Recent advances in blazed diffraction grating manufacturing technology for synchrotron, FEL, EUV and spectroscopy applications

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Technology summary

Inprentus has achieved several breakthroughs in mechanical ruling technology to manufacture blazed diffraction gratings for semiconductor, synchrotron, FEL and spectroscopy applications. Recent advances and manufacturing innovations are highlighted using metrology data from scientists and customers across the world

1. Extra long (480 mm), ultra-low blaze angle grating - metrology report from EUXFEL
2. High efficiency, extreme VLS grating for EUV - CXRO, LBNL metrology
3. High efficiency spectroscopy master gratings - Inprentus update
4. Grating performance efficiency - metrology from ALS
5. Rapid efficiency simulation software - Inprentus update
6. High resolving power manufacturing - Inprentus update
7. Groove shape technology - Inprentus update on diagnostic gratings and unconventional groove shapes

Extra long ruling (480 mm) grating for EUXFEL
0.12 °± 0.02°, 50 lpmm VLS

Inprentus delivered an extra-long grating of ruled length 480 mm on a extra-long substrate of 530 mm for EUXFEL. Slides 4-7 contain highlights of metrology performed by the customer.

EUXFEL metrology report - 480 mm ruled grating 0.12 °± 0.02°, 50 lpmm VLS

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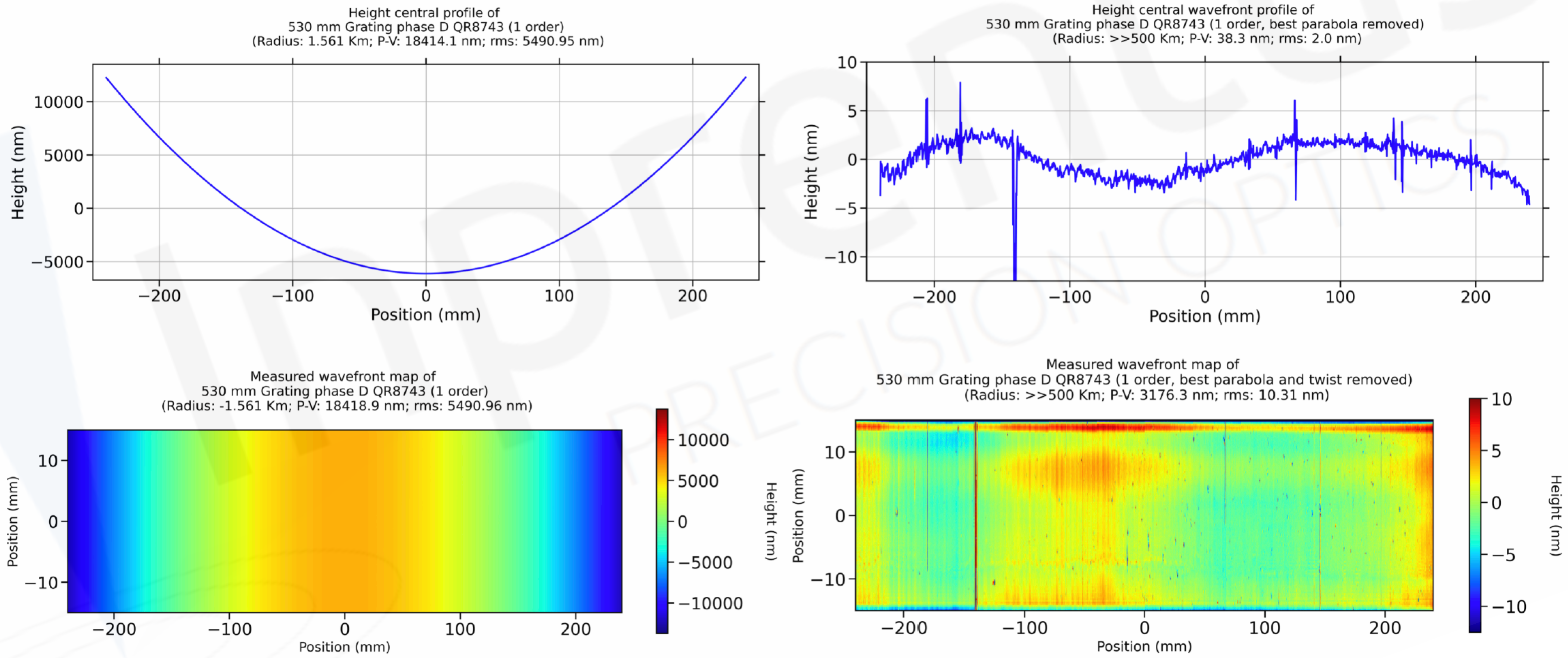
Direct measurement of 1st order of diffraction combining +1 and -1



European XFEL

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EUXFEL metrology report - 480 mm ruled grating 0.12 °± 0.02°, 50 lpmm VLS

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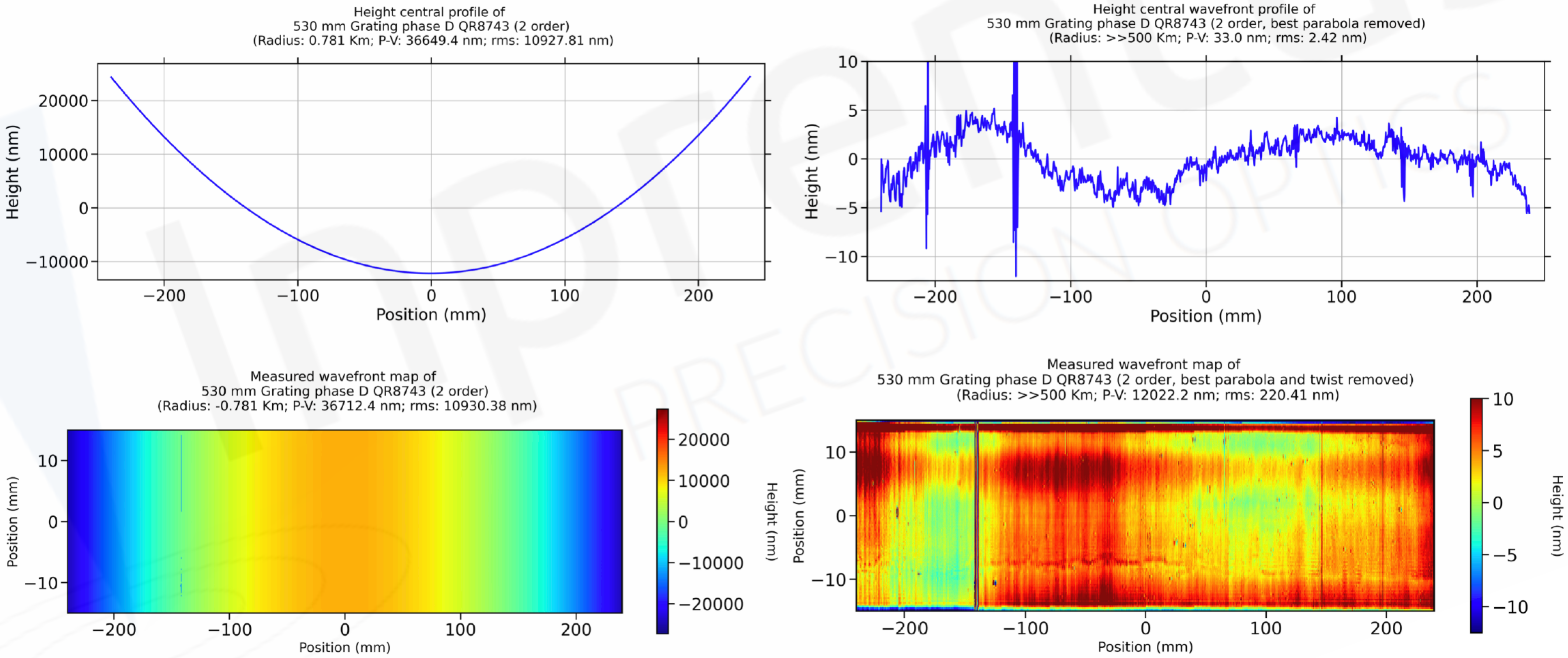
Direct measurement of 2nd order of diffraction combining +2 and -2



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EUXFEL metrology report - 480 mm ruled grating 0.12 °± 0.02°, 50 lpmm VLS

Fitting parameters

Desired:

b_1=(101± 1.6) x 10^{-5} l/mm^2

b_2=(0± 2) x 10^{-7} l/mm^3

Measured (average of all measurements):

b_1= 101.2 x 10^{-5} l/mm^2

b_2= < 0.07 x 10^{-7} l/mm^3

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EUXFEL metrology report - 480 mm ruled grating 0.12 °± 0.02°, 50 lpmm VLS

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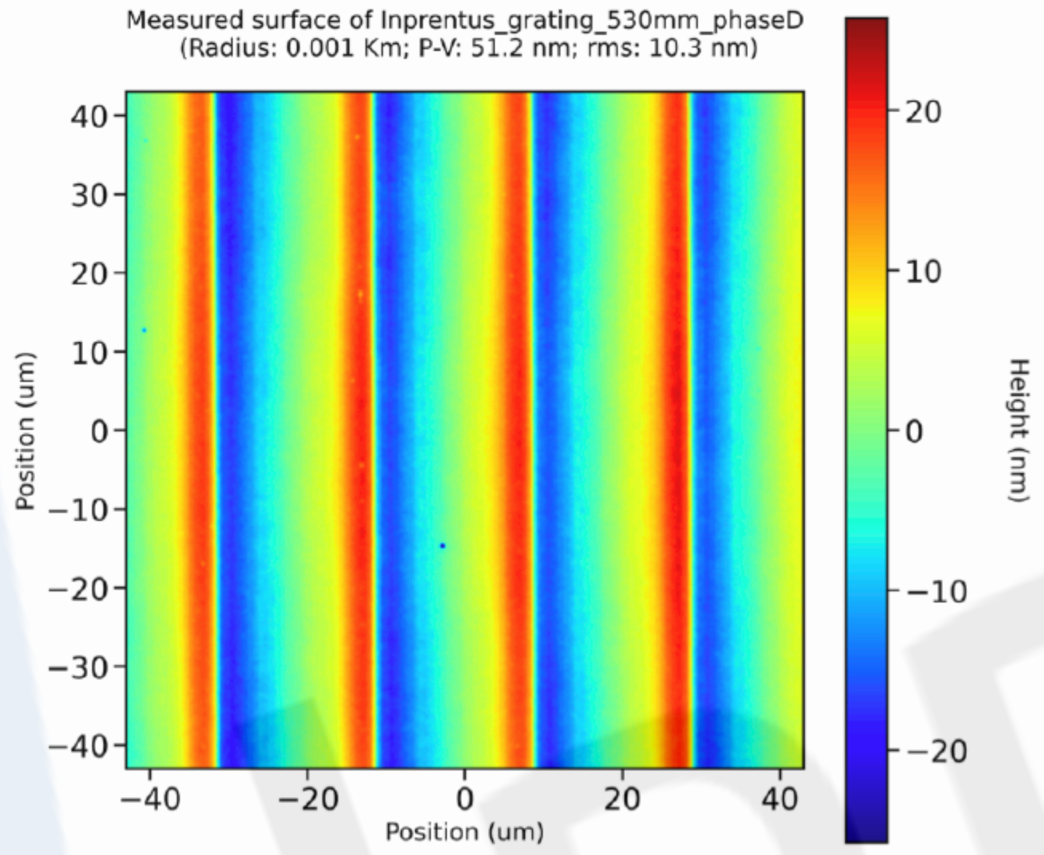
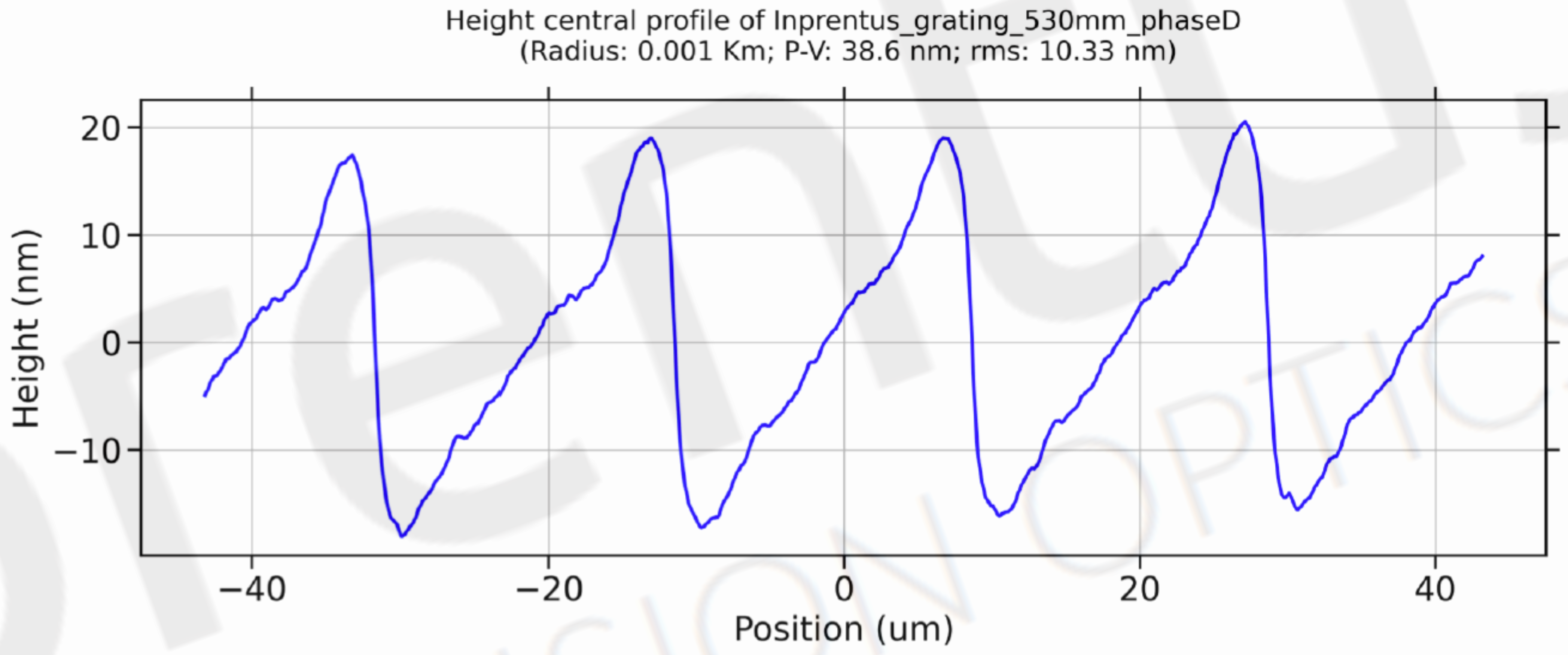
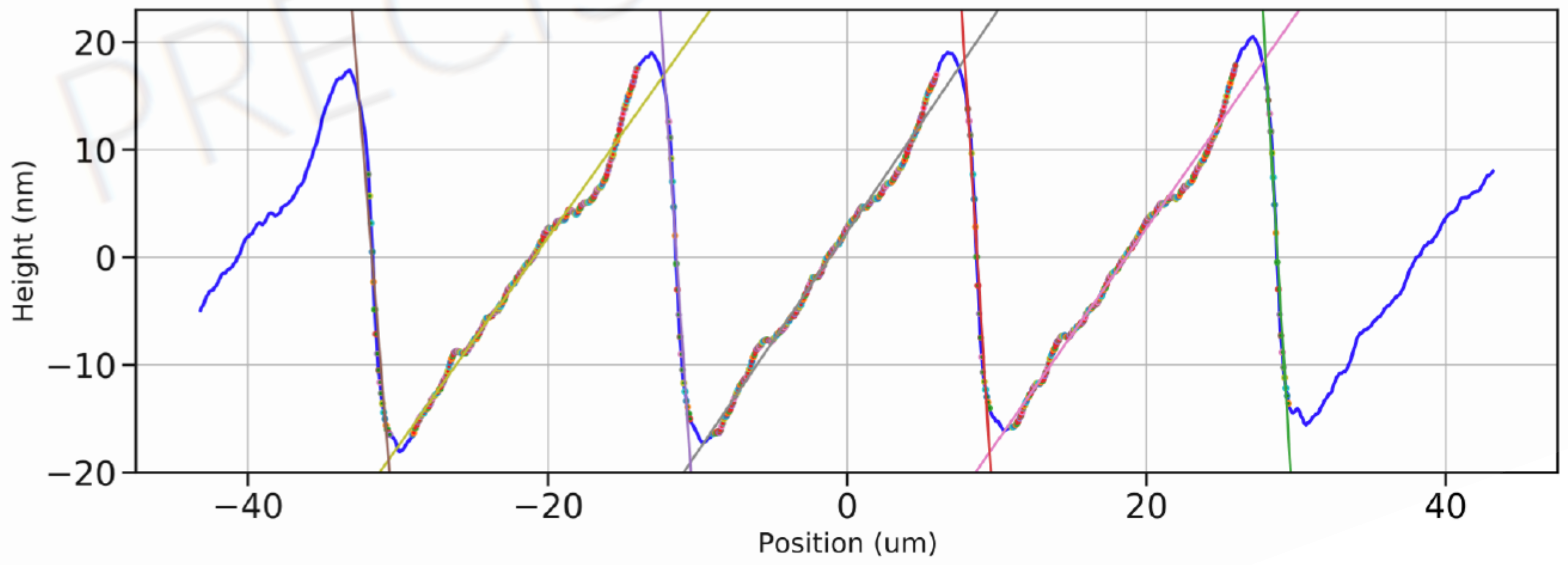




Measured angles
Blazed: 0.11°
Anti-blazed: -1.22°

Requested:
0.12° ± 0.02° Blaze
1.26° ± 0.1° Anti-blaze



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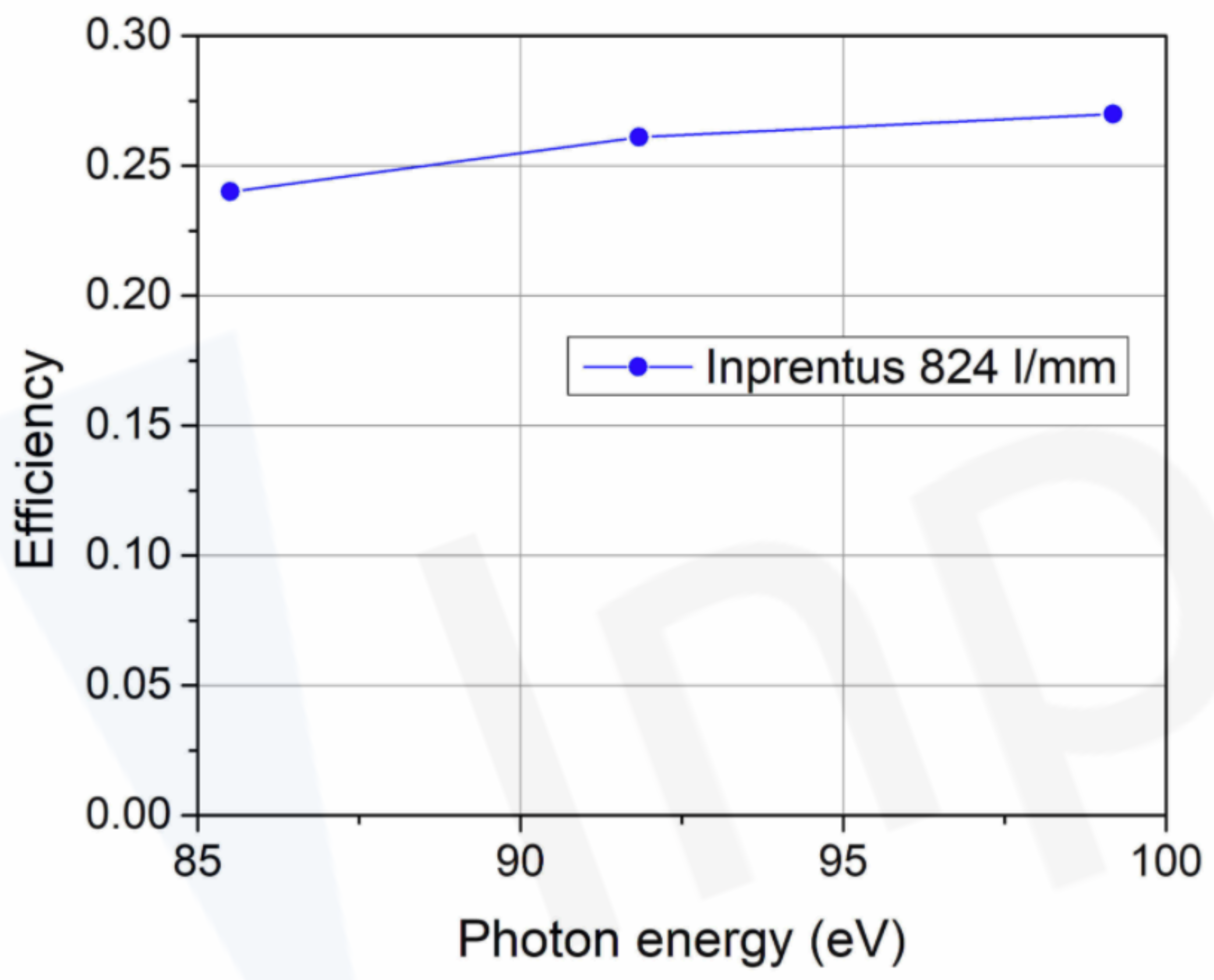
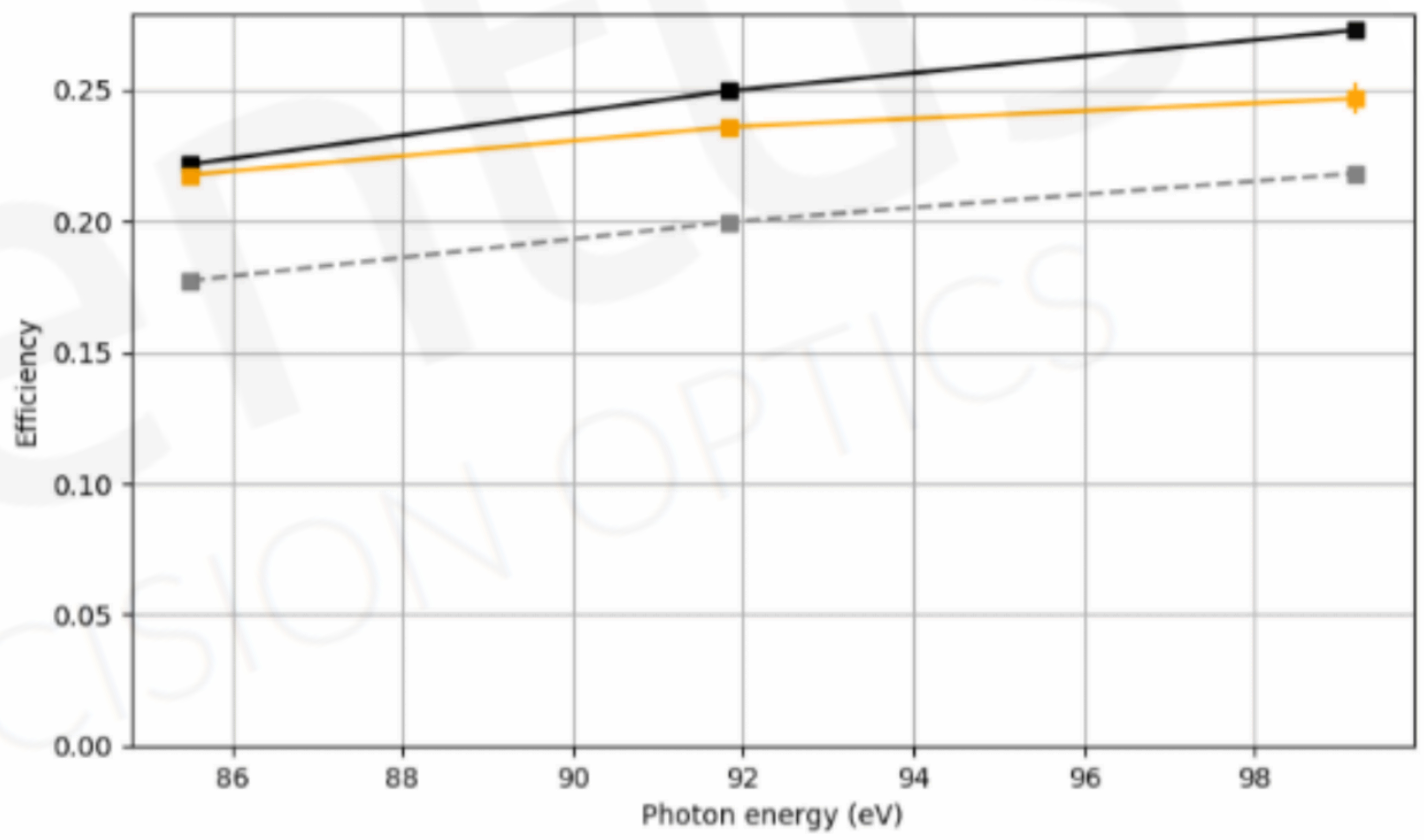
High efficiency, extreme VLS grating for EUV application

3.3 °± 0.1°, 824 lpmm

Inprentus manufactured a grating for an EUV application that utilized a high degree of focusing. Metrology shown in next few slides was performed by the Center for X-Ray Optics at Lawrence Berkeley National Laboratory. For questions about custom, upgrade or drop-in replacement gratings in your EUV application, please email info@inprentus.com

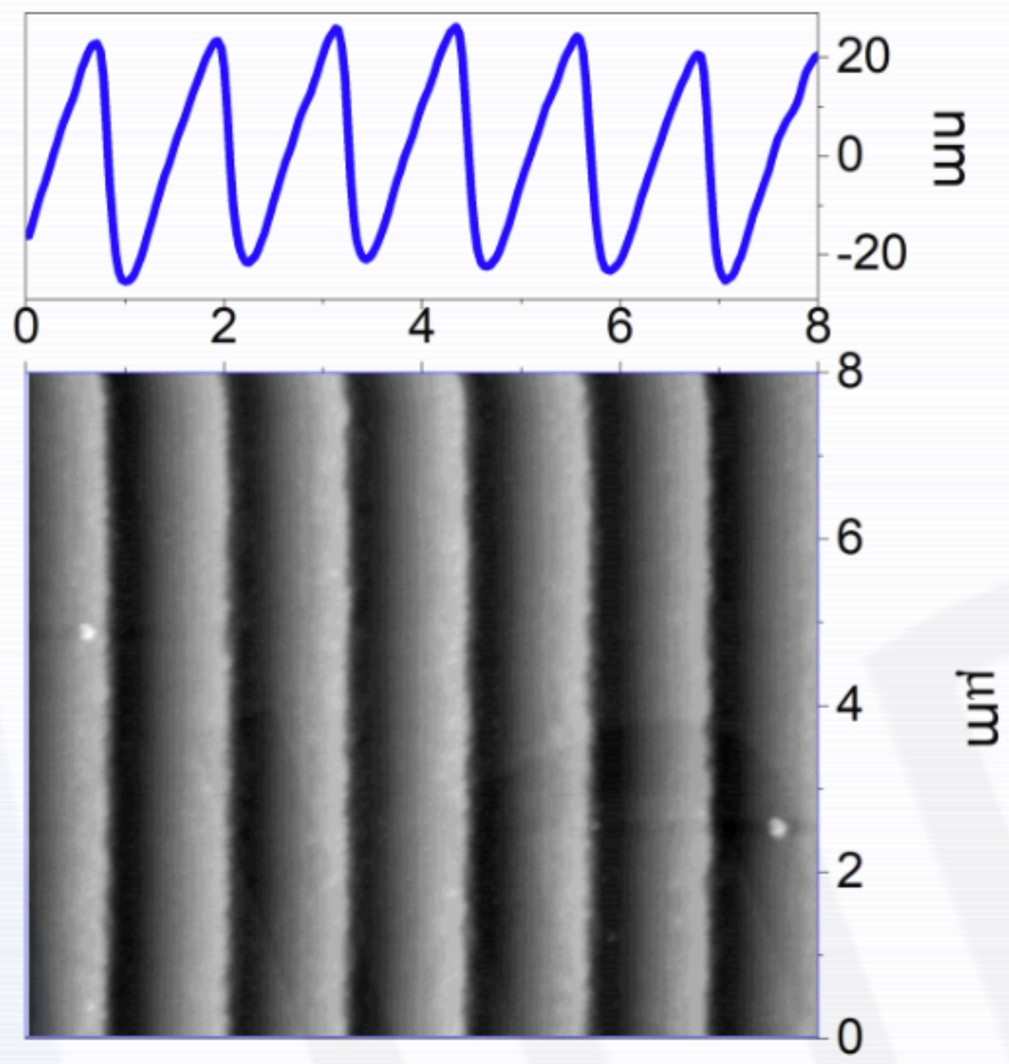
High efficiency, extreme VLS achieved for EUV application
3.3 °± 0.1°, 824 lpmm

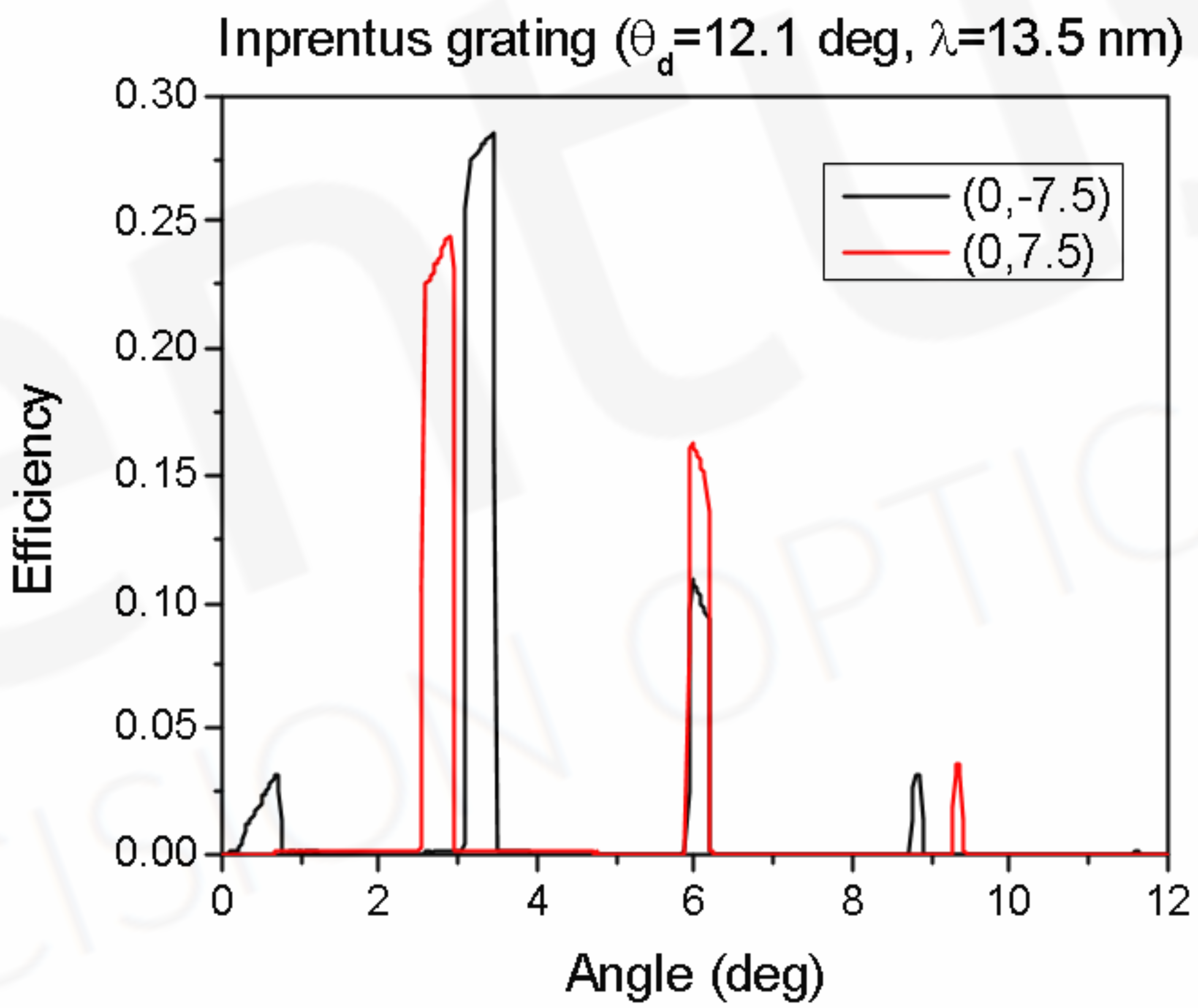




Inprentus EUV grating with extreme VLS was measured to provide near-ideal efficiency at design wavelengths shown in the left panel. The measurement was performed at the Center for X-Ray Optics at Lawrence Berkeley National Laboratory. The right panel shows Inprentus simulated efficiency of manufactured grating. The Nevière algorithm-based simulations performed at Inprentus allow efficiency calculations to be made of the manufactured grating (orange symbols with error bars) and compared to the specified theoretical grating (black symbols) and 80% of theoretical grating (grey symbols).

High efficiency, extreme VLS achieved for EUV application
3.3 °± 0.1°, 824 lpmm





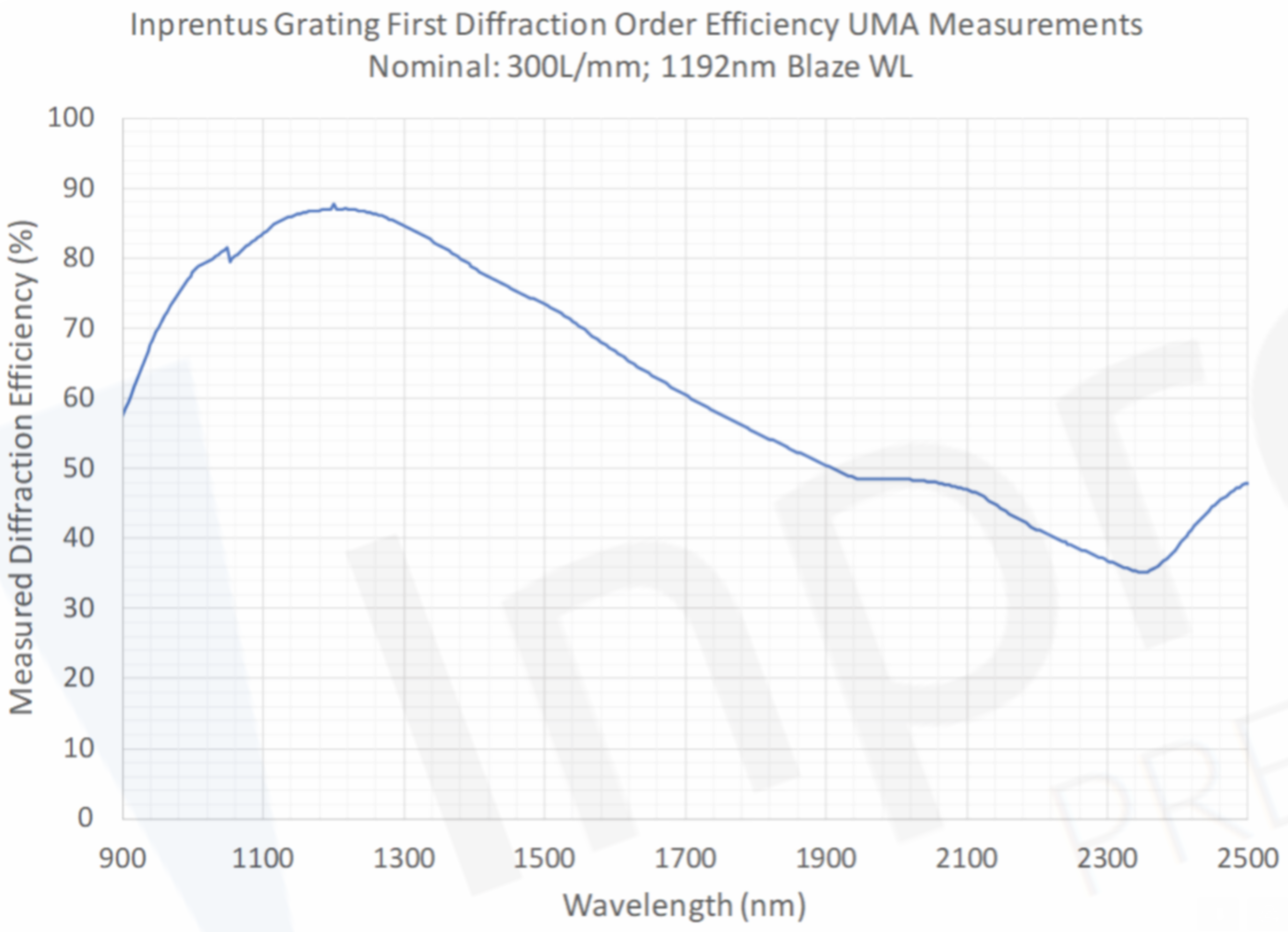
Manufacturing advancements have enabled extreme line density extrema ranging from 736 lpmm to 930 lpmm while maintaining a blaze angle of 3.3° +/- 0.04°. An atomic force microscope (AFM) grayscale height map of manufactured grooves is shown on the left panel along with groove profile in blue. Use of high VLS gratings can help reduce focussed image size by around 50x and make instrument significantly more compact. Efficiency measured at CXRO at different spots of high VLS grating is shown on the right. The efficiency differences are due to the line density variation.

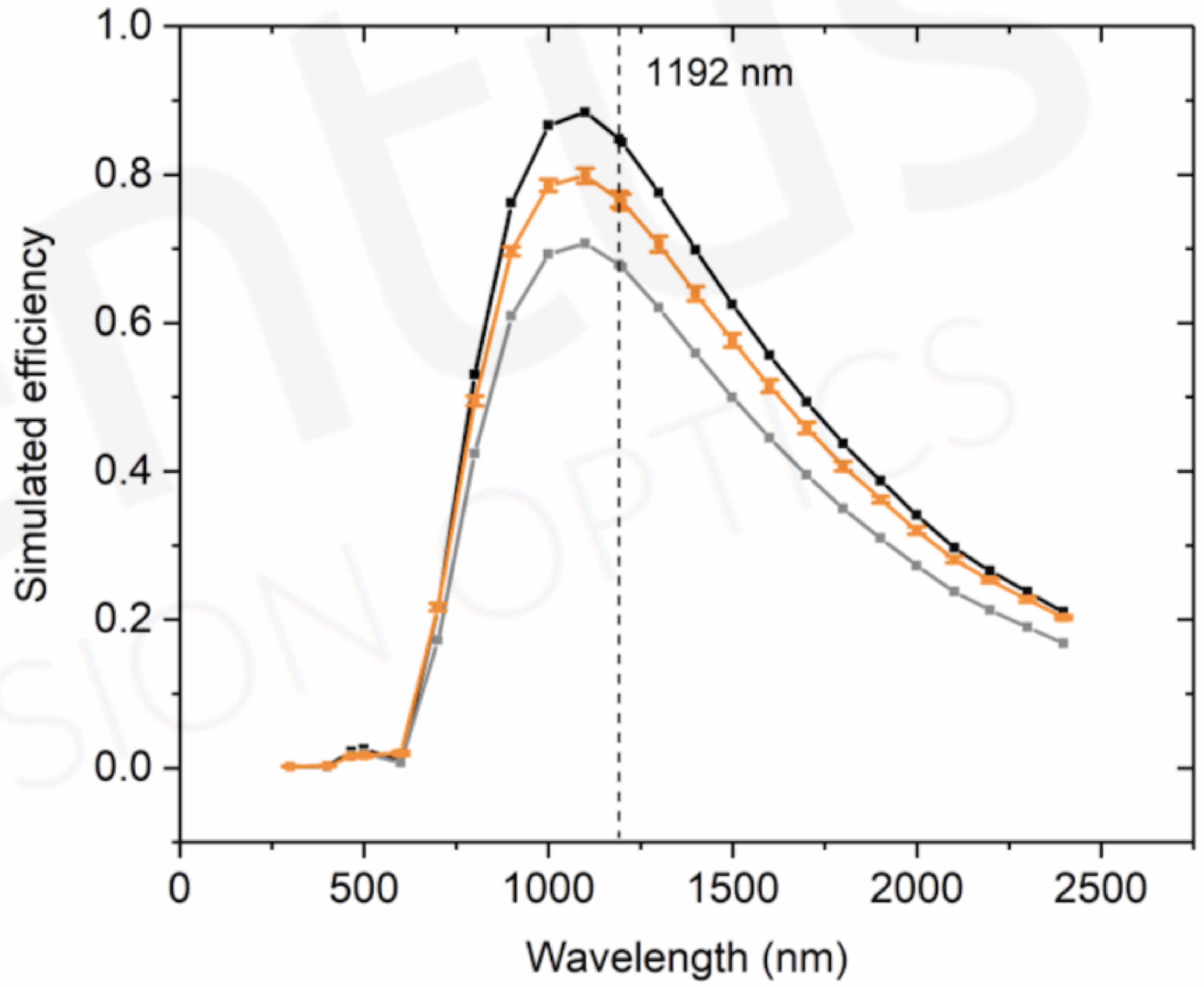
High efficiency spectroscopy masters

10.5°± 0.2° , 300 lpmm

Inprentus has the ability to manufacture Echelle gratings, specifically optimized for high blaze efficiency. These can be used in a range of wavelengths in the UV to IR region and in a wide variety of sizes and specifications. The master gratings are used as is or with further replication in cutting-edge spectroscopy applications. Metrology performed on a grating sample optimized for 1192 nm is shown in the following slides. For the questions or a loaner grating sample for metrology purposes, please email info@inprentus.com

High efficiency spectroscopy masters
10.5°± 0.2° deg, 300 lpmm

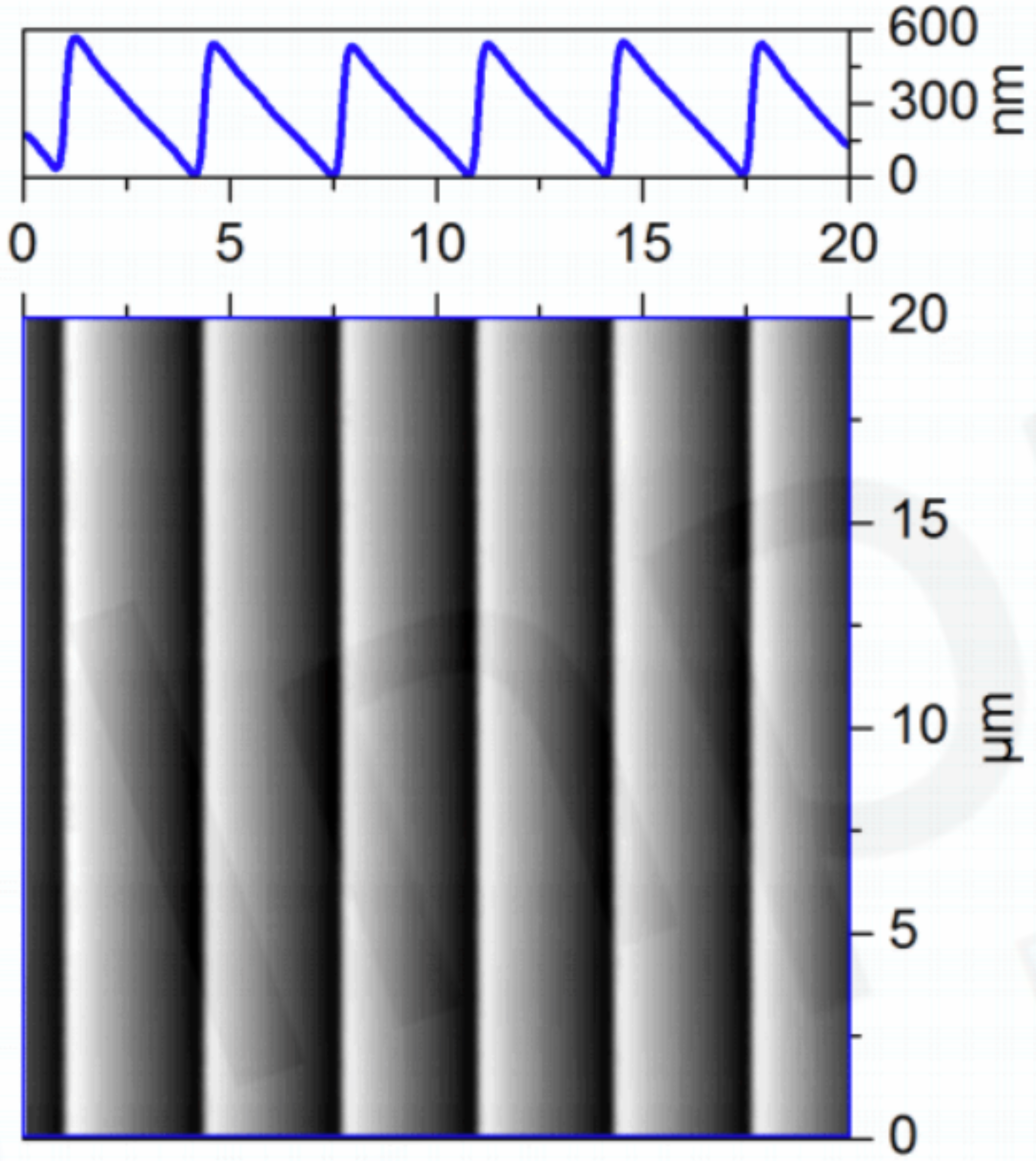


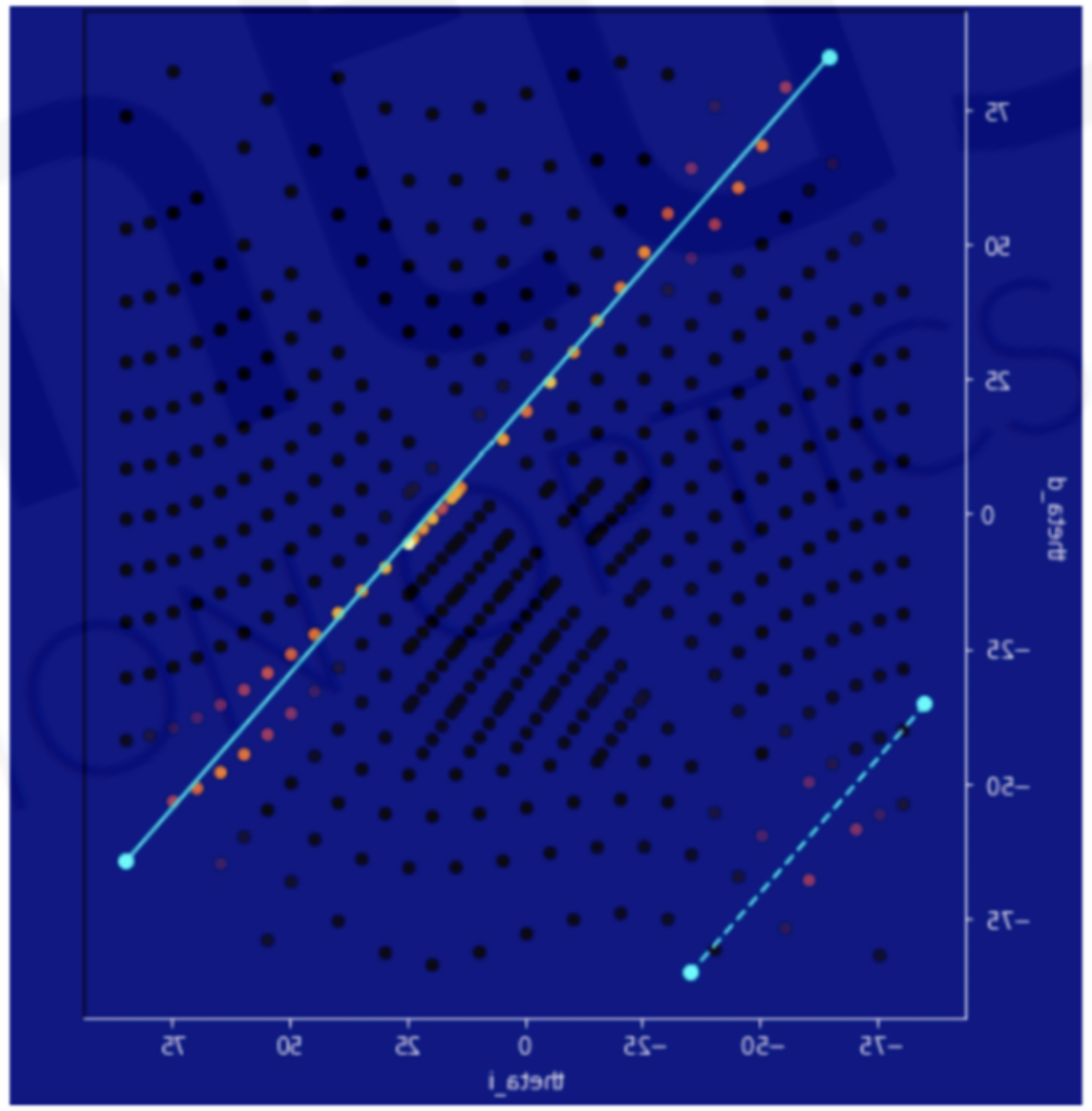


Inprentus spectroscopy grating sample was verified to give more than 80% efficiency at design wavelength. The measurement was performed by a third party using an industry standard spectrophotometer and is shown in the left panel. The right panel shows Inprentus simulated efficiency of manufactured grating, consistent with the measurement. The Nevière algorithm-based simulations performed at Inprentus allow efficiency calculations to be made of the manufactured grating (orange symbols with error bars) and compared to the specified theoretical grating (black symbols) and 80% of theoretical grating (grey symbols).

High efficiency spectroscopy masters

10.5°± 0.2° deg, 300 lpmm





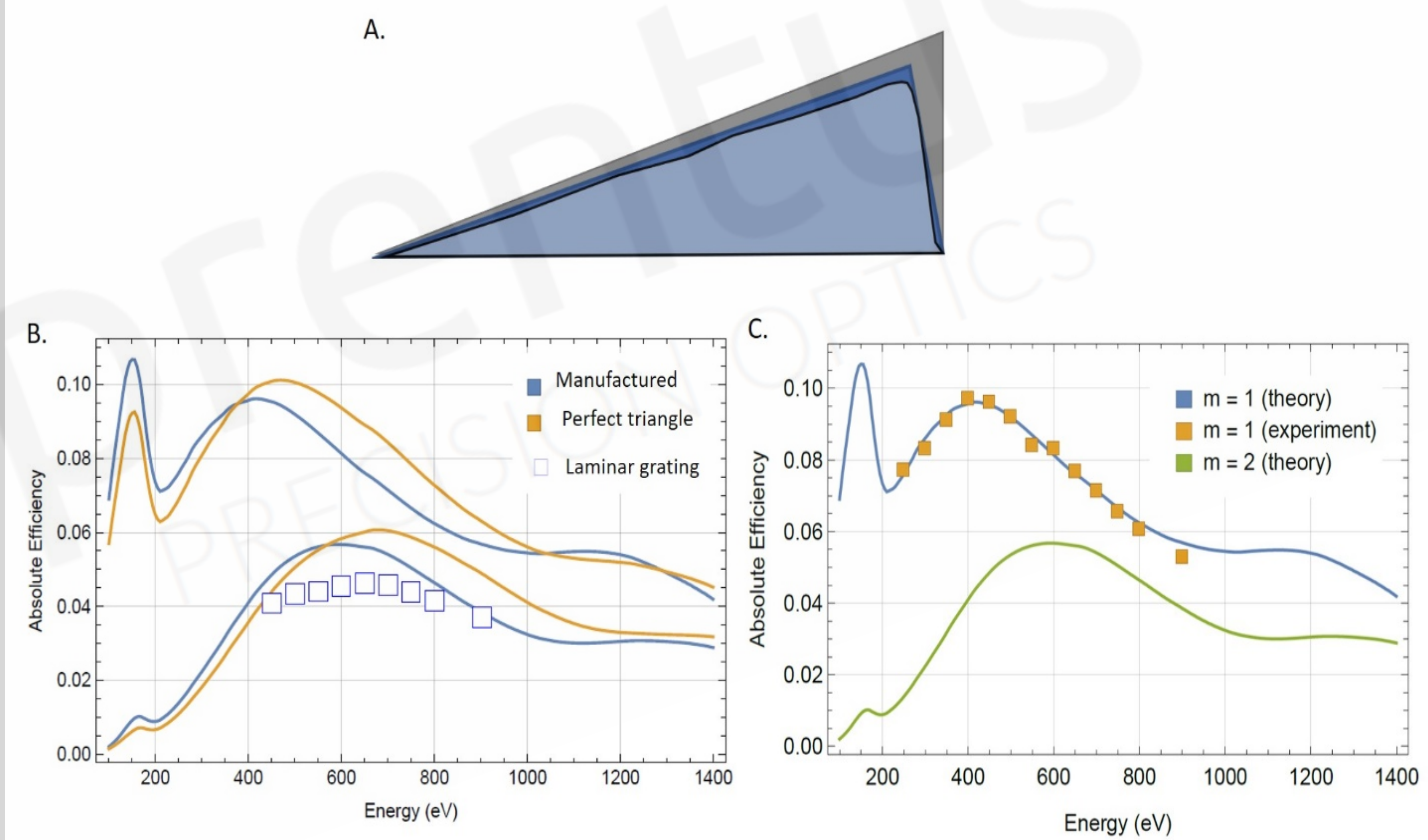
An atomic force microscope (AFM) grayscale height map of manufactured grooves is shown on the left along with groove profile in blue. Echelle grating angles are also confirmed with a two-circle diffractometer technique using 543 nm light. Shown on the right are measured grating reflections at various incident and diffracted angles which are then compared with ideal groove reflections.

Grating performance - Efficiency Metrology at ALS, Berkeley

Panel A. A candidate ideal triangle (grey) is shown with apex angle 90 deg along with a perfect triangle (dark blue) with obtuse apex angle (antiblaze 3x blaze) and profile of a candidate manufactured sawtooth shape with minor deviations (light blue).

Panel B. Simulated efficiency of manufactured and perfect triangle is compared to a laminar grating performance measured at ALS, Berkeley. G-Solver is used for efficiency simulations in these graphs.

Panel C. Simulated efficiency of Inprentus manufactured grating in first order is compared to measured efficiency at ALS, Berkeley.

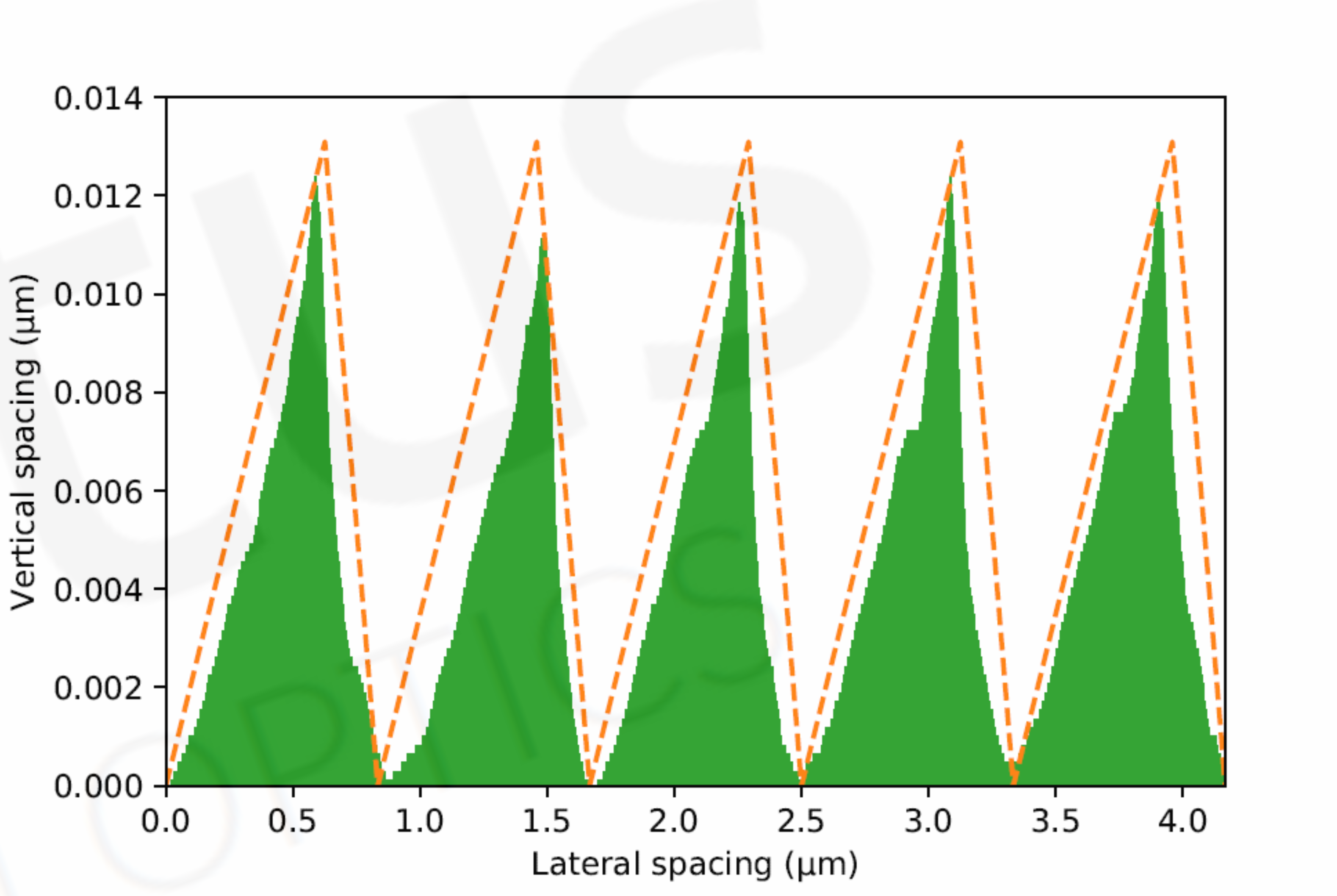


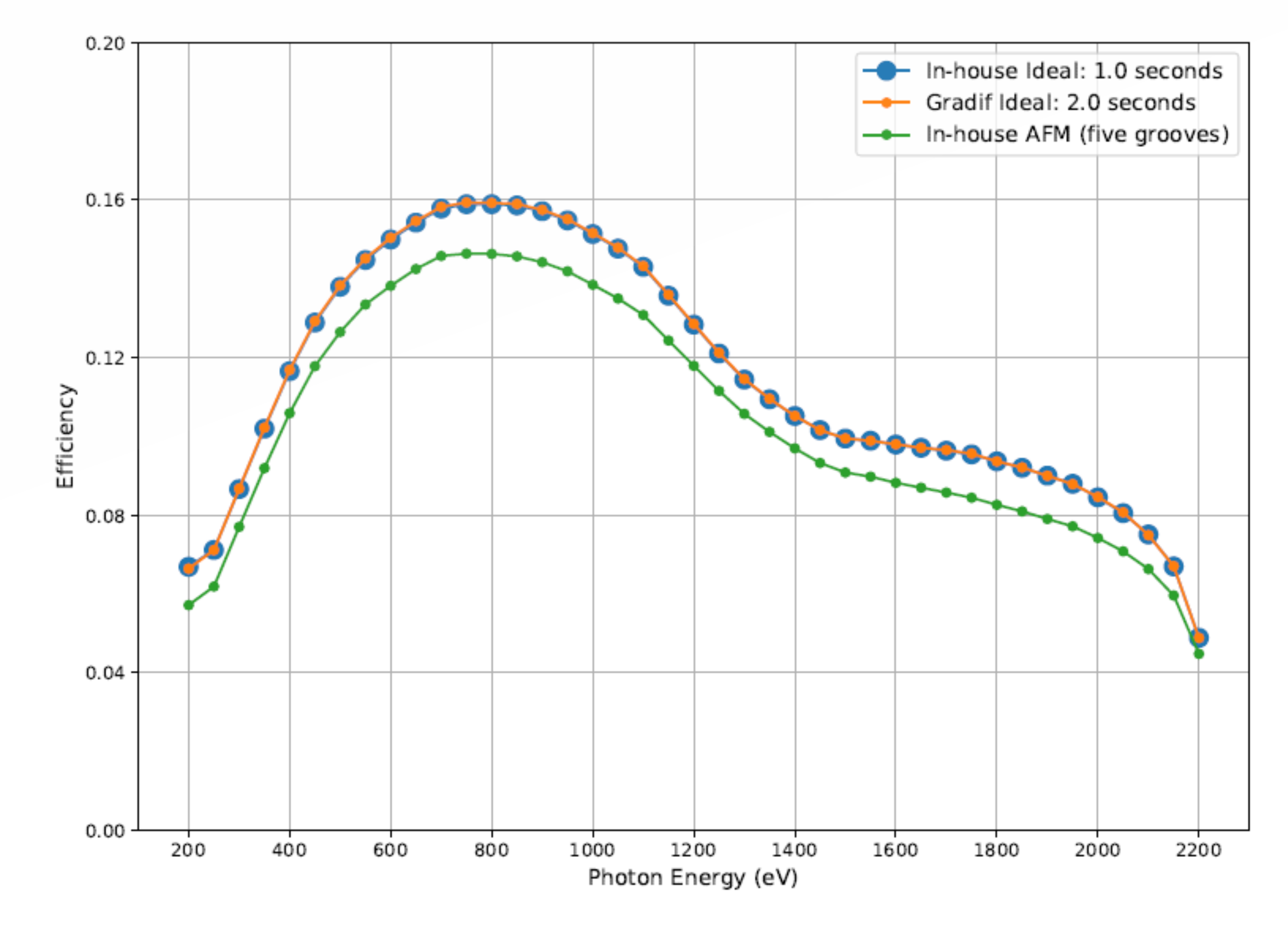
Inprentus rapid efficiency simulation software

In-house efficiency simulation software is developed to simulate efficiency of arbitrarily profiled imperfect groove shapes while deciding tool alignment during manufacturing. The top panel shows ideal and arbitrary groove shapes and bottom panel their corresponding efficiency simulated using in house and Gradif (G-Solver) software.

Inprentus software is scriptable, transparent, modifiable, python scripted while being compatible with manufacturing requirements. Solutions are 2-3x faster for grating efficiencies compute in first order and 15-60x faster for higher order computations. It is also more robust in computing arbitrary profile shapes and Fourier orders and can handle numerous grooves in a single run to study superlattice effects.

Inprentus guarantees above 75% aggregate efficiency of manufactured grating relative to a perfect grating of specified blaze angle and tolerance.



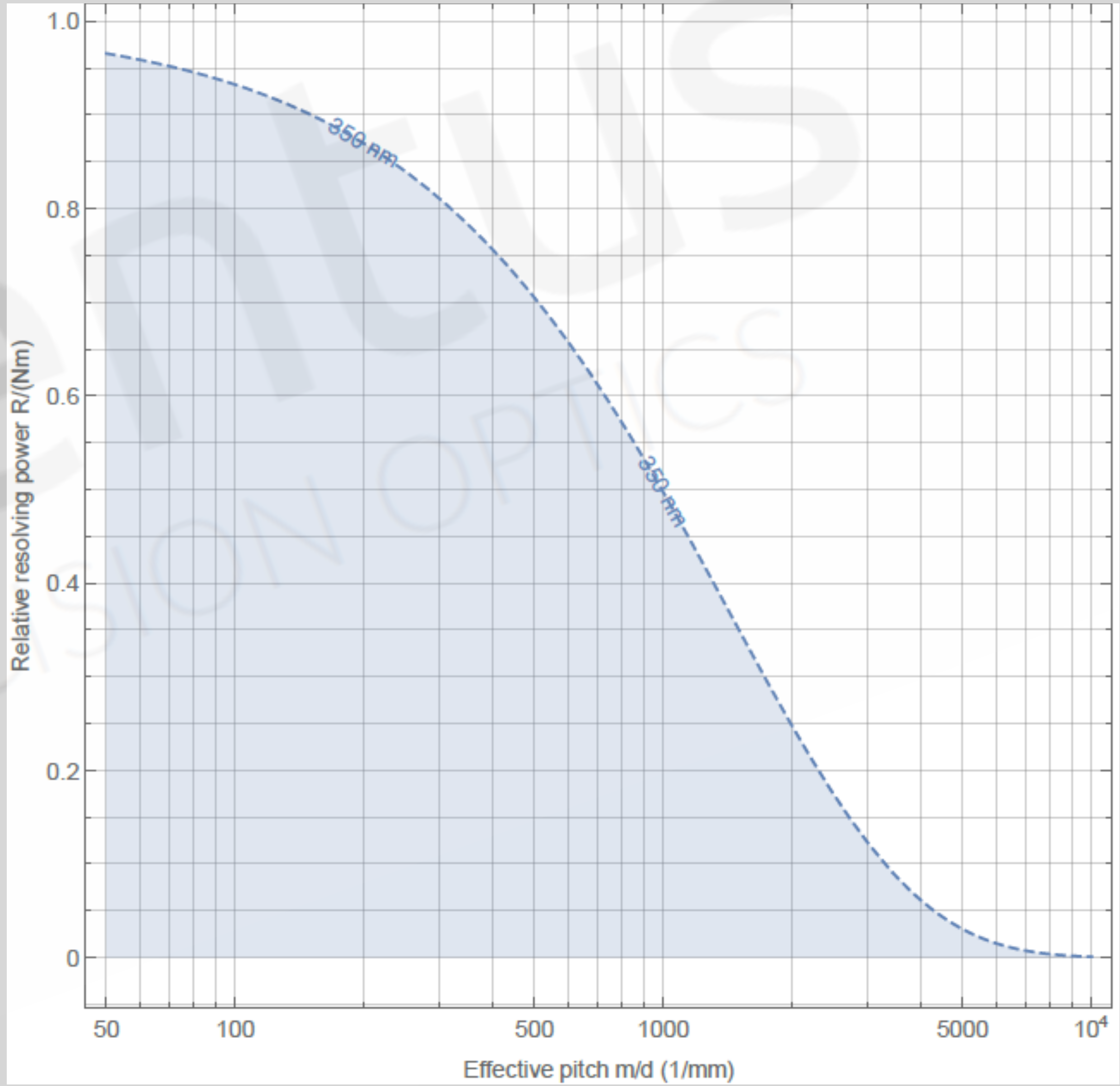


Grating performance - Resolving power

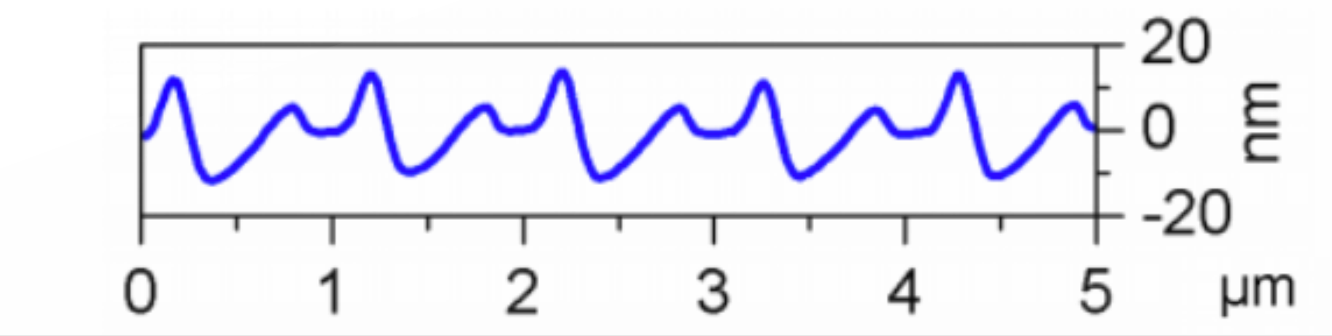
For a grating of N lines, resolving power can never be greater than theoretical limit of N. A requested 100,000 resolving power grating must have at least 100,000 total ruled lines. In manufacturing, the relevant parameter of interest therefore is the relative resolving power given by (R/N) for a first order grating.

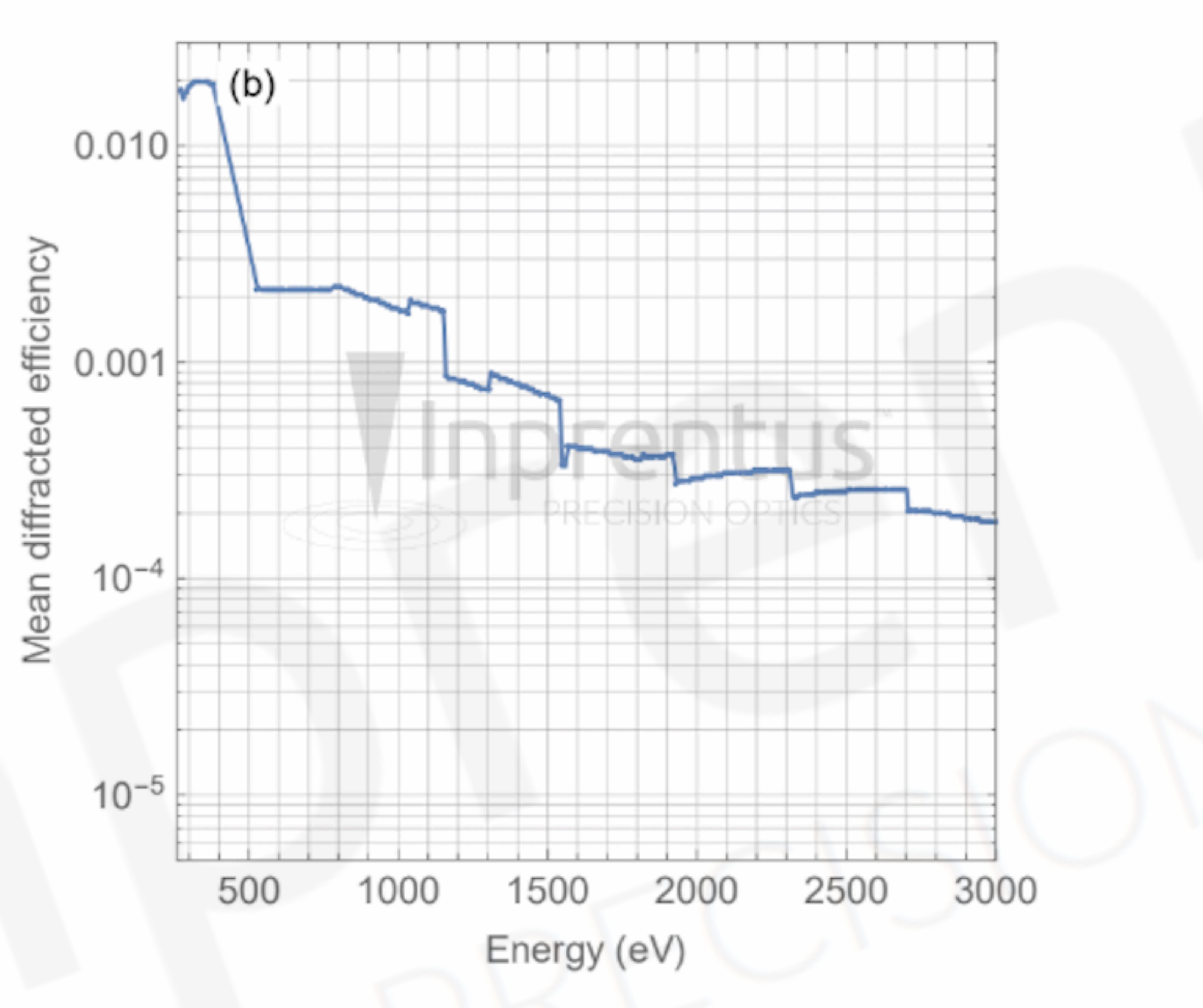
The graph here shows the relative resolving power Inprentus achieved in 2019 as a function of line spacing of the grating. The larger the period of the grating (low line densities), better is our ability to achieve the theoretical resolving power limit.

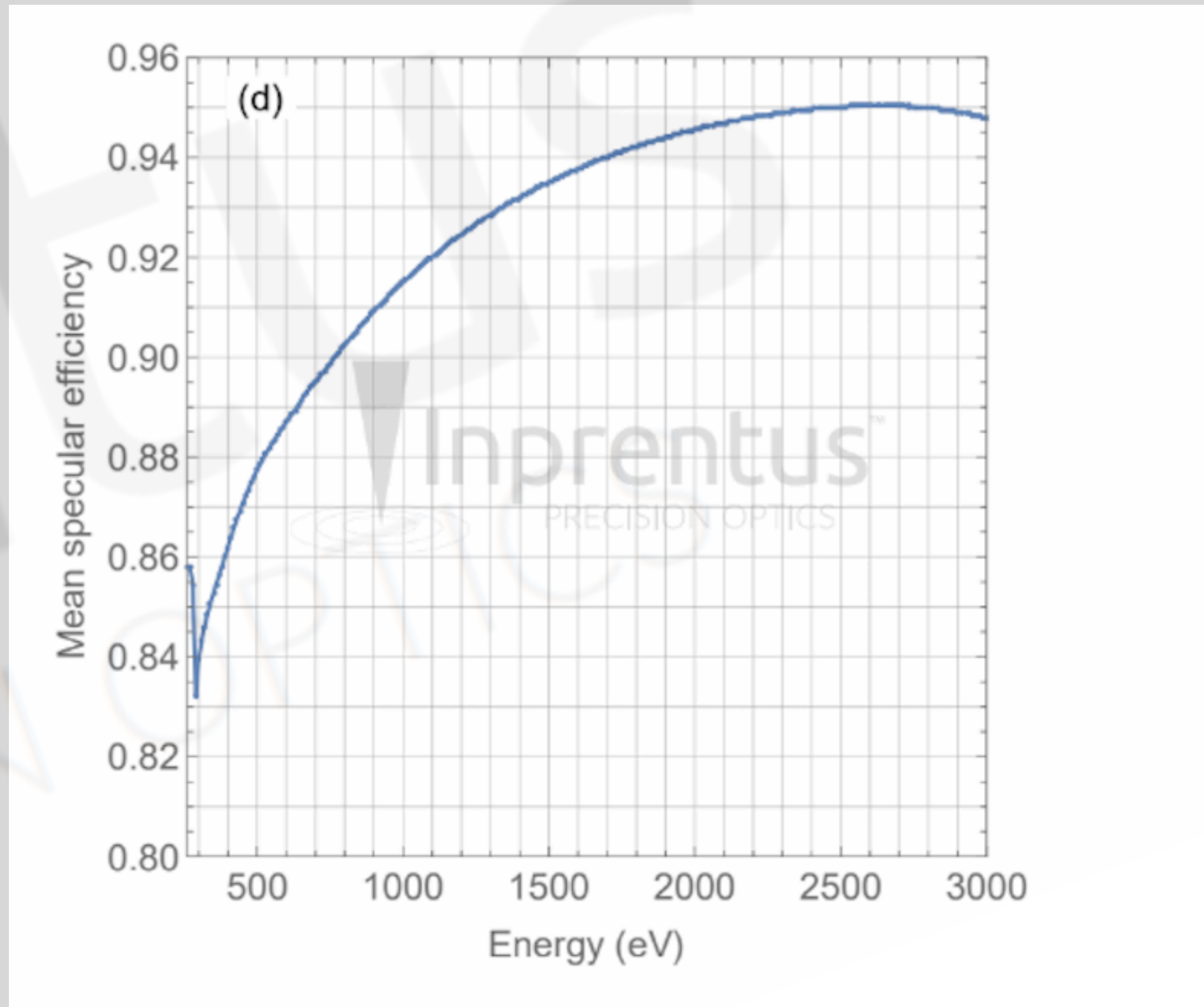
Inprentus R&D continues to achieve higher resolving powers in manufacturing, especially higher line densities where higher resolving power might be required. Please contact us if your resolving power requirement falls outside the blue region shown in the graph.



Groove shape technology

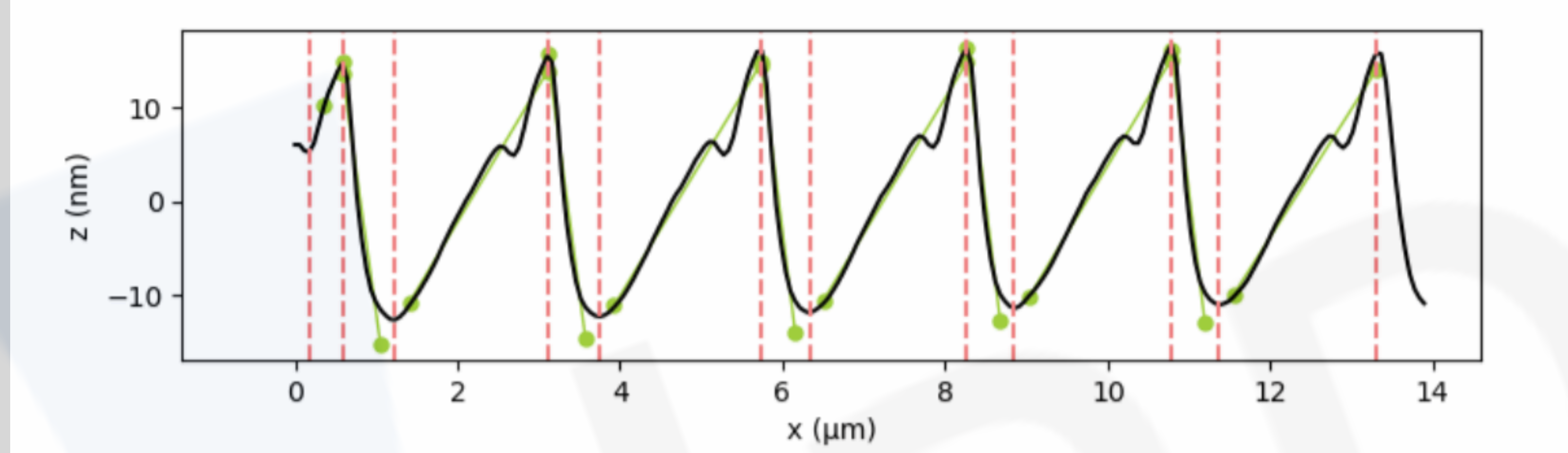


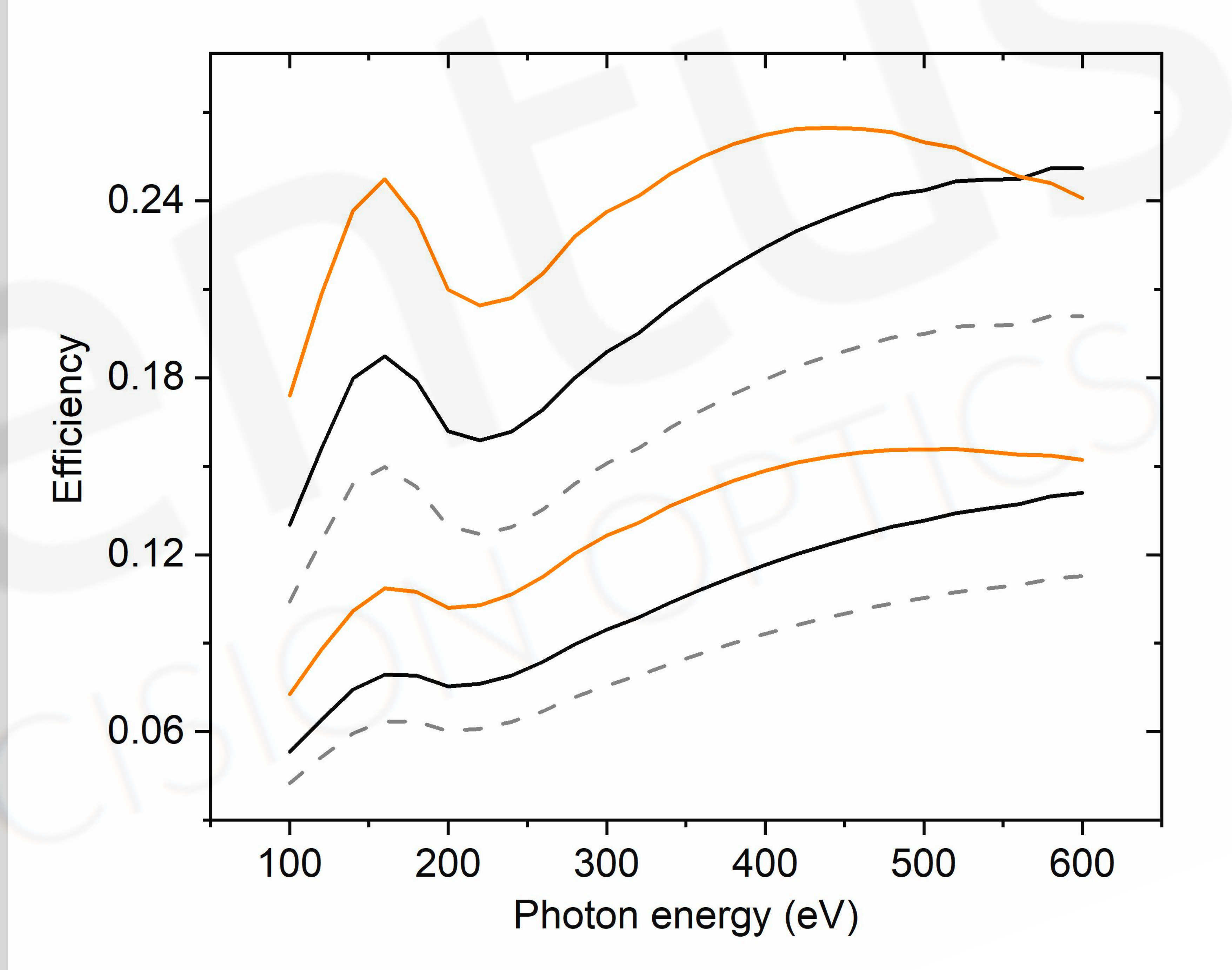




For several applications a continuous sawtooth is not the best option. A beam diagnostic grating is one such example. Here Inprentus manufactured a precision, discontinuous groove shape (left panel) that resulted in 0.1%-1% of the beam be diffracted (middle panel) and used for beam diagnostics. The specular efficiency was preserved to be above 80% across a wide range of energies (right panel). Inprentus scientists can help optimize customized diagnostic grating requirements.

Groove shape technology





A continuous sawtooth or customer specified blaze angle, on occasion, is found to not provide the best efficiency. Here we show efficiency of a continuous ideal triangle profile (black line) compared to discontinuous grooves (orange line, profile shown on the left) for a two sets of plane illumination conditions. Grey dotted line represents 80% of continuous ideal triangle profile (black line). If you have a high efficiency requirement, please contact us for customizable solutions.