings manufactured by Inprentus. The Inprentus gratings are blazed for high efficiency to maintain sufficient photon flux in this extraordinarily narrow linewidth, and provide near diffraction-limited imaging.

Introduction

An energy-resolution record for resonant inelastic x-ray scattering (RIXS) was set at NanoTerasu beamline BL02U. Two Inprentus diffraction gratings, designed for ultra-high resolving powers with high diffraction efficiencies, monochromatize the incident beam and energy-resolve scattered photons.

The resolving power of a diffraction grating goes as $E/\Delta E \propto k\nu$, where k is the employed diffraction order, and ν is the physical line density. Kinematically, the only relevant quantity is the effective density, $k\nu$, and we are free to increase k or ν to increase dispersion.

From a dynamical point of view, increased dispersion generally reduces the diffraction efficiency of a grating. Fortunately, this limitation can be overcome by customizing the profile of the constituent grating lines, a process called *blazing*. Unlike resolving power, the efficiency of a blazed grating depends on both k and ν independently, and we must consider which combination is best suited for each use case.

Inprentus Design Services

For NanoTerasu BL02U, Inprentus suggested operating its monochromator and ultra-high resolution analyzer gratings at $k > 1$. For instance, the resolving power of the monochromator grating was maintained by changing the original 1800 lines/mm design at $k = 1$ diffraction order to a grating with 900 lines/mm operating at $k = 2$.

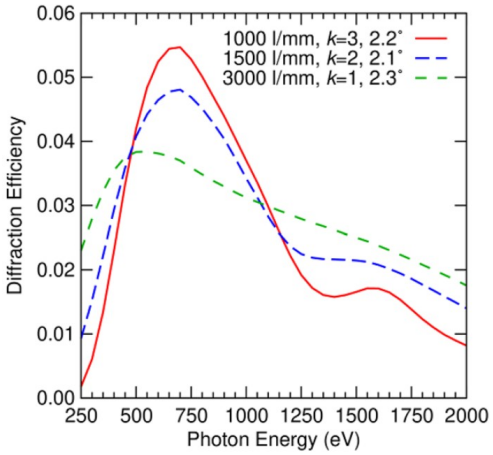

Figure 1: Simulated diffraction efficiencies for three different combinations of line density, diffraction order k, and blaze angle. From Ref. [1]

Figure 1 shows the results of simulations jointly performed by Inprentus and NanoTerasu staff that explored this scenario for the ultra-high energy analyzer grating. Simulations commonly show that the diffraction efficiency of a lower density grating operated at higher or-

Parameter	Mono	Spectrometer
Center line density ν (lines/mm)	900	1000
Diffraction order k	2	3
Effective density (lines/mm)	1800	3000
Specified blaze angle (°)	1.6	2.2
Measured blaze angle (°)	1.59 ± 0.17	2.04 ± 0.21
Specified slope error (nrad RMS)	< 50	< 50
Measured slope error (nrad RMS)	45	39

Table 1: Monochromator and spectrometer grating parameters.

der is similar to a higher density grating at $k = 1$. In this case, the theoretical efficiency of a 1000 lines/mm grating at $k = 3$ surpassed the performance of the original design with a 3000 lines/mm grating at $k = 1$ over the 500–1000 eV range. The peaked response seen in Fig. 1 is characteristic of operating at higher diffraction orders. The peak can be shifted by tuning the grating blaze angle. Inprentus can achieve blaze angles below 1°.

Inprentus and NanoTerasu staff collaborated to create gratings that provided strong efficiency profiles that peaked over 500–1000 eV and were well-matched to the scientific and mechanical requirements of the 2D-RIXS spectrometer. Monochromator and spectrometer grating parameters are tabulated in Table 1.

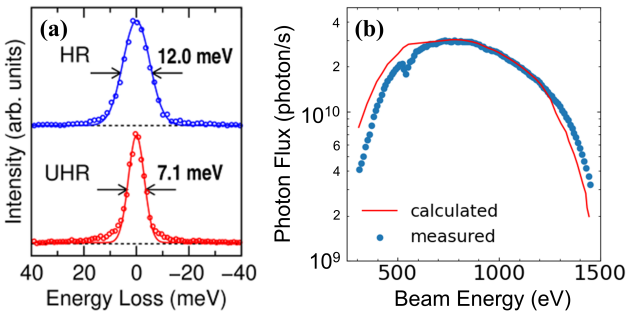

Figure 2: (a) Elastic-line data at $E = 710$ eV from the 2D-RIXS spectrometer obtained from a multilayer sample. The linewidth of the elastic line is 7.1 meV in UHR mode (red, $E/\Delta E = 10^5$). (b) Measured photon flux (blue circles) compared with calculated profile (red). Adapted from Ref. [1].

Performance at NanoTerasu

The 2D-RIXS spectrometer at NanoTerasu BL02U demonstErated ultra-high energy resolution (UHR) capabilities by achieving a world-leading RIXS energy resolving power using Inprentus-made diffraction gratings.

Figure 2(a) compares the elastic line from a multilayer sample measured in UHR mode (in red) to measurements in high-resolution mode (blue). At the Fe L_3 transition edge (710 eV), the linewidth of the elastic line is 7.1 meV, confirming sub-10-meV performance and demonstrating a record-breaking resolving power of $E/\Delta E = 10^5$. Figure 2(b) shows that the photon flux measured at BL02U compares well with the calculated photon flux profile.

Inprentus is invested in the efforts to extend NanoTerasu's global lead in ultra-high energy resolution RIXS, and achieve the $R = 1.4 \times 10^5$ design goal[2] of the 2D-RIXS spectrometer.

References

[1] J. Miyawaki, *Rev. Sci. Instrum.* **97** 063103 (2026).

[2] J. Miyawaki, K. Fujii, T. Imazono, *et al.*, *J. Phys.: Conf. Ser.* **2380** 012030 (2022).