

X-RAY AND UV REFLECTION GRATING DEVELOPMENT

Drew M. Miles (Caltech → PSU) + **PSU Fabrication Team**

Fabien Grisé – fabrication lead, Jake McCoy – TASTE lead,

Ross McCurdy – TASTE postdoc, Aditi Gangadharan – GRA, Nolan McPhaul – GRA

Randall McEntaffer – PSU → Colorado State

X-ray Gratings

- James Tutt (PSU)
- Bridget O'Meara (PSU)
- Jeffrey De Lucca (PSU)
- Casey DeRoo (Iowa) – Raytrace, metrology, environmental
- SCIL Nanolmprint Solutions – Grating replication
- Micronit – Grating plate processing
- Cosine – Grating alignment

UV Gratings

- University of Colorado / LASP – design, infusions, measurements
 - Brian Fleming
 - Kevin France
 - Nicholas Kruczek
- Johns Hopkins University – design, infusions, measurements
 - Stephan McCandliss
 - Mackenzie Carlson
 - Emily Witt
 - Jack Ford
- University of Iowa – metrology and env. testing
 - Casey DeRoo

FABRICATION BASIS

Electron-beam lithography (direct write)

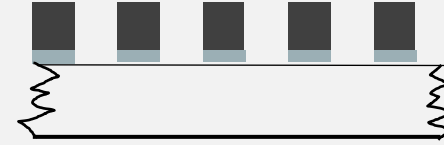
1) Deposit process layers



2) Pattern EBL Resist



3) Descum and RIE through resist and etch masks



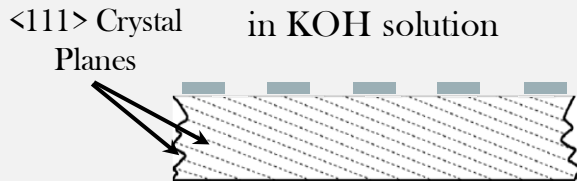
Blazed grating production

KOH etching

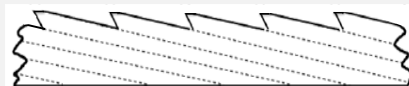
4) O₂ etch to remove remaining EBL resist, then BOE bath to remove oxide



5) Anisotropically etch Si substrate in KOH solution



6) HF soak to remove Si₃N₄ hardmask



Ion-beam etching

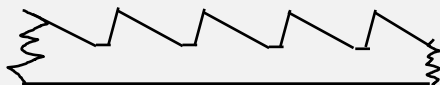
4) Transfer pattern into substrate with RIE



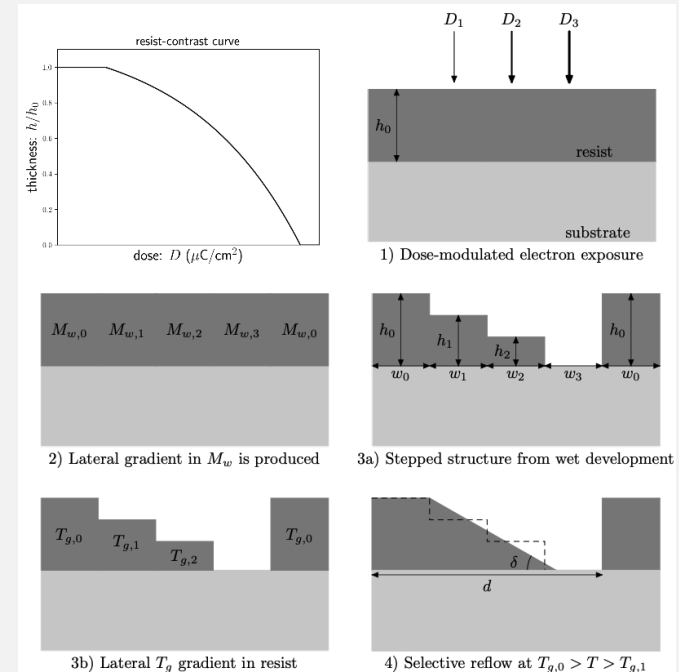
5) Strip etch mask



6) Blaze grating with direction ion-beam etching (IBE)



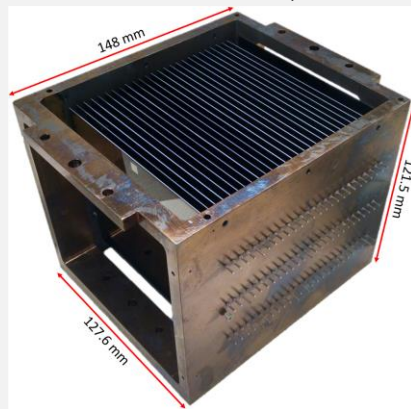
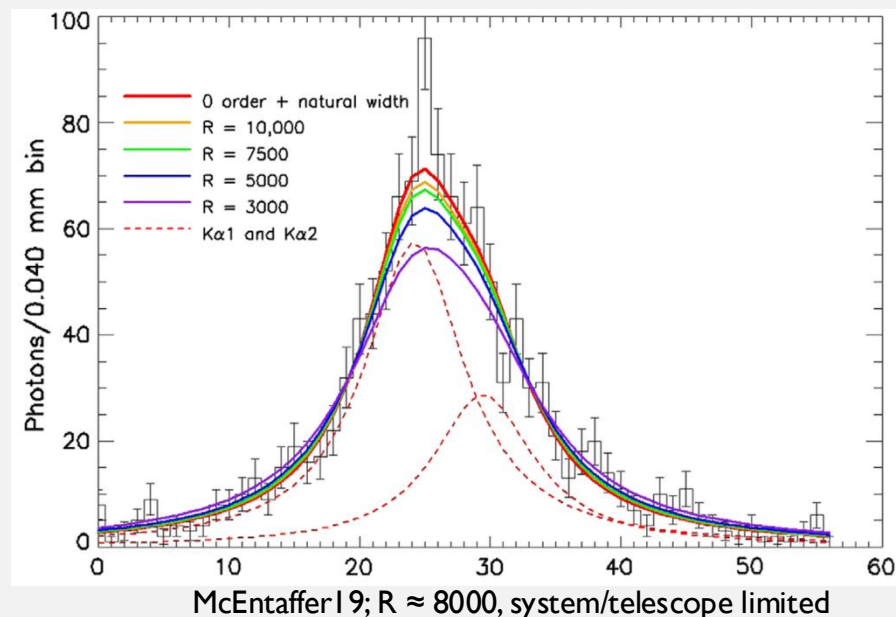
Thermally activated selective topography equilibration (TASTE)



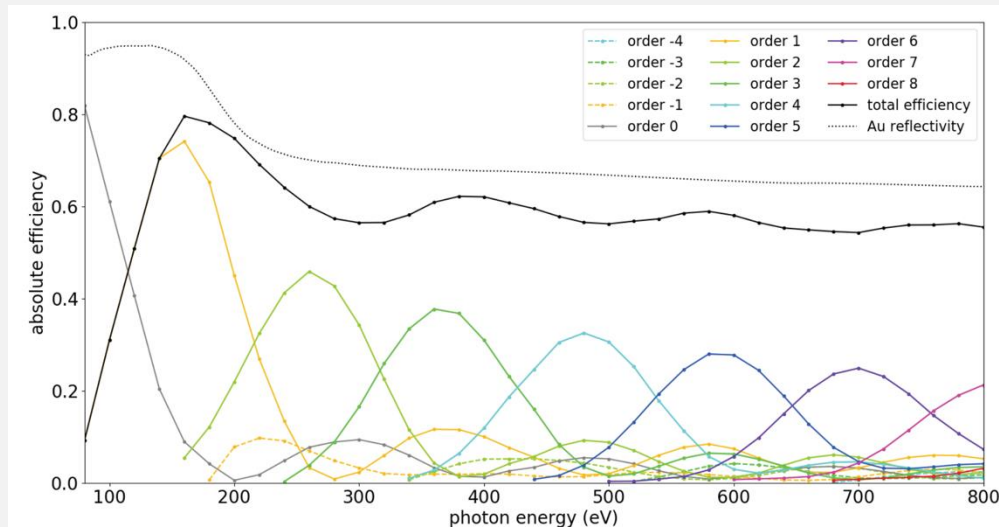
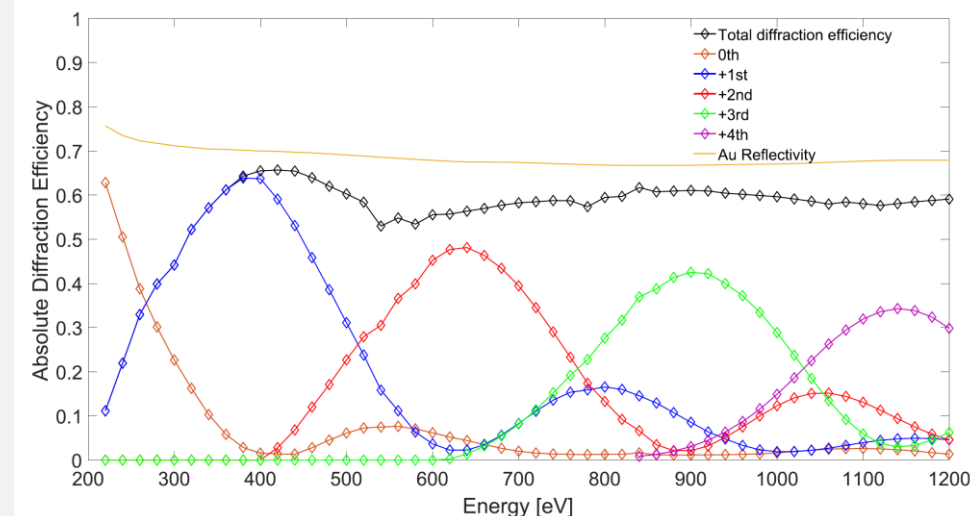
STATE OF X-RAY REFLECTION GRATINGS

Tier I Tech Gap: high-efficiency ($>45\%$), large-format X-ray grating arrays with high spectral resolving power ($R > 7500$) in soft-X-ray band
 → High-volume replication and alignment of high-performance gratings

tREXS; semi-passive alignment,
 36/module

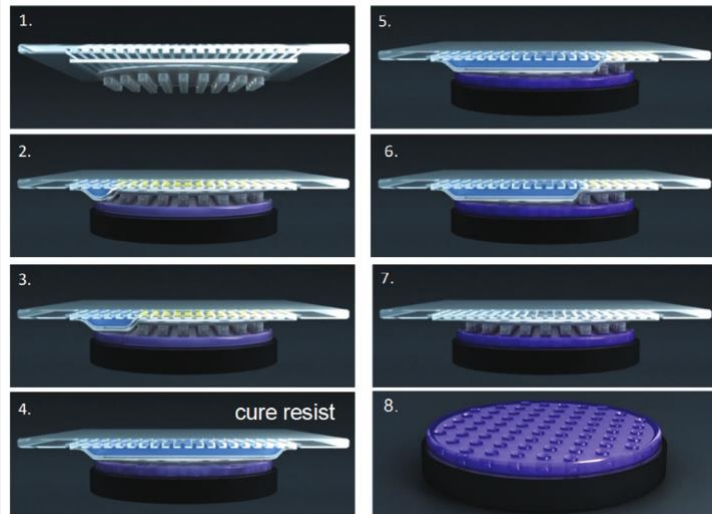


Tutt+I 9; active alignment,
 26 in one module

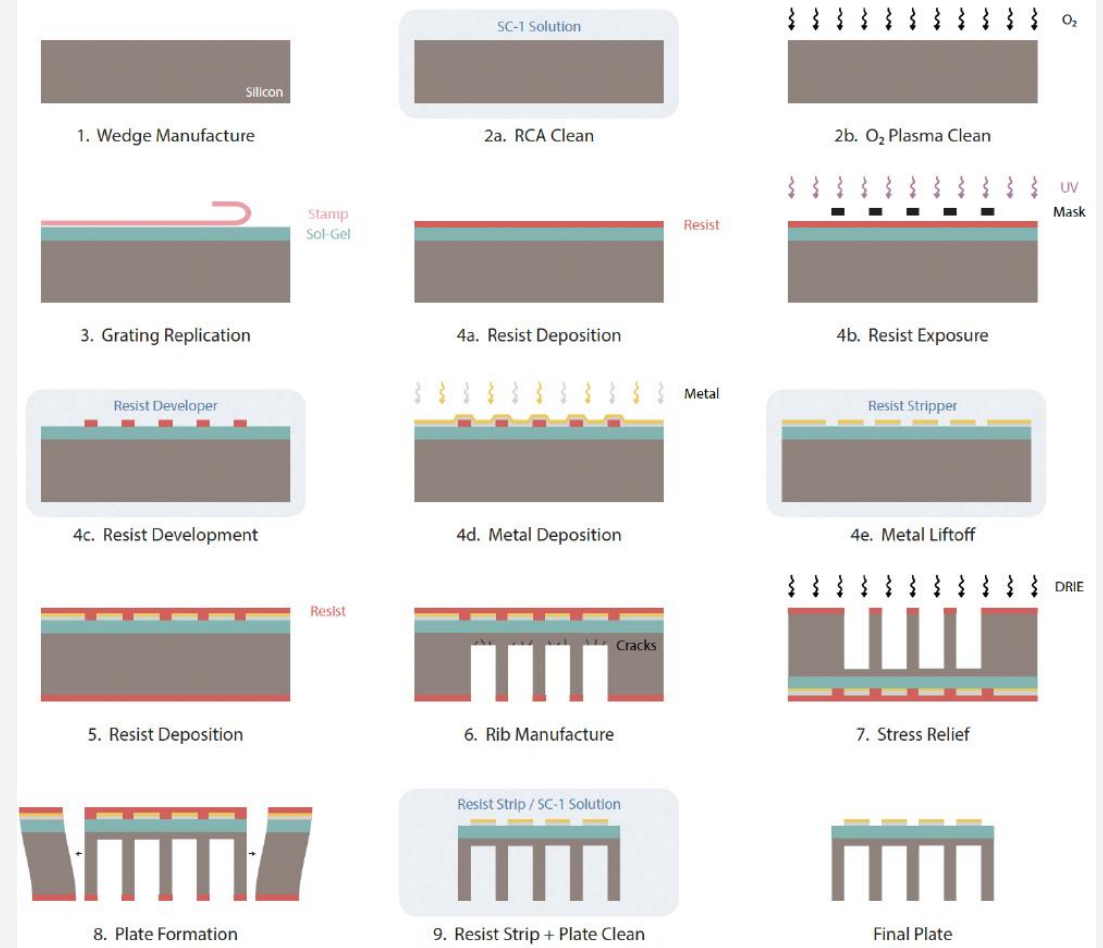


STATE OF X-RAY REFLECTION GRATINGS

Primary focus in active development:
replicating and co-aligning many gratings

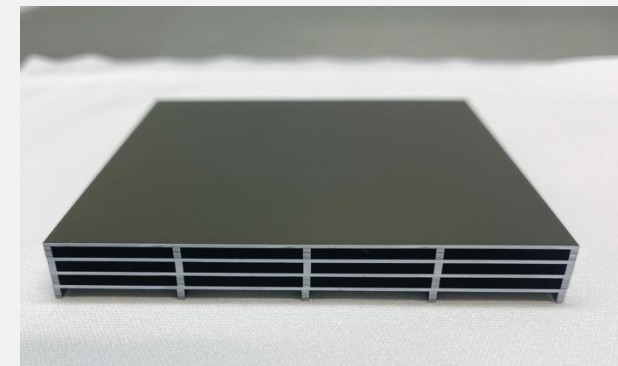
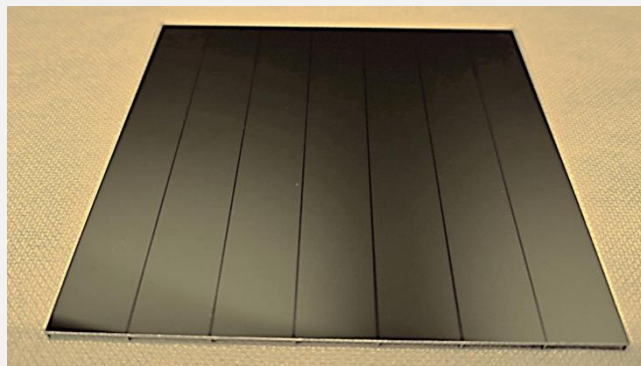
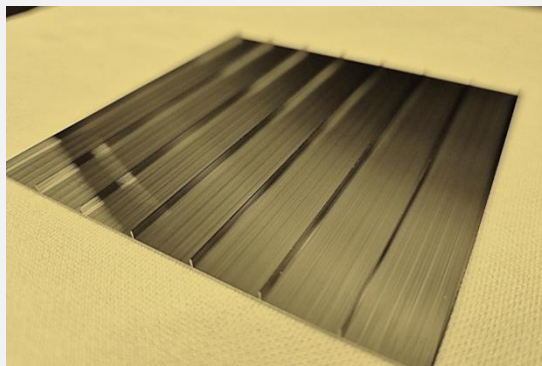


Verschuuren+I8; substrate-conformal imprint lithography (SCIL) – autoSCIL tooling allows hundreds of replicas per day



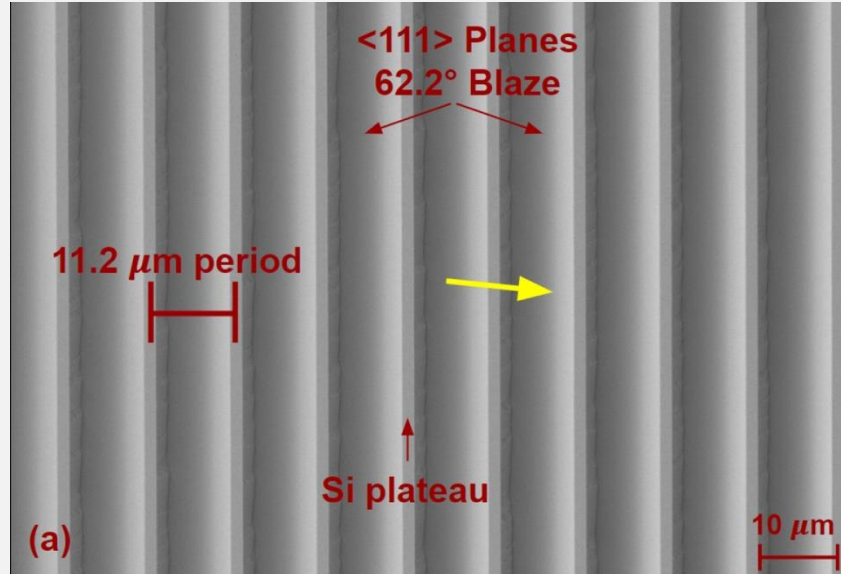
McCoy+25; production of wedged and ribbed grating replicas

NewAthena-like
direct bonding for
grating stack
alignment



STATE OF UV REFLECTION GRATINGS

Tier I Tech Gap: high-efficiency, low-scatter, high- and low-ruling-density, high- and low- blazed-angle UV gratings
 → Custom gratings for wide range of applications

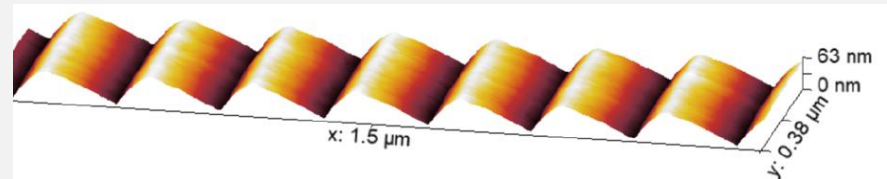


Kruczek+22/26; 63-degree blaze echelle grating, 89 lines/mm, >80% FUV peak-order groove efficiency

See also: EBL Pollux prototype

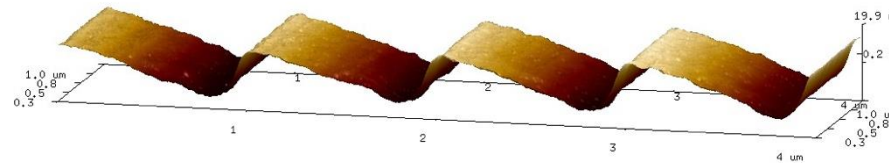


France+19; 4-degree blaze angle with ≈70% peak-order EUV efficiency



Top: IBE-blazed grating with 5000 lines/mm and 20 degree blaze angle

Bottom: TASTE grating with 1000 lines/mm and ≈1.5 degree blaze angle



G20_1 Average density: 6286				G20_2 Average density: 7132				G20_3 Average density: 8297			
5913	6116	6333	6566	6816	7084	7373	7686	8025	8392	8792	
-6.3	-6.5	-6.7	-6.9	-7.2	-7.5	-7.8	-8.1	-8.5	-8.9	-9.3	
5928	6133	6352	6587	6839	7111	7404	7721	8064	8438	8845	
-5.6	-5.8	-6.0	-6.2	-6.4	-6.7	-7.0	-7.2	-7.6	-7.9	-8.3	
5941	6148	6369	6606	6860	7134	7431	7751	8100	8479	8893	
-4.9	-5.1	-5.2	-5.4	-5.6	-5.9	-6.1	-6.4	-6.6	-6.9	-7.3	
5953	6161	6383	6622	6879	7155	7454	7778	8131	8515	8935	
-4.2	-4.4	-4.5	-4.7	-4.9	-5.0	-5.3	-5.5	-5.7	-6.0	-6.3	
5962	6172	6395	6636	6894	7173	7475	7802	8158	8546	8971	
-3.5	-3.6	-3.8	-3.9	-4.1	-4.2	-4.4	-4.6	-4.8	-5.0	-5.3	
5971	6181	6406	6647	6907	7188	7491	7821	8180	8572	9001	
-2.8	-2.9	-3.0	-3.2	-3.3	-3.4	-3.5	-3.7	-3.9	-4.0	-4.2	
5977	6188	6414	6656	6917	7199	7505	7836	8198	8592	9026	
-2.1	-2.2	-2.3	-2.4	-2.5	-2.6	-2.7	-2.8	-2.9	-3.1	-3.2	
5981	6193	6419	6663	6925	7208	7515	7848	8211	8608	9044	
-1.5	-1.5	-1.6	-1.6	-1.7	-1.8	-1.8	-1.9	-2.0	-2.1	-2.2	
5984	6196	6423	6667	6930	7213	7521	7855	8219	8618	9055	
-0.8	-0.8	-0.8	-0.9	-0.9	-0.9	-1.0	-1.0	-1.1	-1.1	-1.2	
5985	6197	6424	6668	6931	7216	7523	7858	8223	8622	9061	
-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	

Location (mm)	Measured Period (nm)	Design Period (nm)	Difference (nm)
0.5	134.1 ± 1.3	133.5	0.6
20	138.1 ± 1.9	137.4	0.7
25	139.3 ± 2.0	138.5	0.8
35	141.4 ± 0.7	140.6	0.8
45	143.4 ± 1.6	142.8	0.6
65	147.2 ± 1.1	146.9	0.3
75	149.5 ± 1.5	149.1	0.4
78	150.3 ± 2.6	149.7	0.6

Grise+21; high ruling density, aberration-correcting profile for ESCAPE concept

SUMMARY AND PATH FORWARD

- Individual X-ray reflection gratings are capable of meeting requirements for next-gen X-ray flagship missions
- Focused development on manufacturing pipeline: high-performance grating masters, high-volume replication, and efficient alignment
- UV gratings demonstrating high efficiency for high- and low-blaze angles, patterning from ≈ 90 – 9000 lines/mm, and aberration-correcting groove layouts
- Active SAT program for IBE/TASTE development, and several proposed infusion opportunities

**See Grisé poster on UV grating fabrication and
Miles poster for more X-ray/UV details**