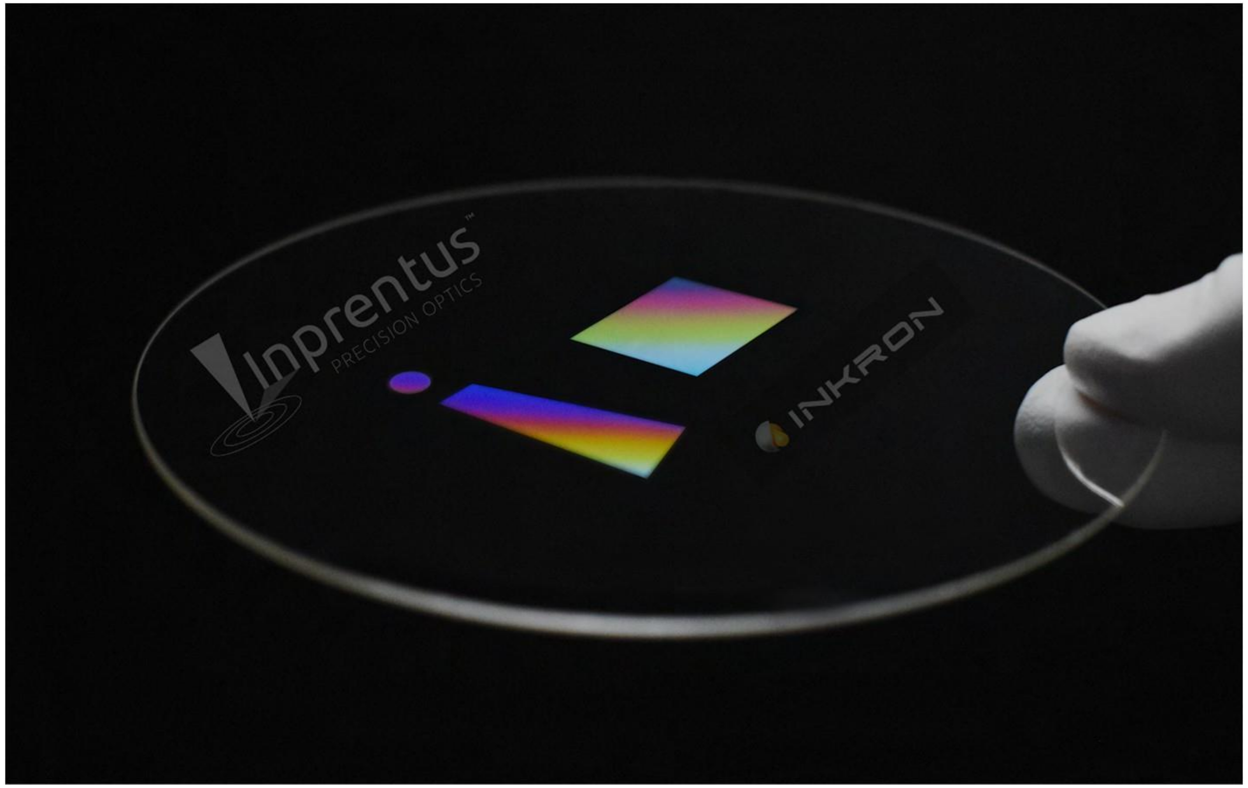
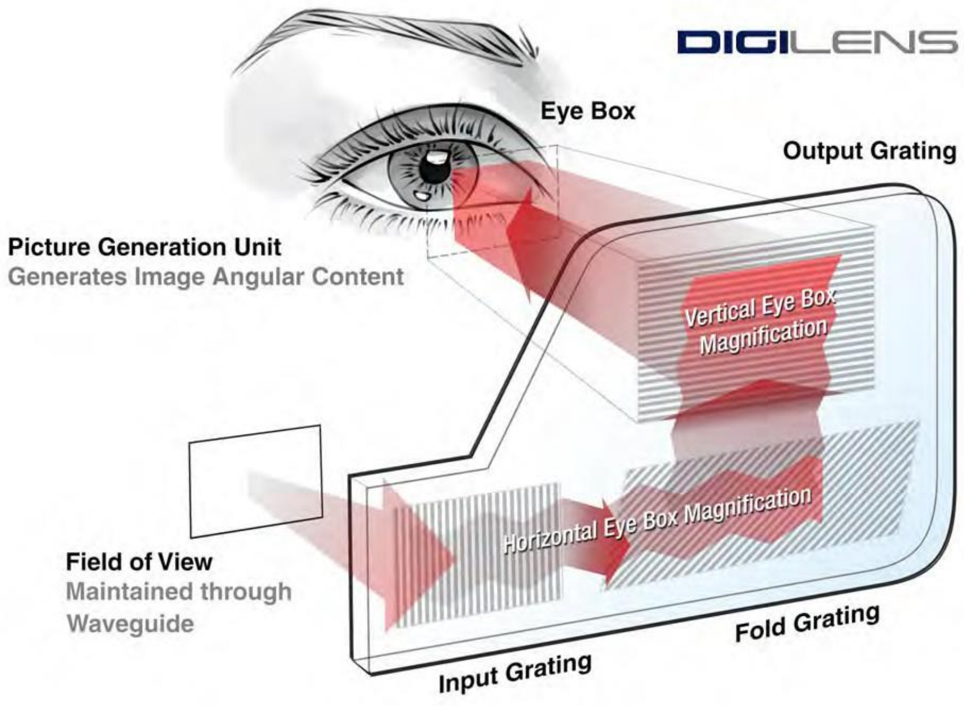
Inprentus™
PRECISION OPTICS
(founded: 2012)

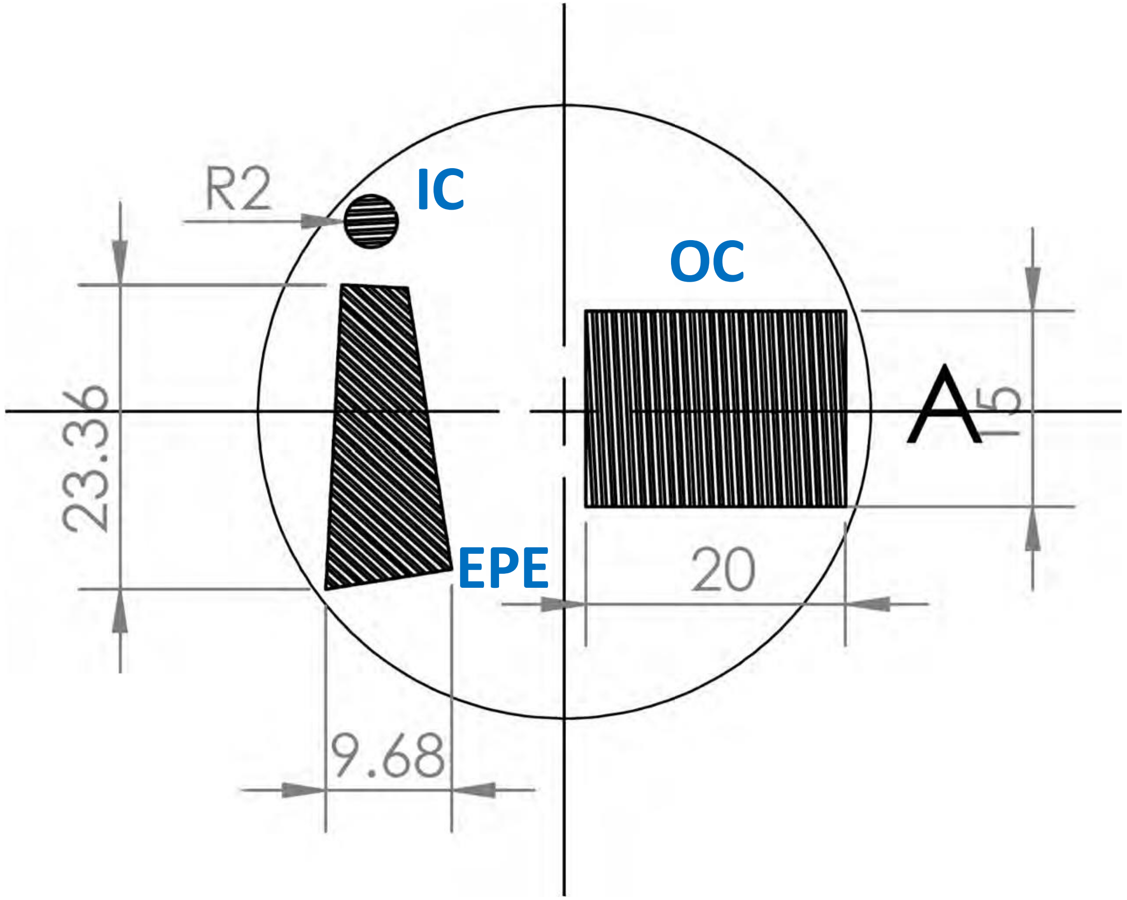


Blazed gratings for AR made by contact-mode lithography

Peter Abbamonte
Inprentus, Inc.
University of Illinois, Urbana-Champaign
Champaign, IL, USA

AR eyepiece = beam expanding periscope



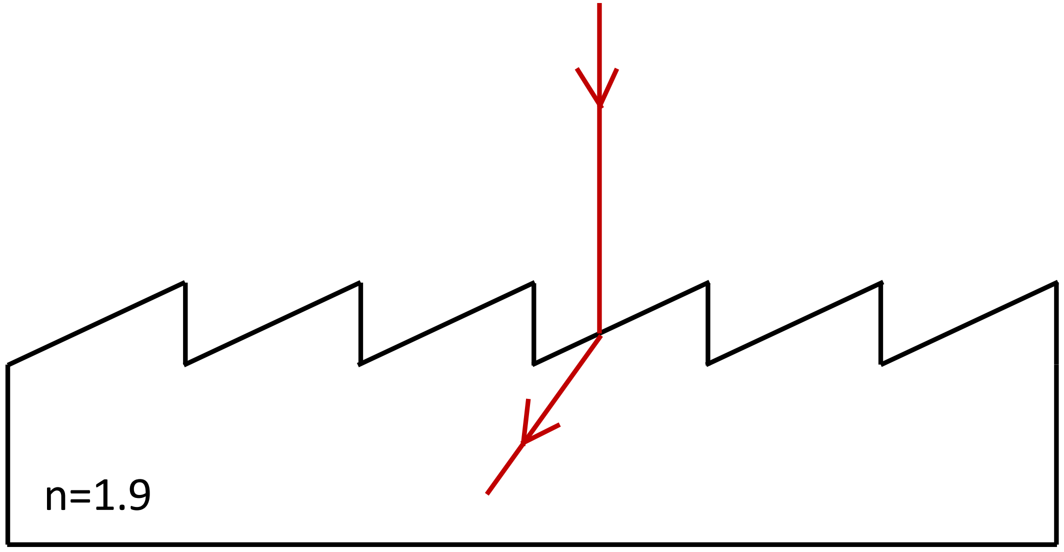


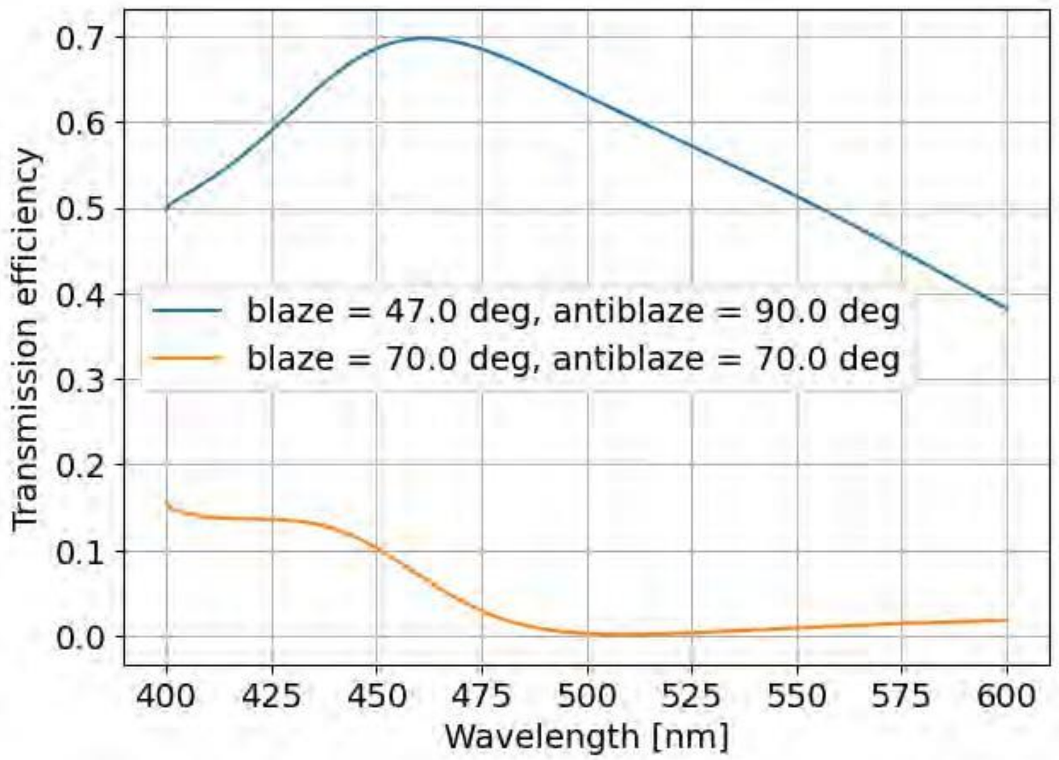
Grating Properties:

- **Controllable efficiency (high or low)**
- **High directionality**
- **Pitch uniformity Δd<100 pm**
- **Modulation**
- **Simple (all patterns same setup)**
- **Easy to replicate**

B. C. Kress, I. Chatterjee, Nanophotonics, **10**, 41-74 (2021)

Blazed gratings are tunable

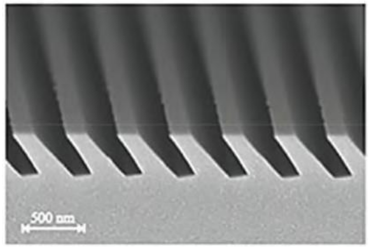




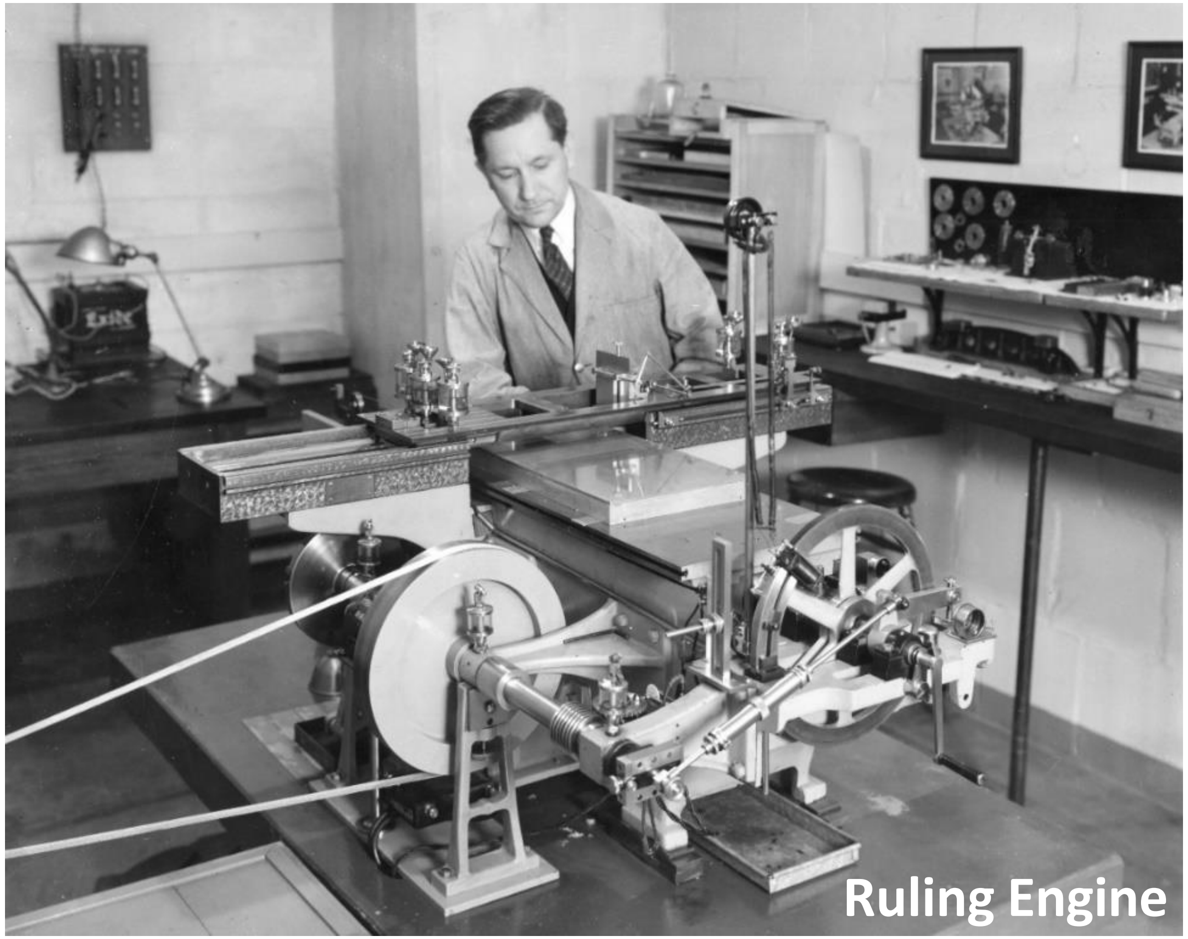
- **Tunable wavelength response (high or low efficiency)**
- **Left-right asymmetry**
- **Easy to replicate**

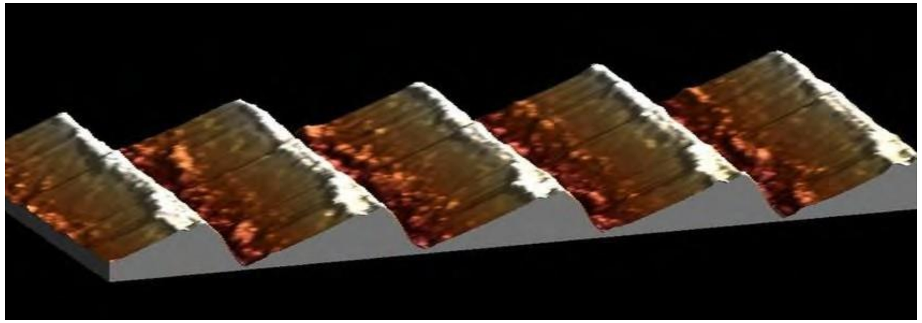
How can we make blazed gratings for AR?

EBL or DUV?



How are blazed gratings made?



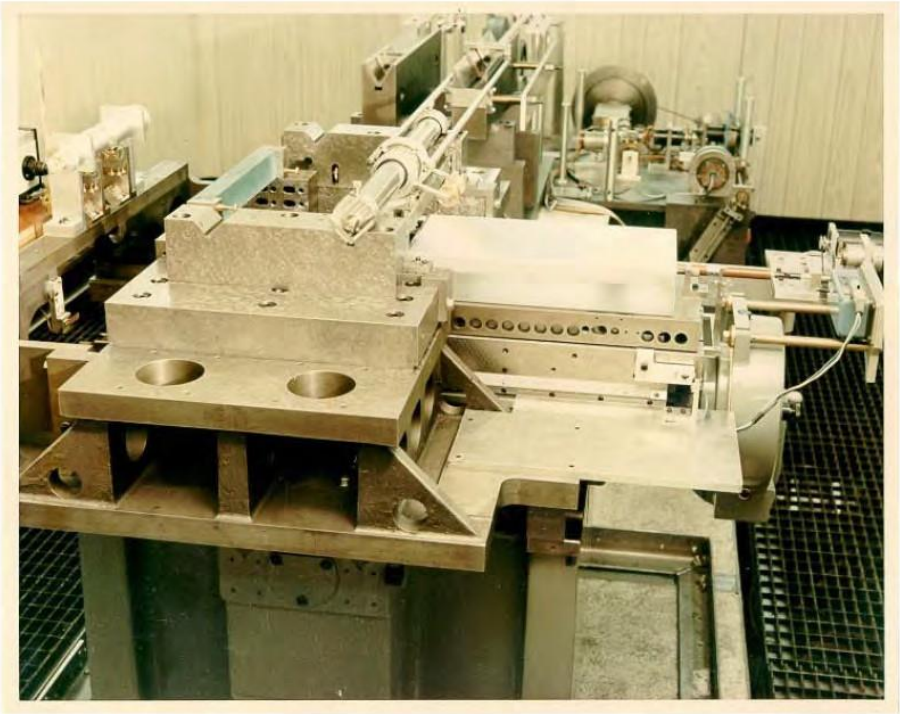


Mechanical ruling:

- Since the 1880's
- Pitch = 170 nm ~ 10 microns
- Mass market replication since 1960s
- Purchased online: Newport, Thorlabs (probably Amazon)

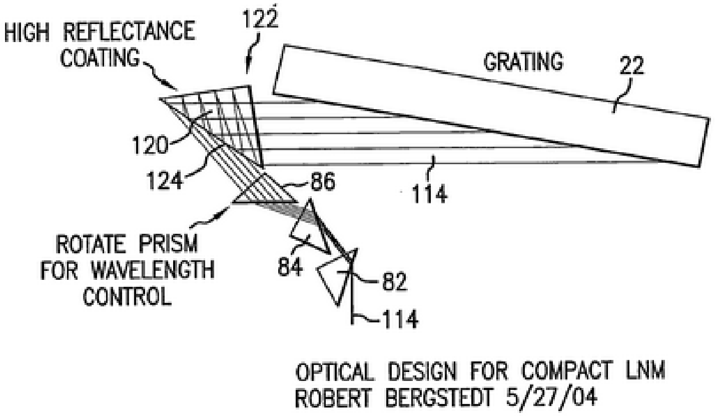
C. Palmer, E. Loewen, *Diffraction grating handbook, 7th Ed.* (Newport Corporation, Rochester, NY, 2014)

We all use mechanically ruled gratings



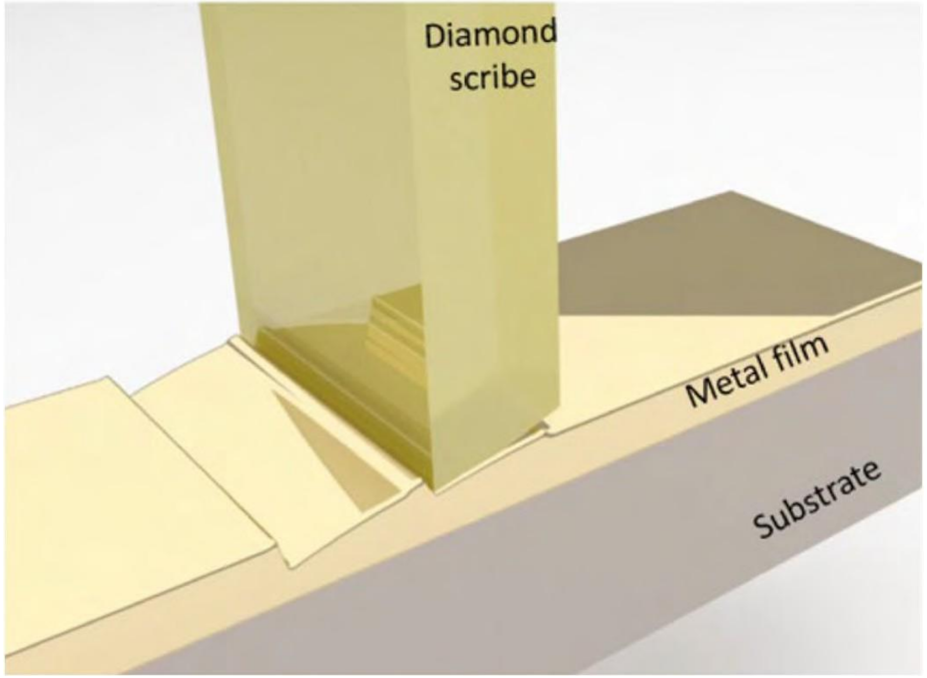
MIT B Engine, Richardson Gratings, Rochester, NY

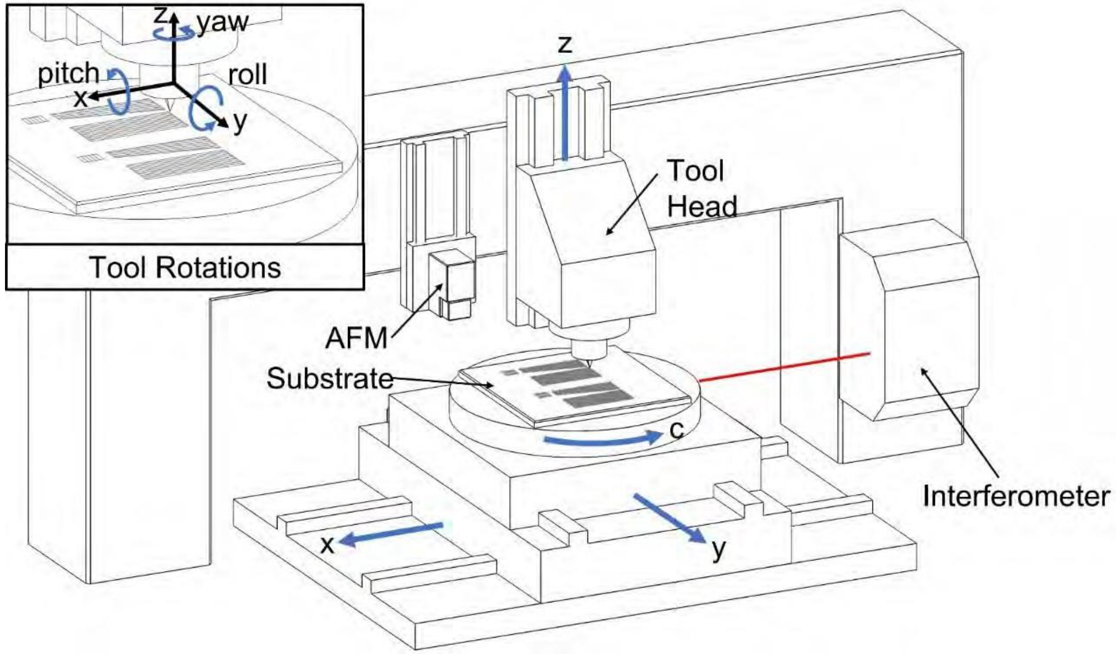
Line Narrowing Module (Cymer) U.S. Patent 8126027B2



- **DUV gratings replicated from masters ruled on MIT B Engine (above)**
- **Built by G. R. Harrison 1960s**
- **Owned by Newport (owned by MKS)**
- **Harrison passed 1979 :(**

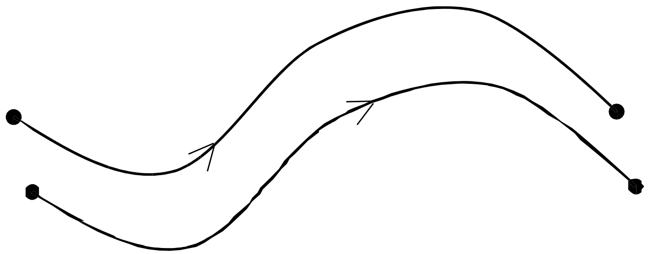
Reinventing the ruling engine



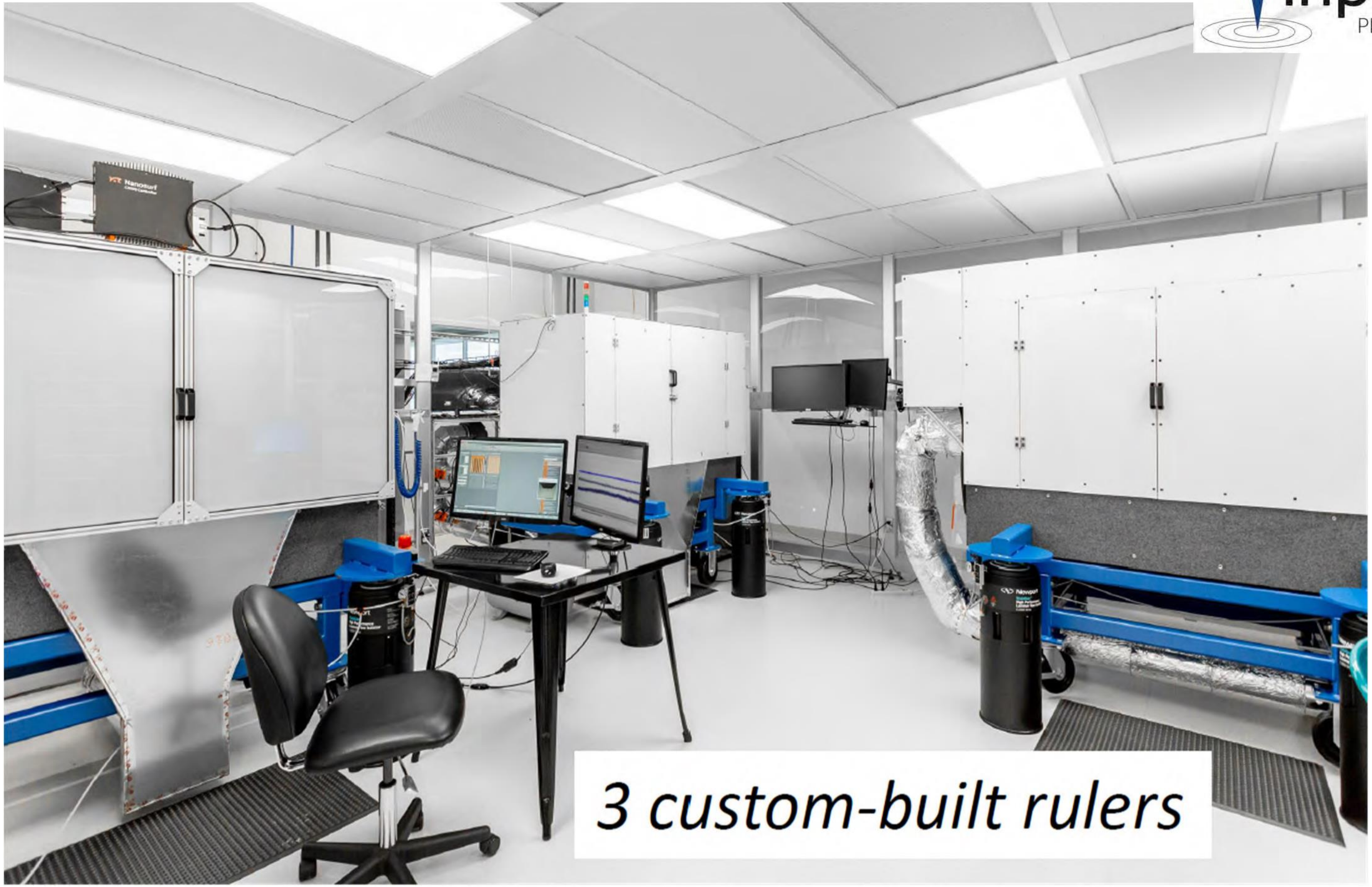


- **7-axis CNC instrument (scriptable)**
- **Serial write (one groove at a time)**
- **Grooves curved, modulated, aperiodic**
- **No write fields**
- **4”-8” wafers, optical flats, etc.**

$$\vec{\xi}(t) = \left(x(t),\ y(t), c(t),\ p(t),\ y(t), r(t),\ F(t)\right)$$



How Inprentus makes gratings

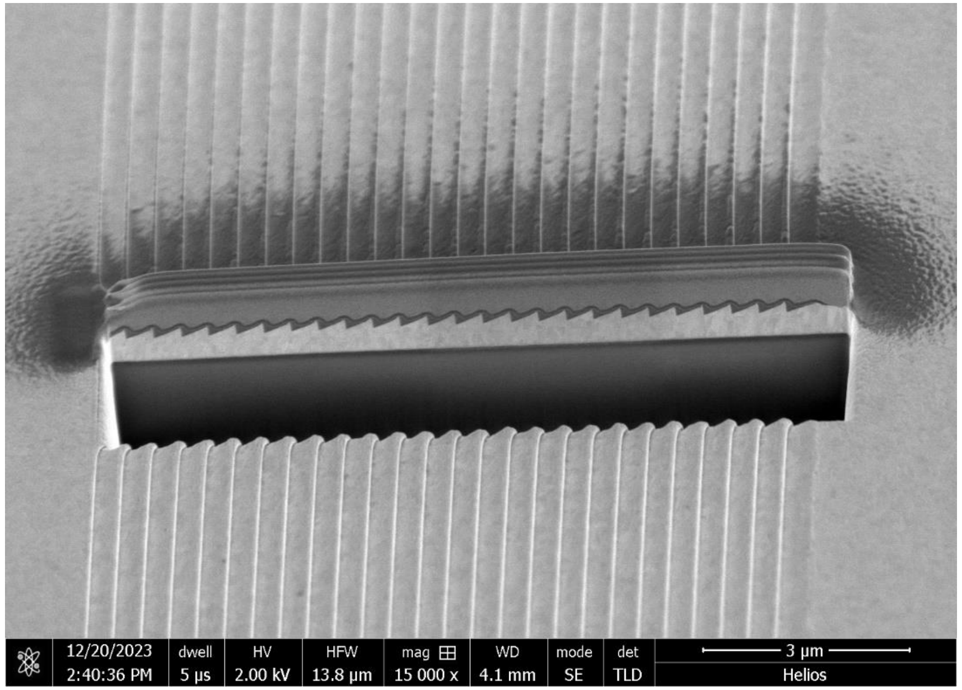


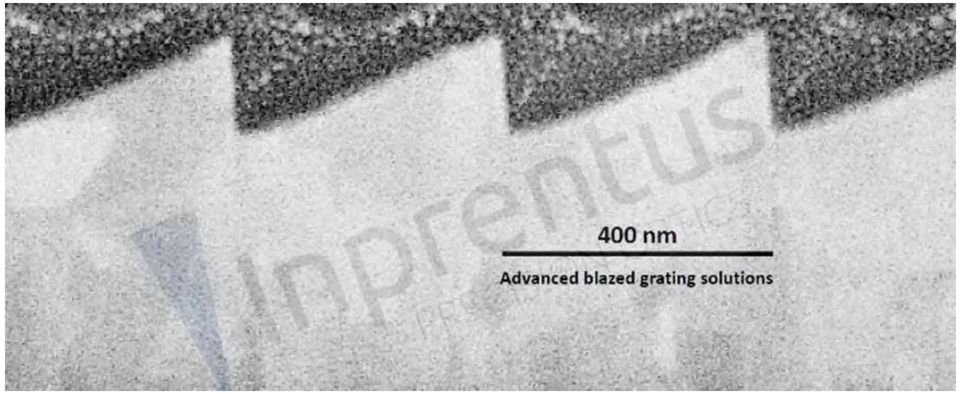
How Inprentus makes gratings

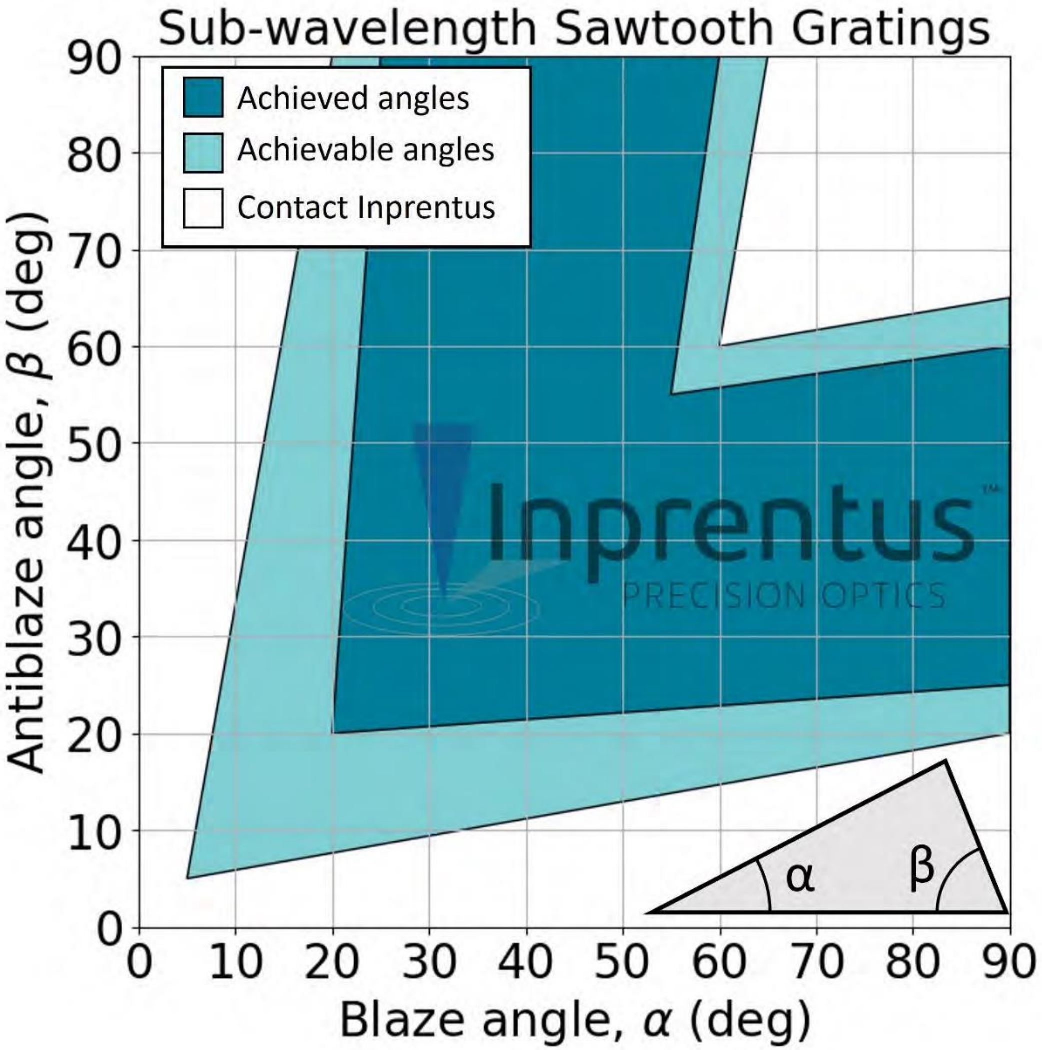
Inprentus
PRECISION OPTICS

Groove shapes

Helios NanoLab 600i DualBeam FIB:

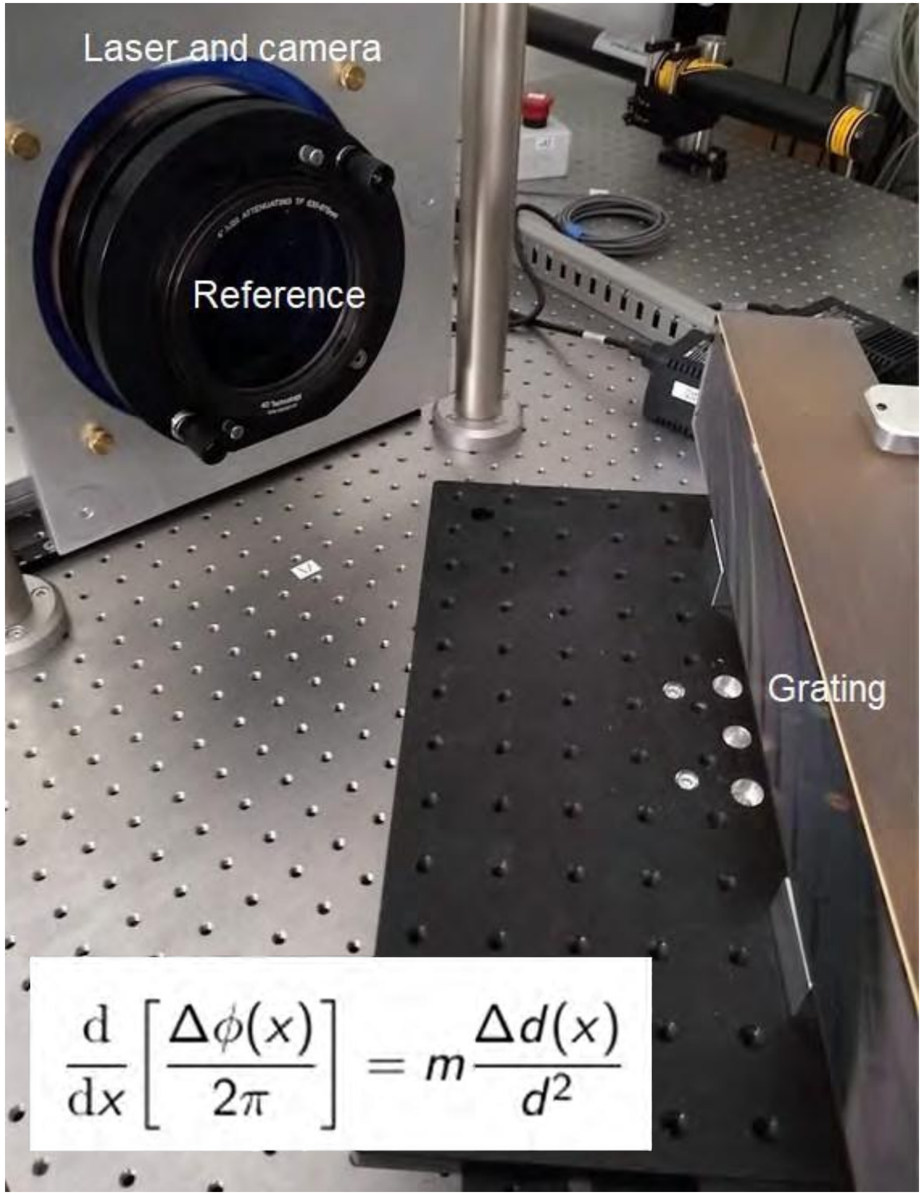




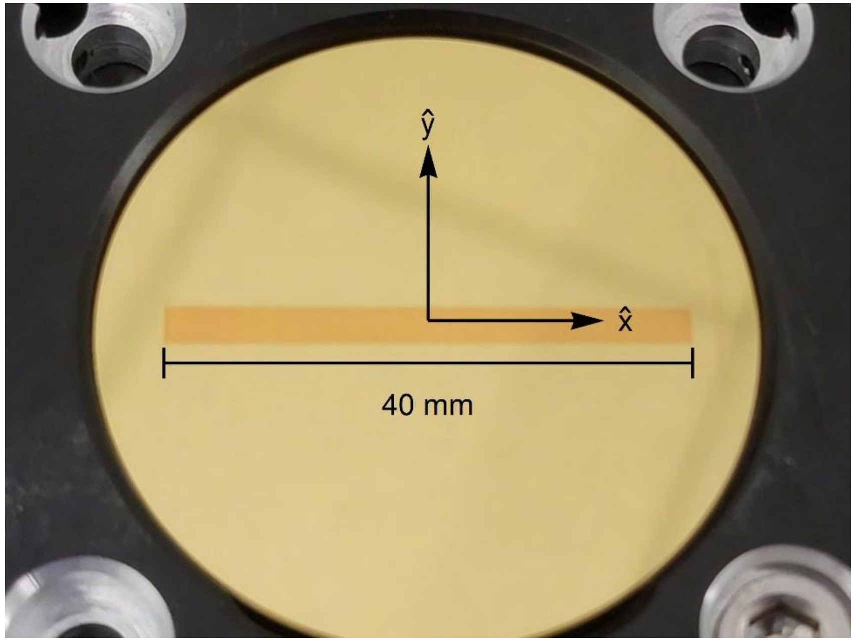


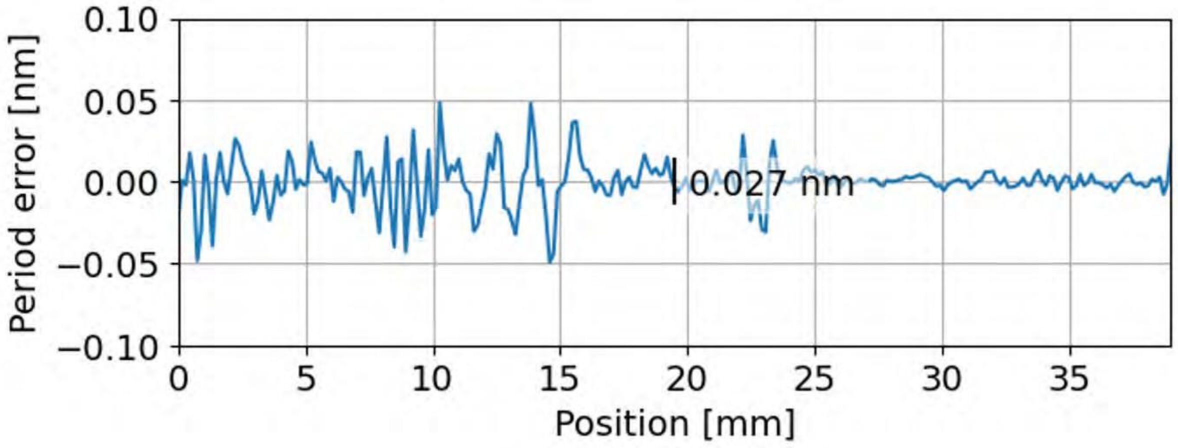
The Grainger College of Engineering
Materials Research Laboratory
UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

Pitch Uniformity by Fizeau Interferometry



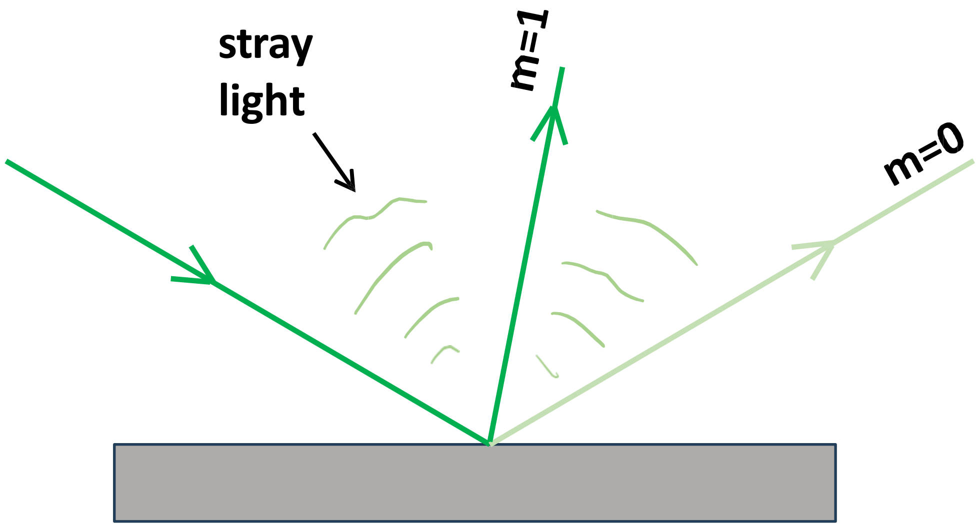
$$\frac{\mathrm{d}}{\mathrm{d}x}\left[\frac{\Delta\phi(x)}{2\pi}\right] = m\frac{\Delta d(x)}{d^2}$$

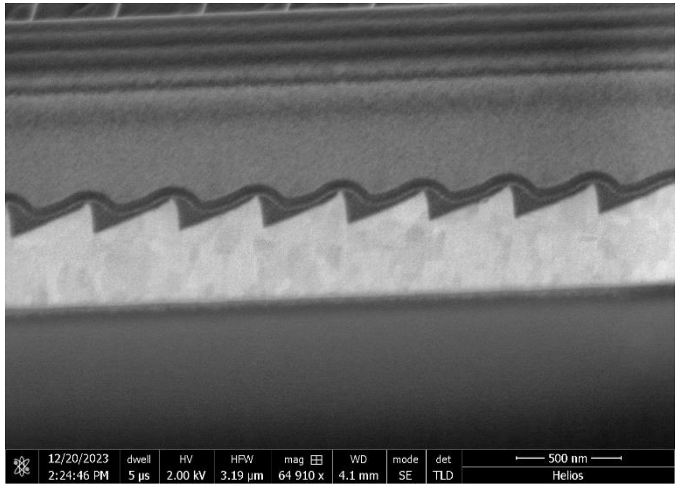


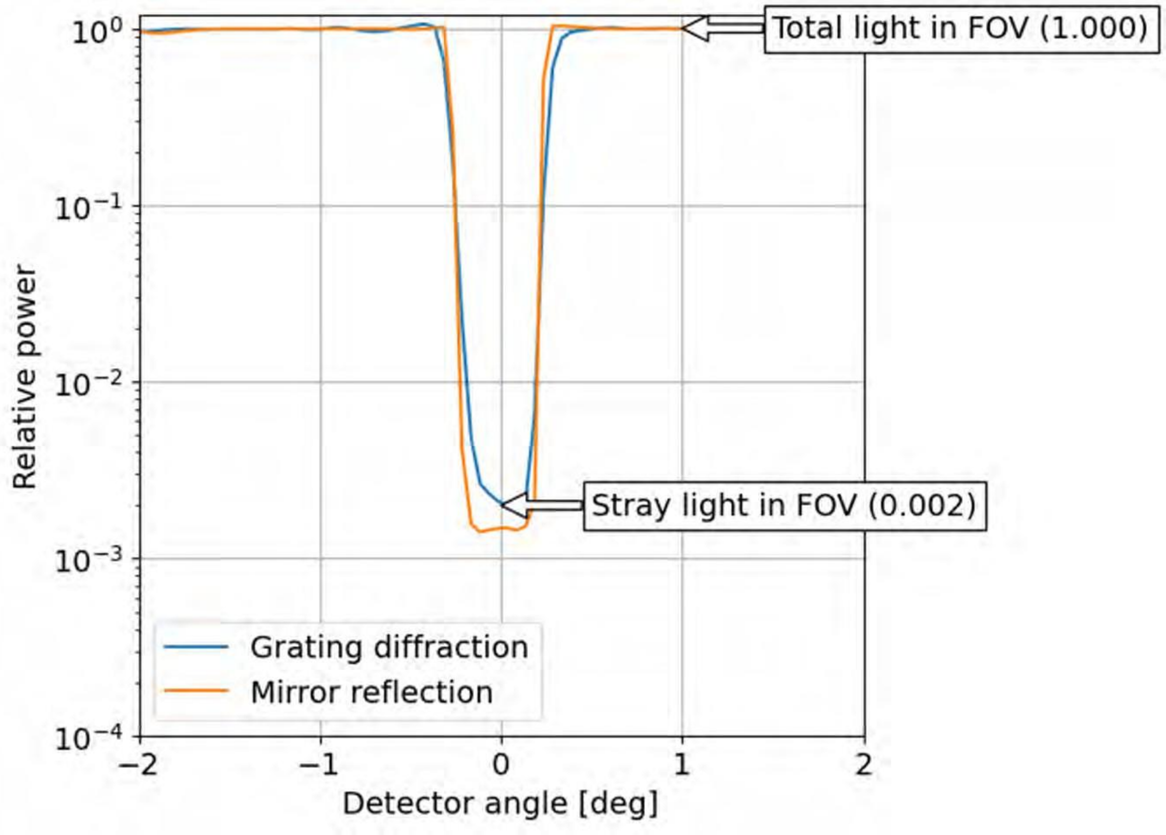


Δd = 27 pm

Low stray light ("haze")





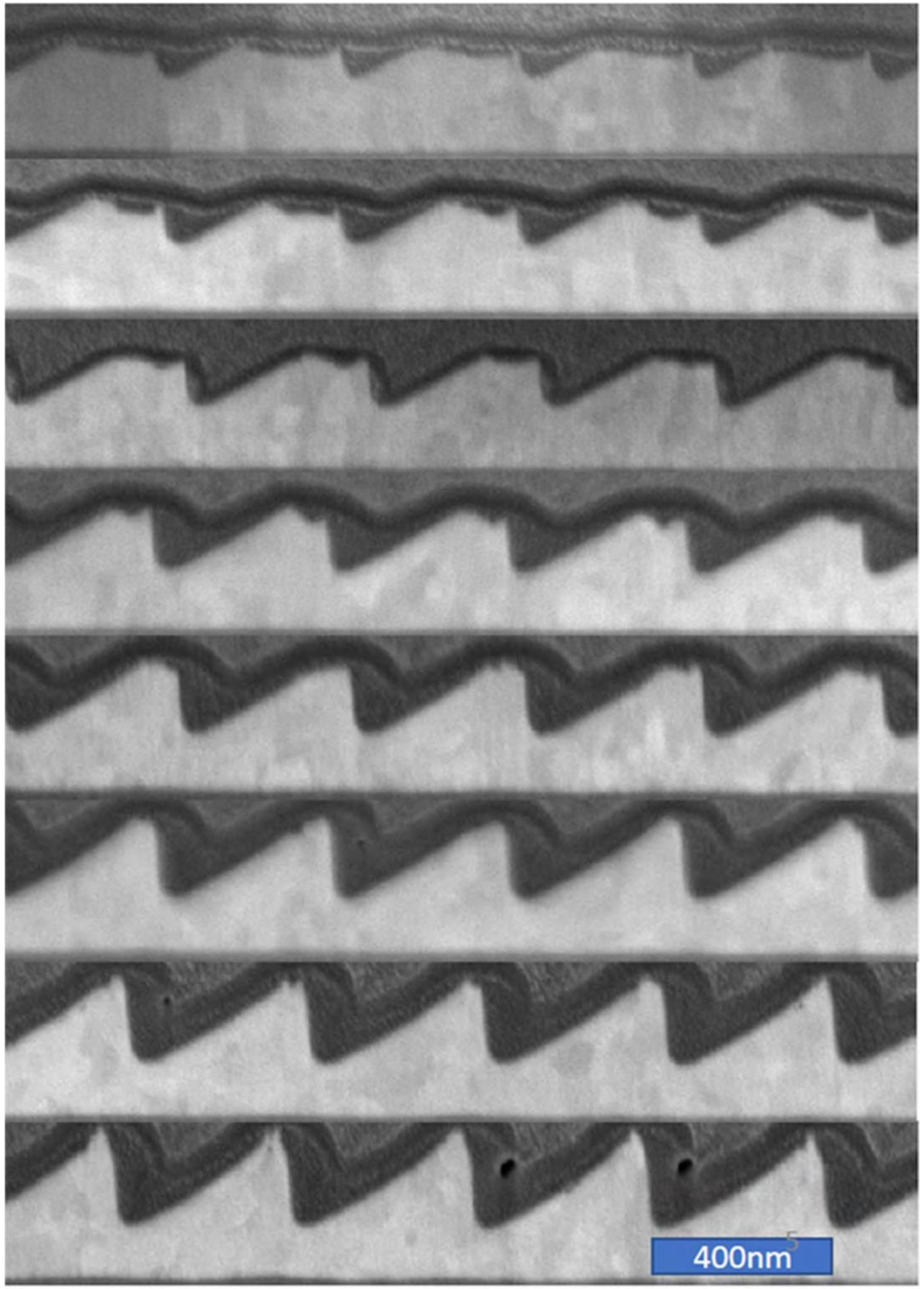


Integrated stray light level (2π steradian) = 0.2%

***This measurement is available as a service.**

Duty cycle modulation

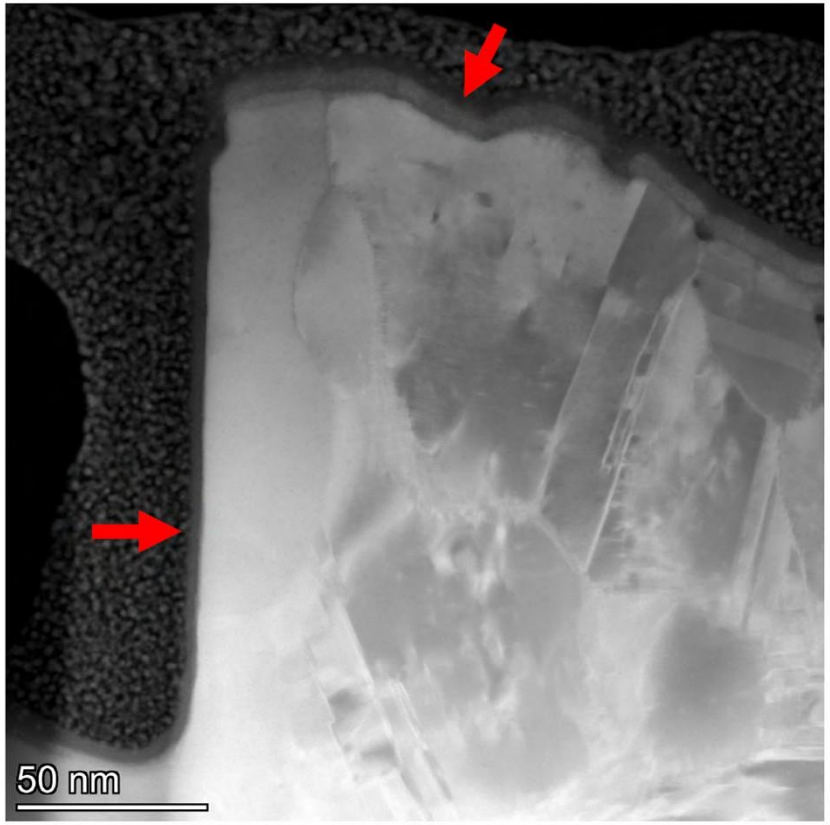
- Lines ruled serially $\Rightarrow$ modulation schemes natural
- Currently doing force modulation
- Other schemes possible (e.g., angle)
- *(Best data are under NDA)*



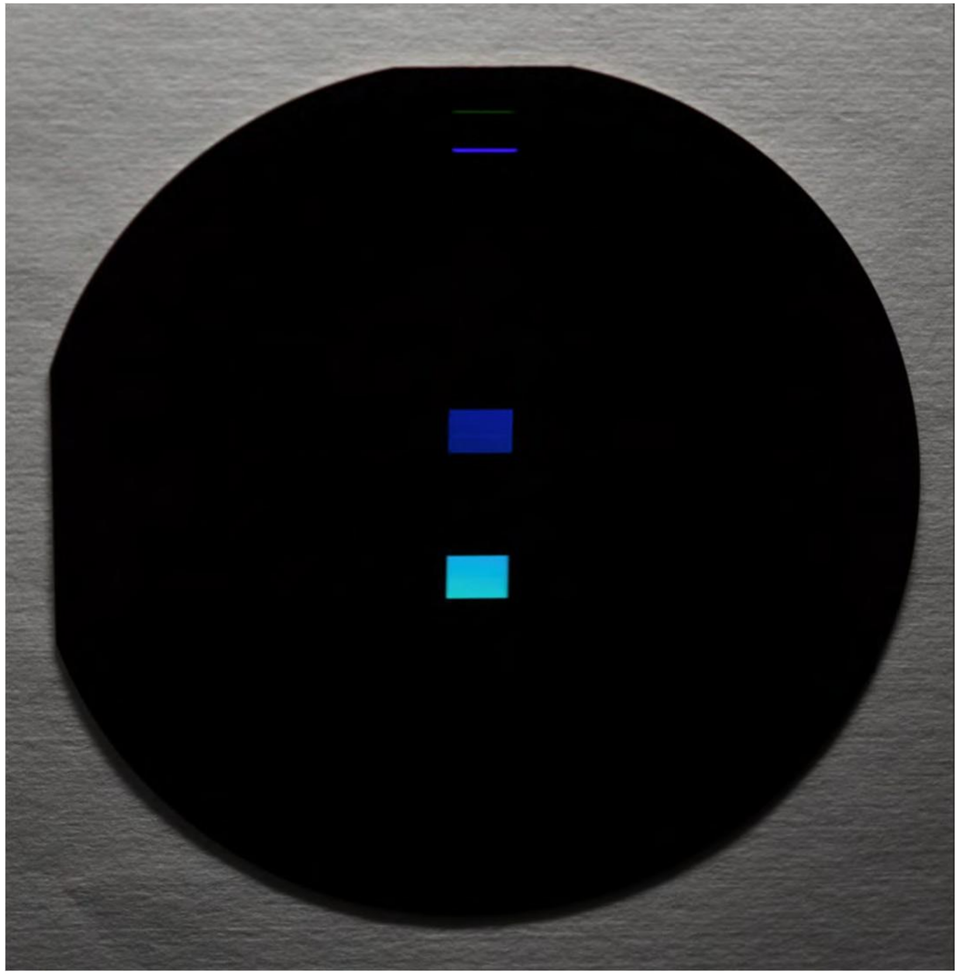
Replication – Inkron & EVG

Sputter surface with 10 nm Ta (done at Inprentus)

These coatings are *conformal*:

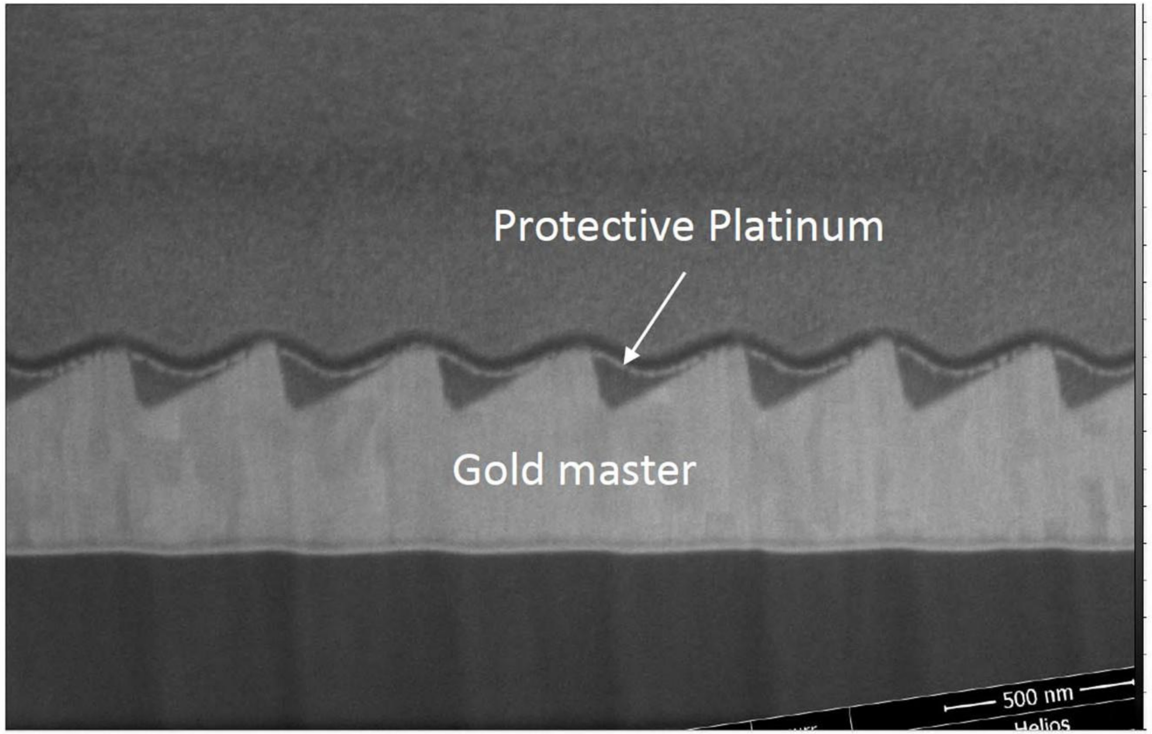


Input-output pair (400 nm pitch) on 6" wafer:

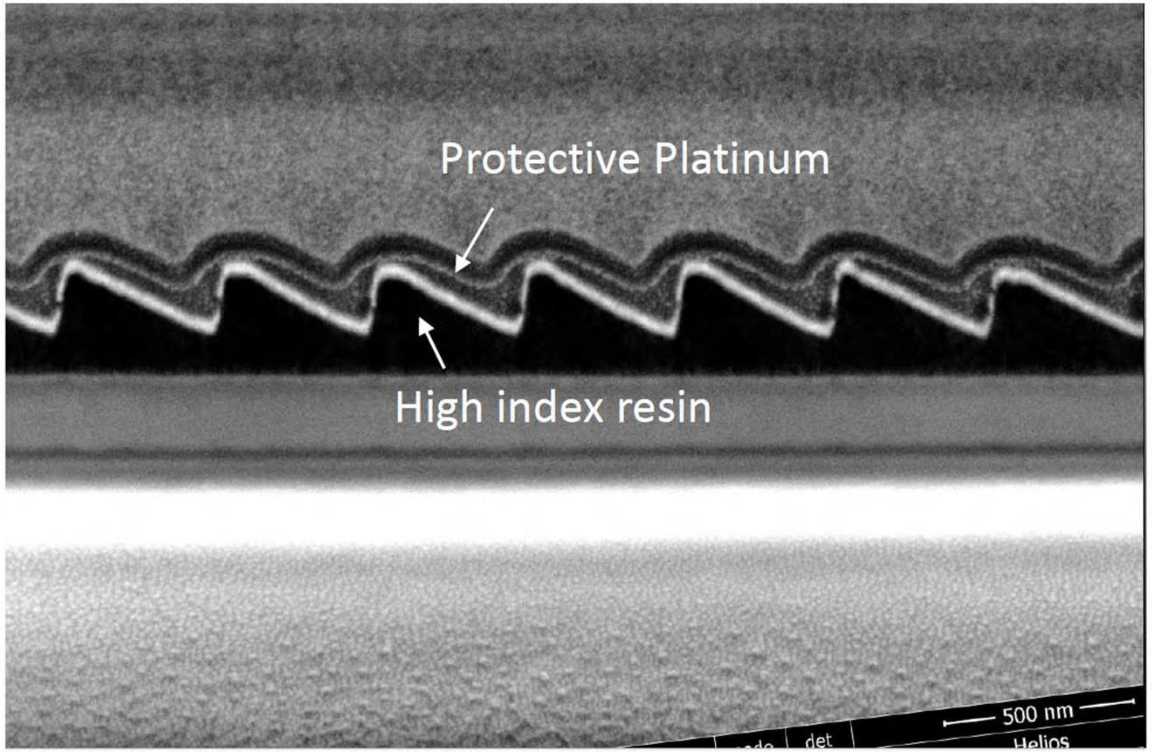


Replication

d=400 nm master ruled in Au



Transparent replica on n=1.9 resin



- **Ruled in Au**
- **10 nm conformal Ta coating**
- **Standard SmartNIL process using EVG 7200 UV System**
- **Replica *n*=1.9 resin**
- **On *n*=1.9 Schott glass**

INKRON
NAGASE Group

Summary

Accepting orders:

- Masters
- Low-volume replicas (n=1.9 waveguides)

Seeking partners:

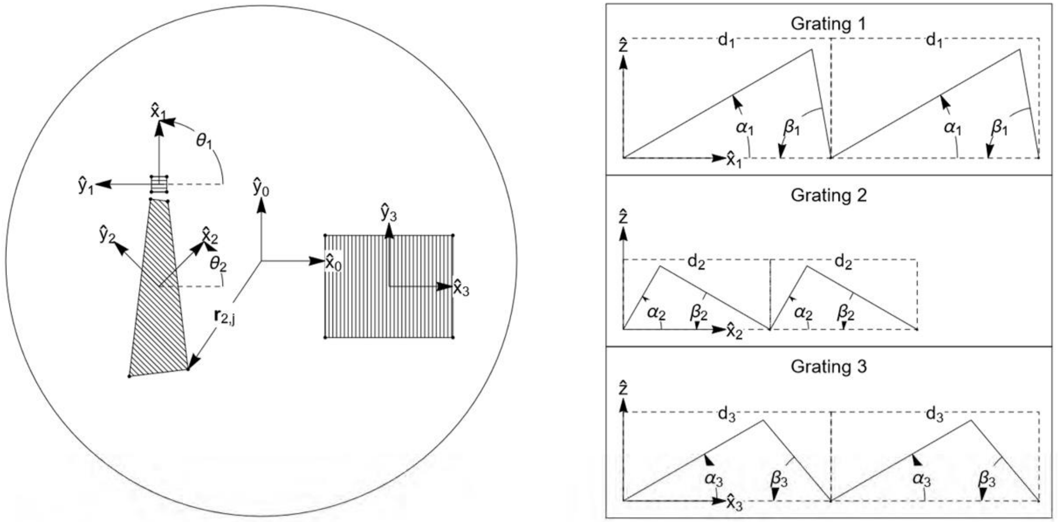
- Integration
- Field testing

Seeking financing:

- Convertible note
- Equity round planned for later this year

Inprentus waveguide order form:

https://www.inprentus.com/augmented-reality-waveguide-masters



Symbol	Meaning
$\hat{\mathbf{z}}$	Substrate normal
$\hat{\mathbf{x}}_0, \hat{\mathbf{y}}_0$	Substrate-surface basis
$\hat{\mathbf{x}}_i$	Dispersive direction of ith grating
$\hat{\mathbf{y}}_i$	Non-dispersive direction of ith grating
d_i	Period of ith grating
α_i	First groove-facet angle, relative to substrate surface, of ith grating
β_i	Second groove-facet angle, relative to substrate surface, of ith grating
θ_i	Angle between $\hat{\mathbf{x}}_i$ and $\hat{\mathbf{x}}_0$
$\mathbf{r}_{i,j}$	For the ith grating, location of jth vertex, relative to substrate origin

Figure 1: Geometric parameters employed in the specification worksheet. The example gratings shown here are for illustration.