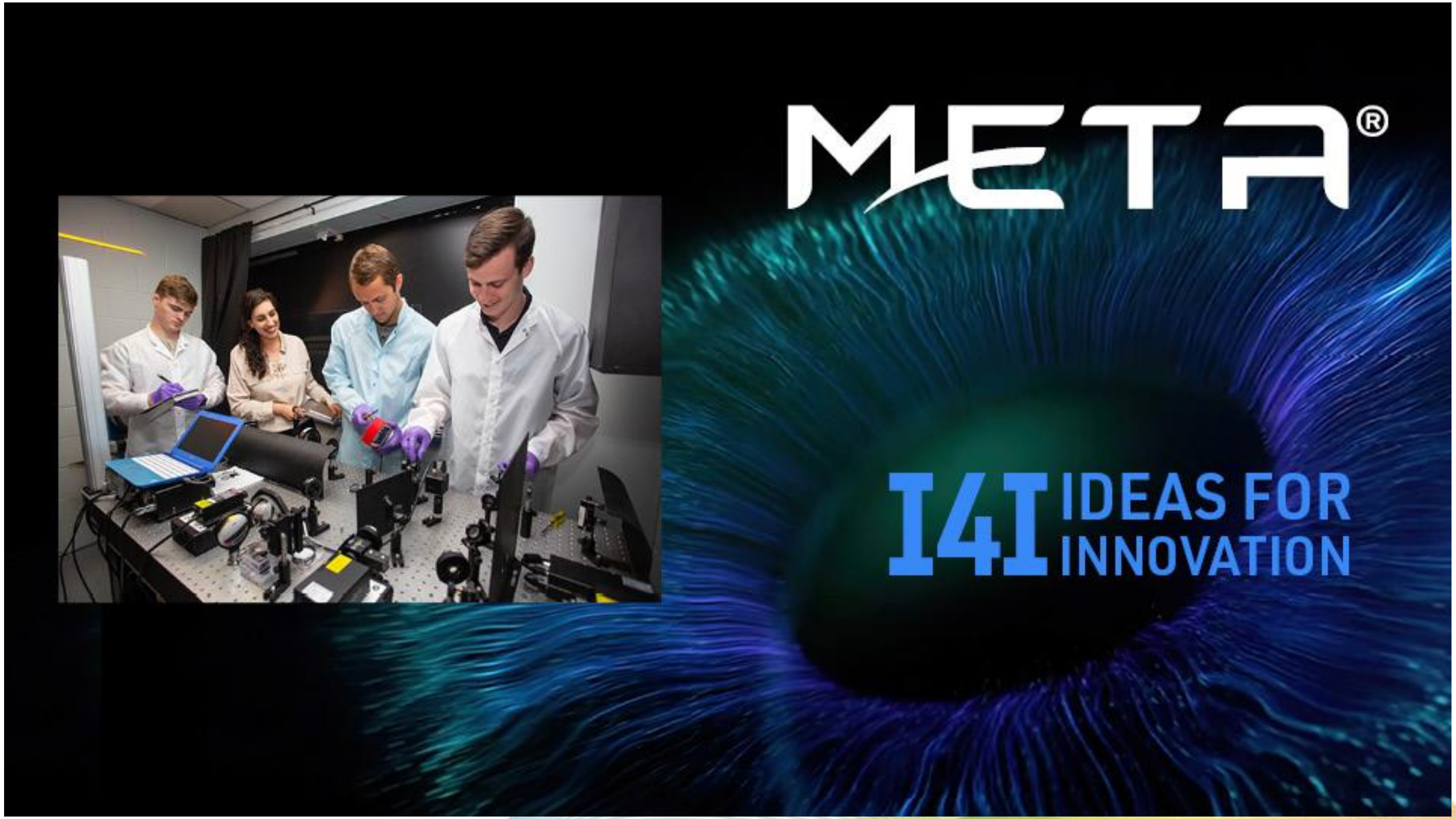
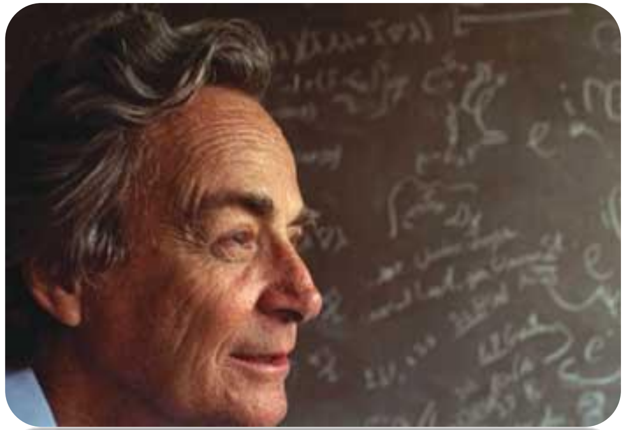
Functional Materials at Scale

Sep 2021AD

Outline

- Why functional materials at scale?
- About META
- Metamaterials 2014
- Example application: Holographic Laser Eye Protection
- META Applications
- Large Scale Manufacturing
- Learnings
- Ideas for Innovation


META®
I4I IDEAS FOR INNOVATION

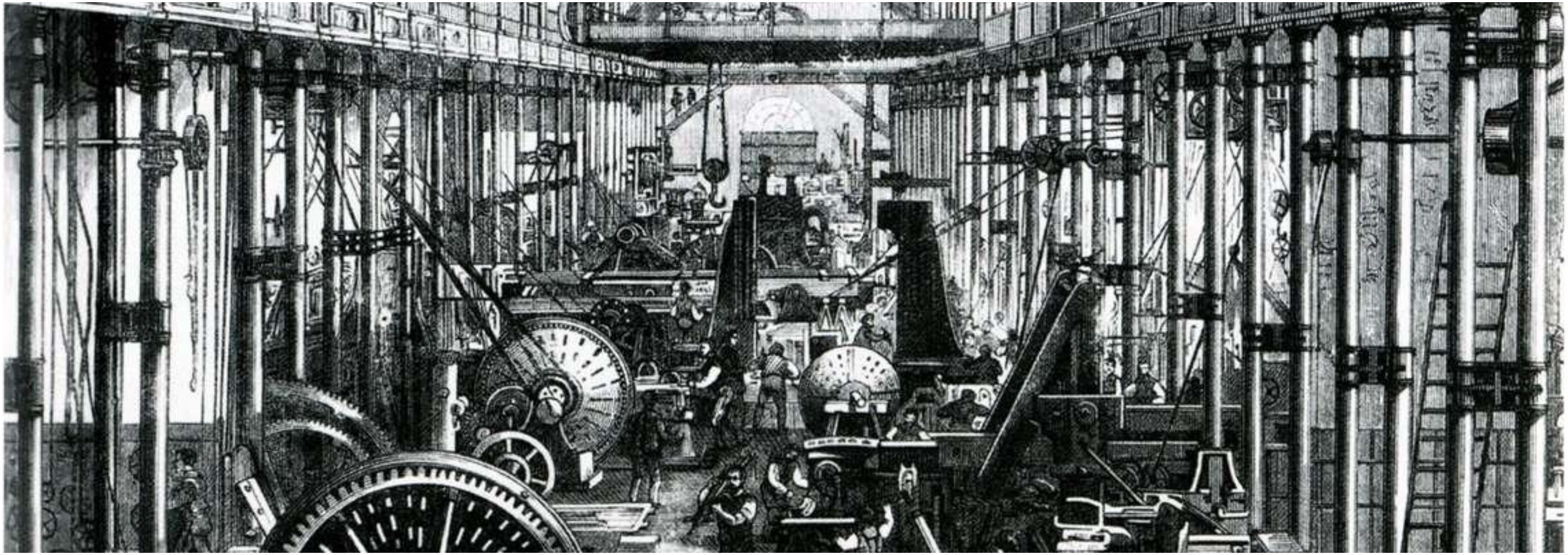


"I can't see what exactly would happen,

but when we have some control of the arrangement of things in the small scale,

we will get an enormously greater range of possible properties that substances can have."

1959



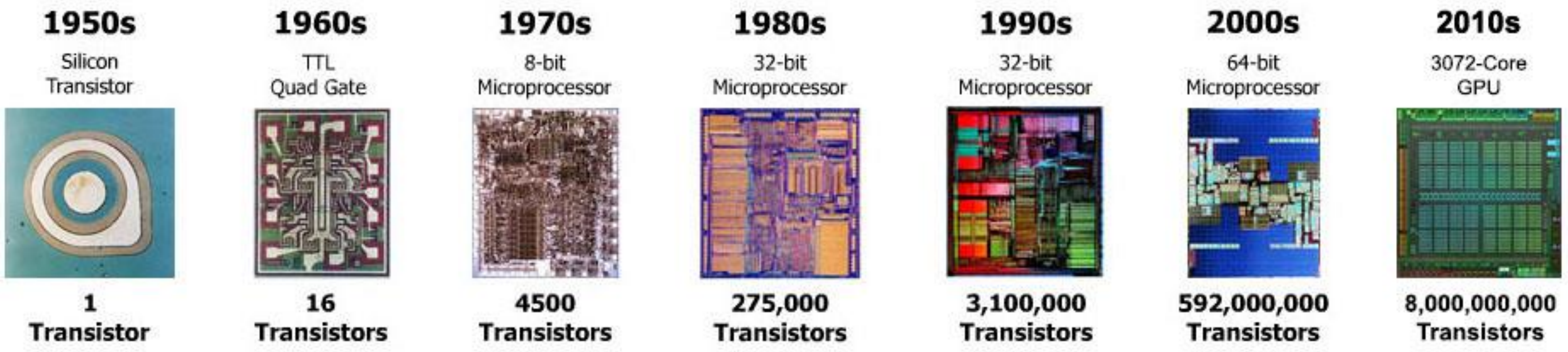


Image Source: Computer History Museum

About META

META
Go Beyond.

The META Timeline

2021	1st Metamaterial Company on NASDAQ
2011	META Founded
2000	Negative Refraction Demonstrated
1968	Veselago's Paper
1865	Maxwell's Equations
1492 AD	America Discovered
55 BCE	Romans invade Britain
776 BCE	First Olympiad
3000 BCE	Great Pyramid Built
10,000 BCE	Farming
200,000 BCE	Early Humans

Global Footprint

Halifax, Nova Scotia, Canada
Head Office
Research and development
Manufacturing facility

London, England, United Kingdom
~~EU~~ Europe Sales office
Research and Development

Boston, MA, Unite States
USA HQ

Pleasanton, California, United States
U.S.A. sales office
Research and development head office

Minato-ku, Tokyo, Japan
Cornes Technologies Ltd.
Japan sales office

Copenhagen, Denmark
SATAIR (Airbus subsidiary)
Sales distribution partner

META®

Key Partnerships

LOCKHEED MARTIN

enel Green Power

Caltech

covestro

CORNES Technologies

Stanford University

DALHOUSIE UNIVERSITY

Universiteit Leiden The Netherlands

UNIVERSITY OF TORONTO

SATAIR

AIRBUS

SUSTAINABLE DEVELOPMENT TECHNOLOGY CANADA

NSERC Green Electronics Network

Metamaterials 2014

Copenhagen, Denmark

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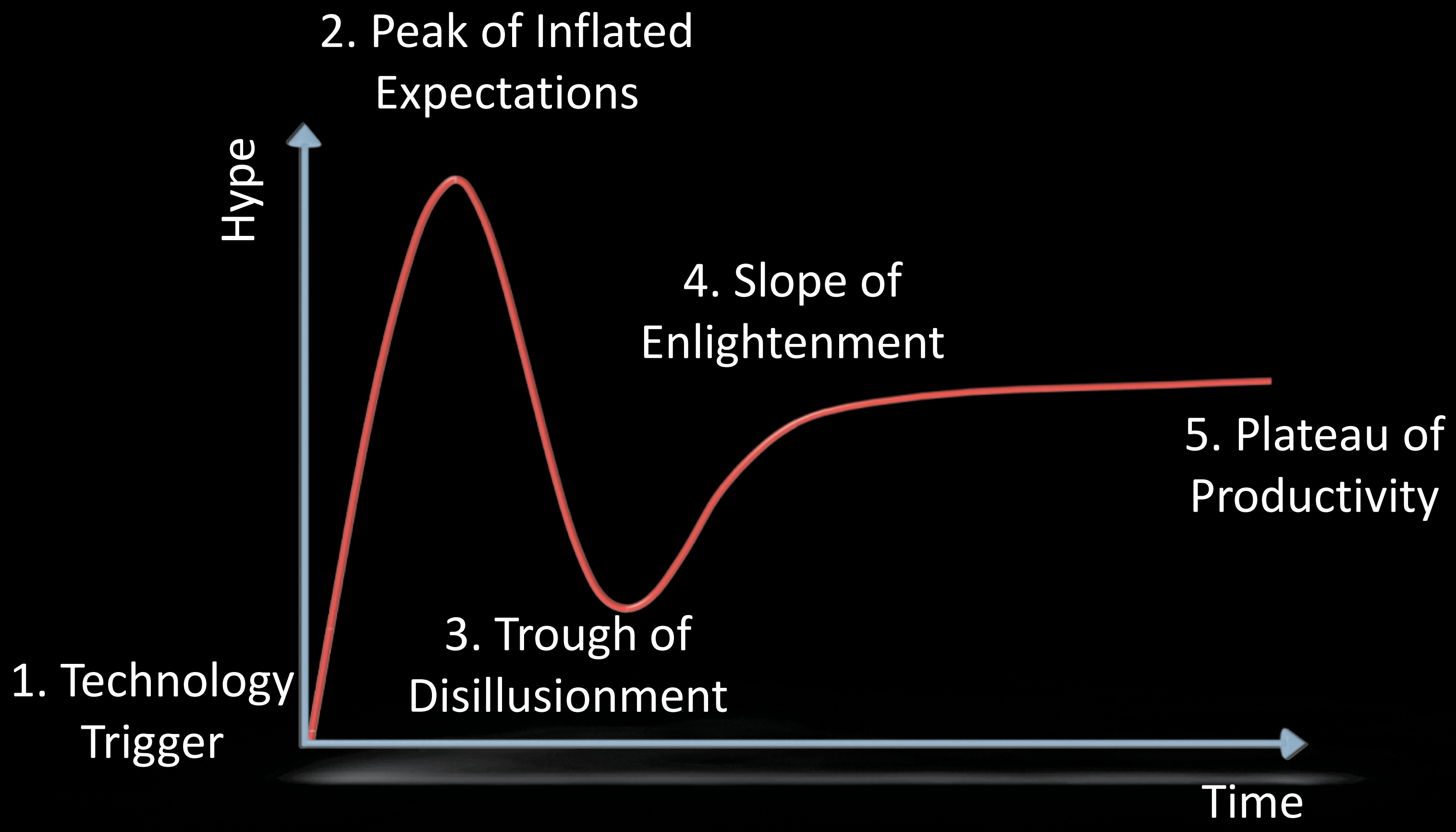
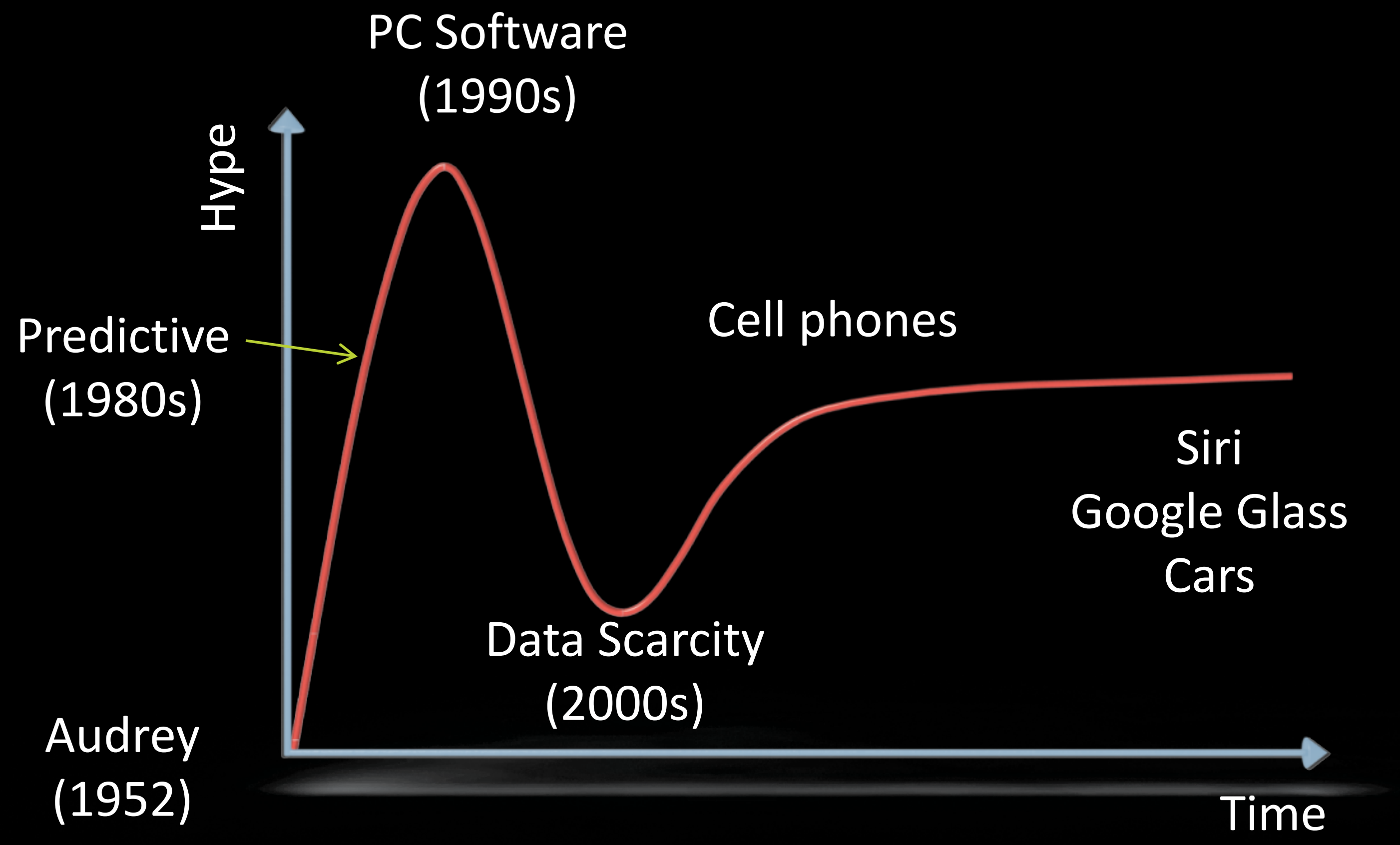
The Gartner Hype Cycle



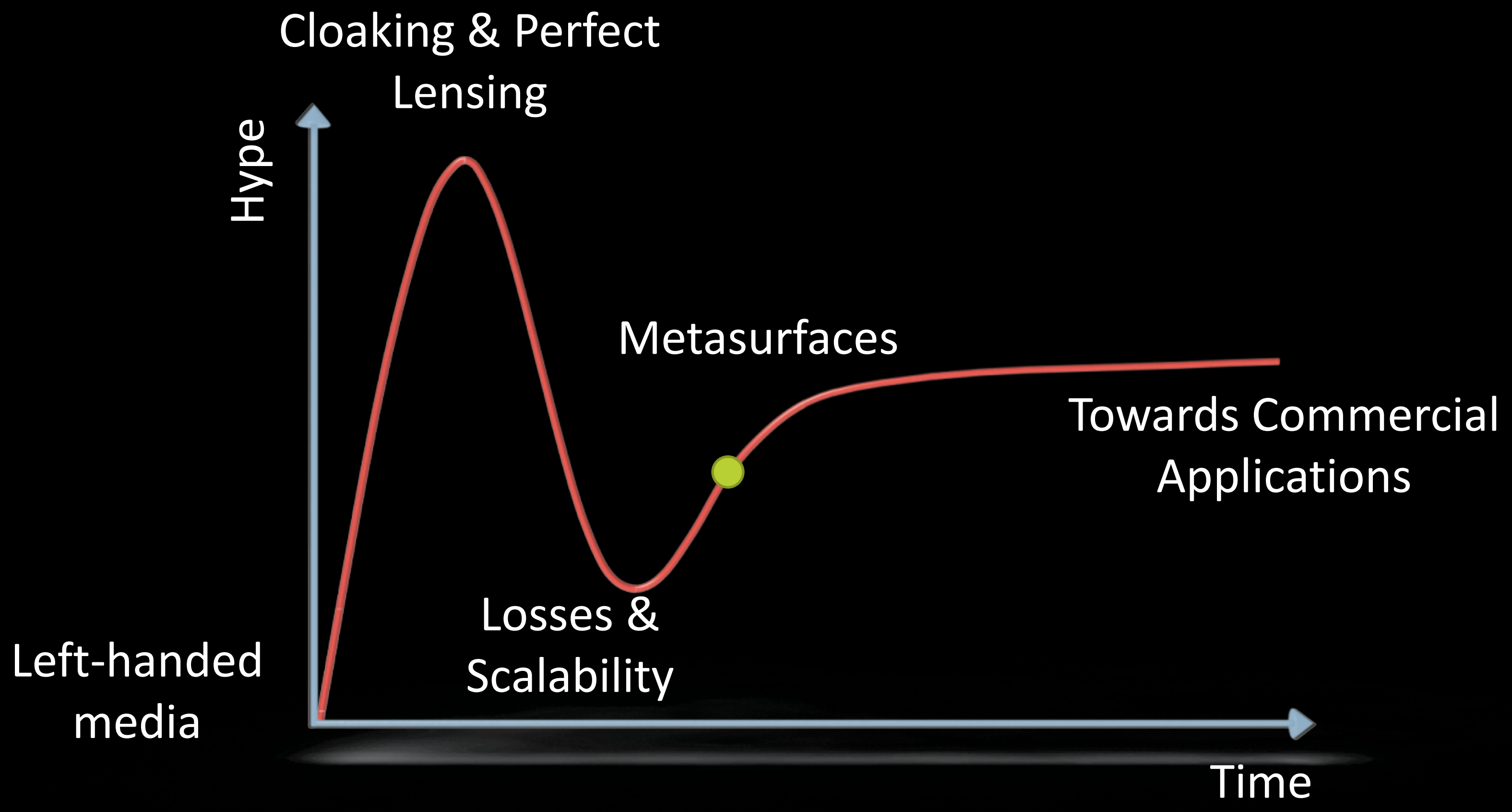
Gartner (2013)

The Hype Cycle – Speech Recognition



Gartner (2013)

The Hype Cycle for Commercial Metamaterials



Gartner (2013)

The Challenges

- Transparency for visible applications

- Large scale nanofabrication

  nm accuracy over meter-long surfaces

- Cost-effective fabrication

  \$1-10 per cm^2 on volume production

Example Application

Laser Eye Protection

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Legitimate Uses

Amateur Astronomy; Laser shows

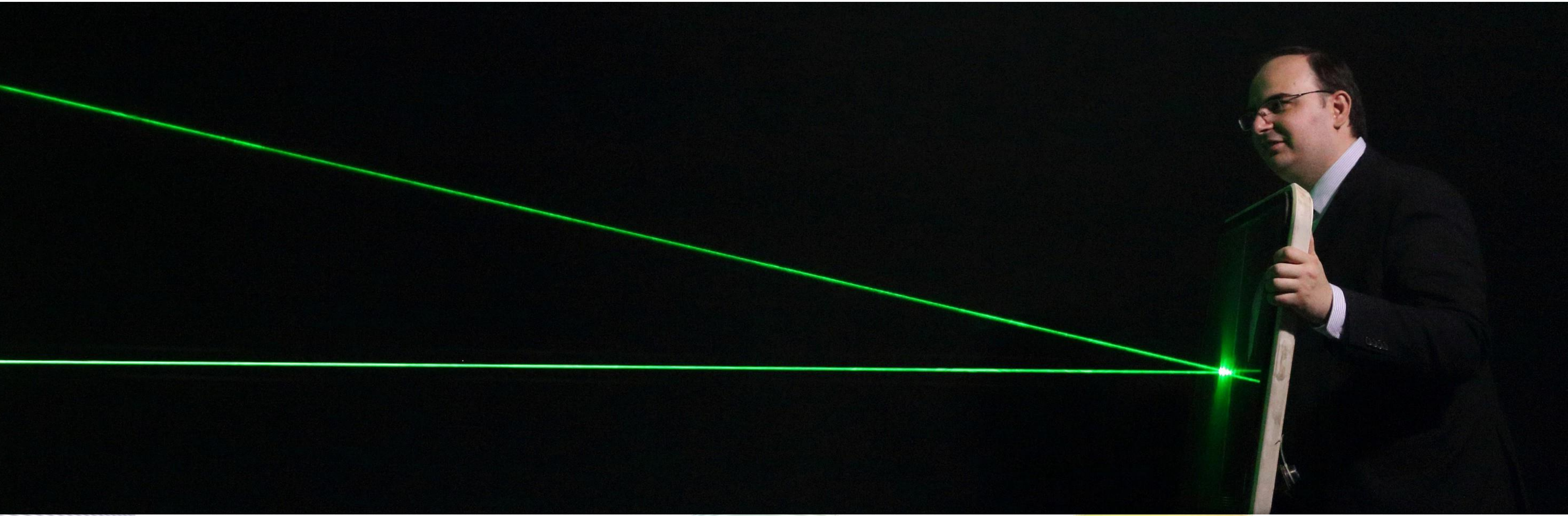
Laser Attacks in Aviation

- Health risk for pilots
- Security risk for aircraft
- Safety risk for passengers
- Economic risks

  (go-arounds, missing flights)

Image Source: FAA

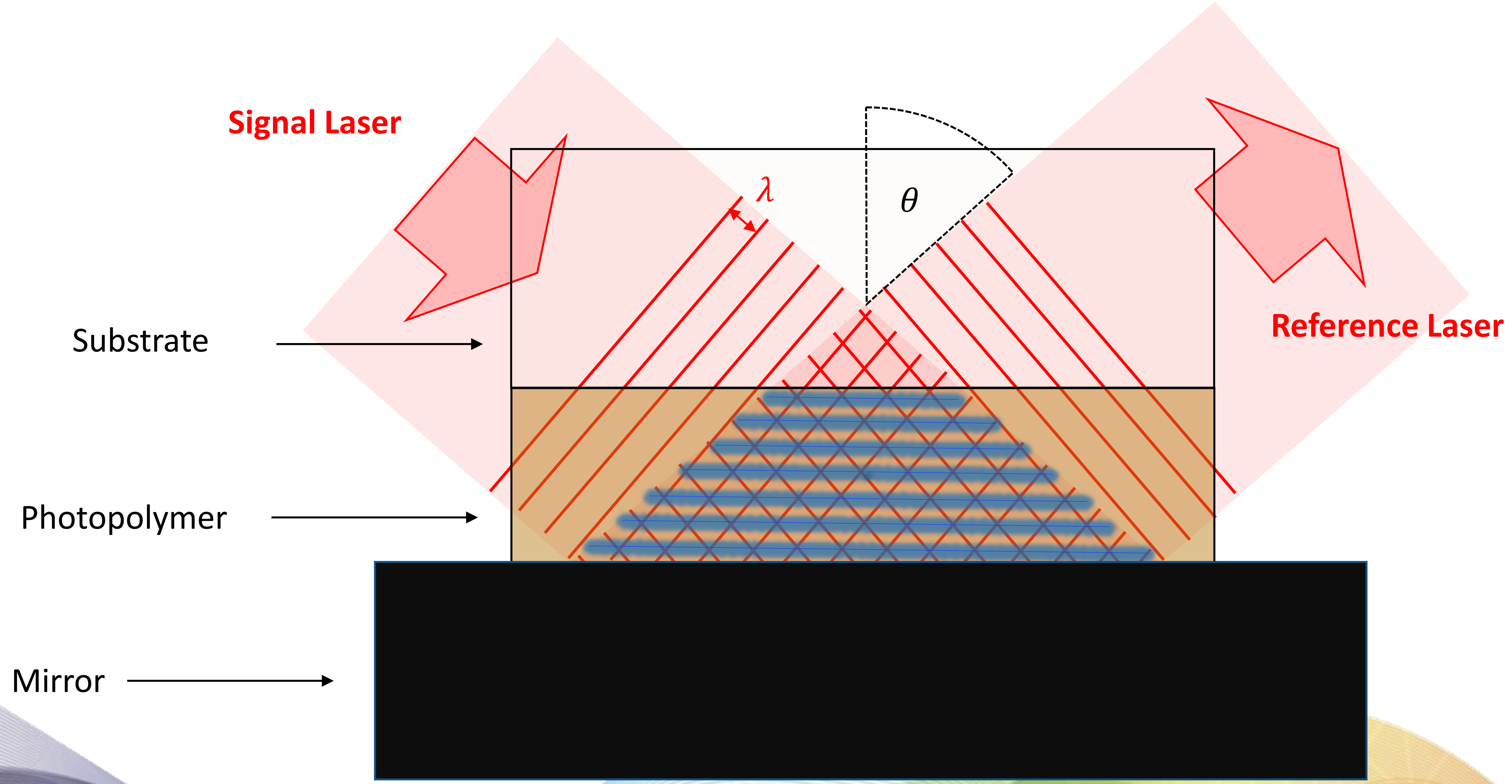
metaAIR®



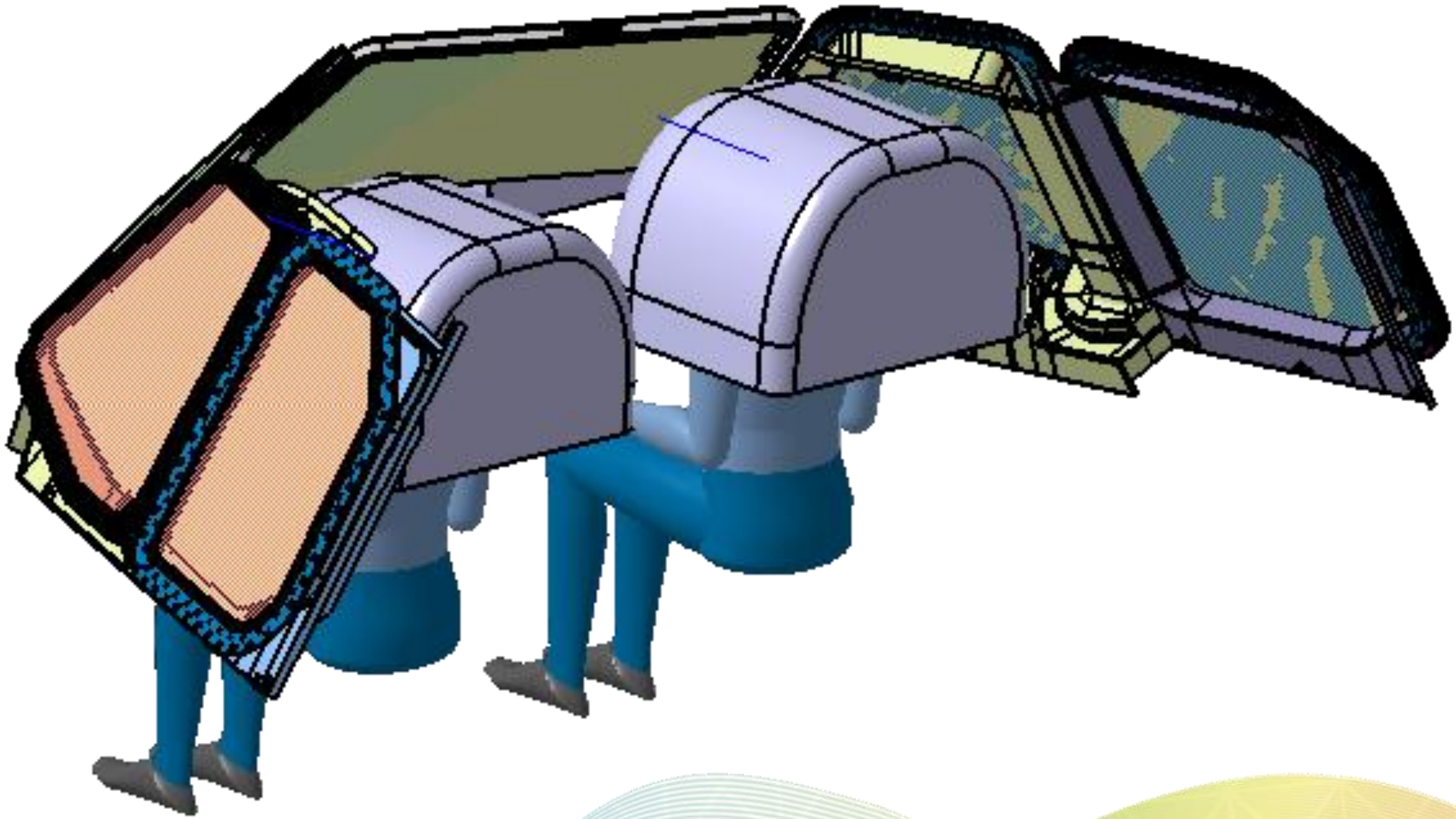
metaAIR®

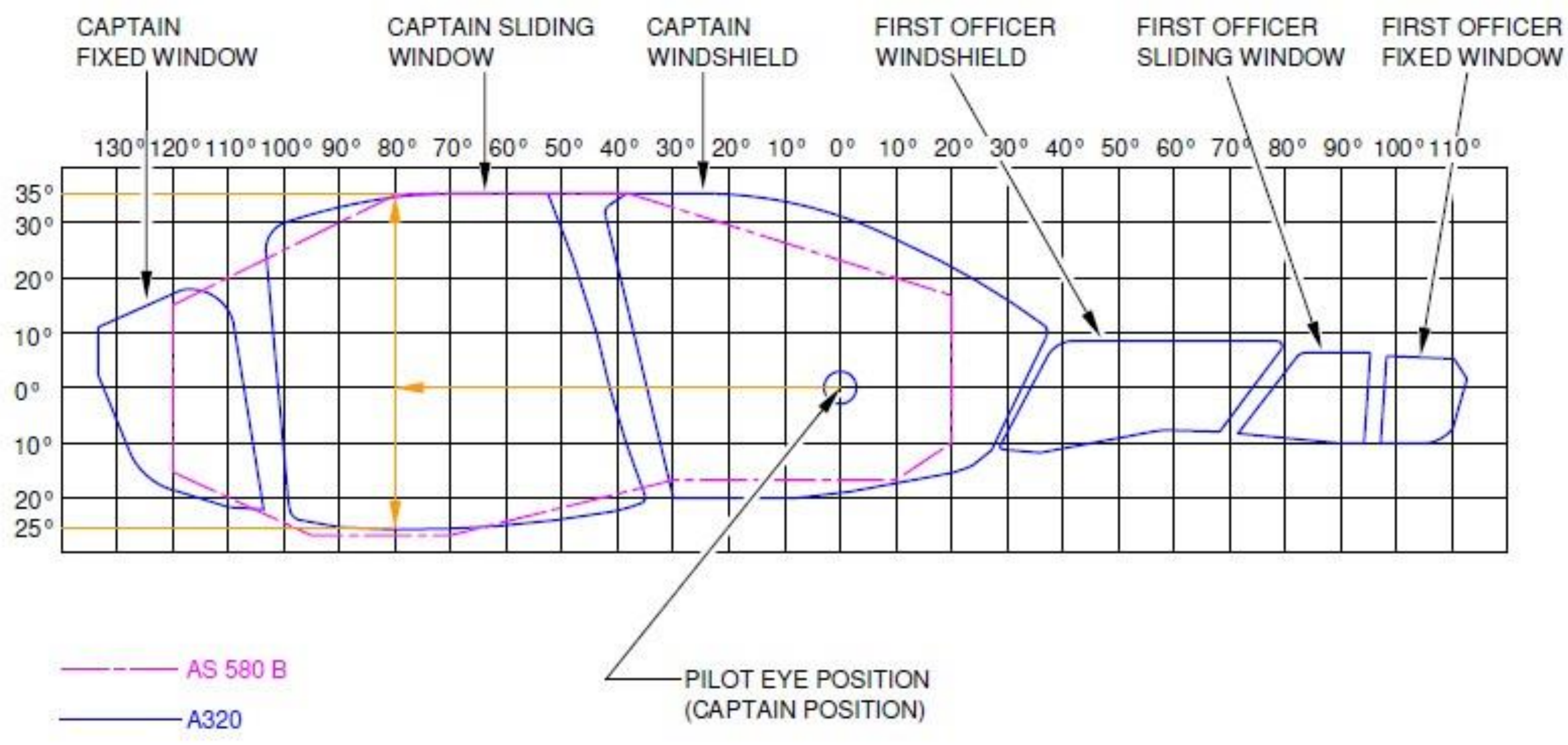
Meter-scale holographic notch filter films for aircraft

Making a mirror for a laser using a mirror and a laser



Practical Considerations





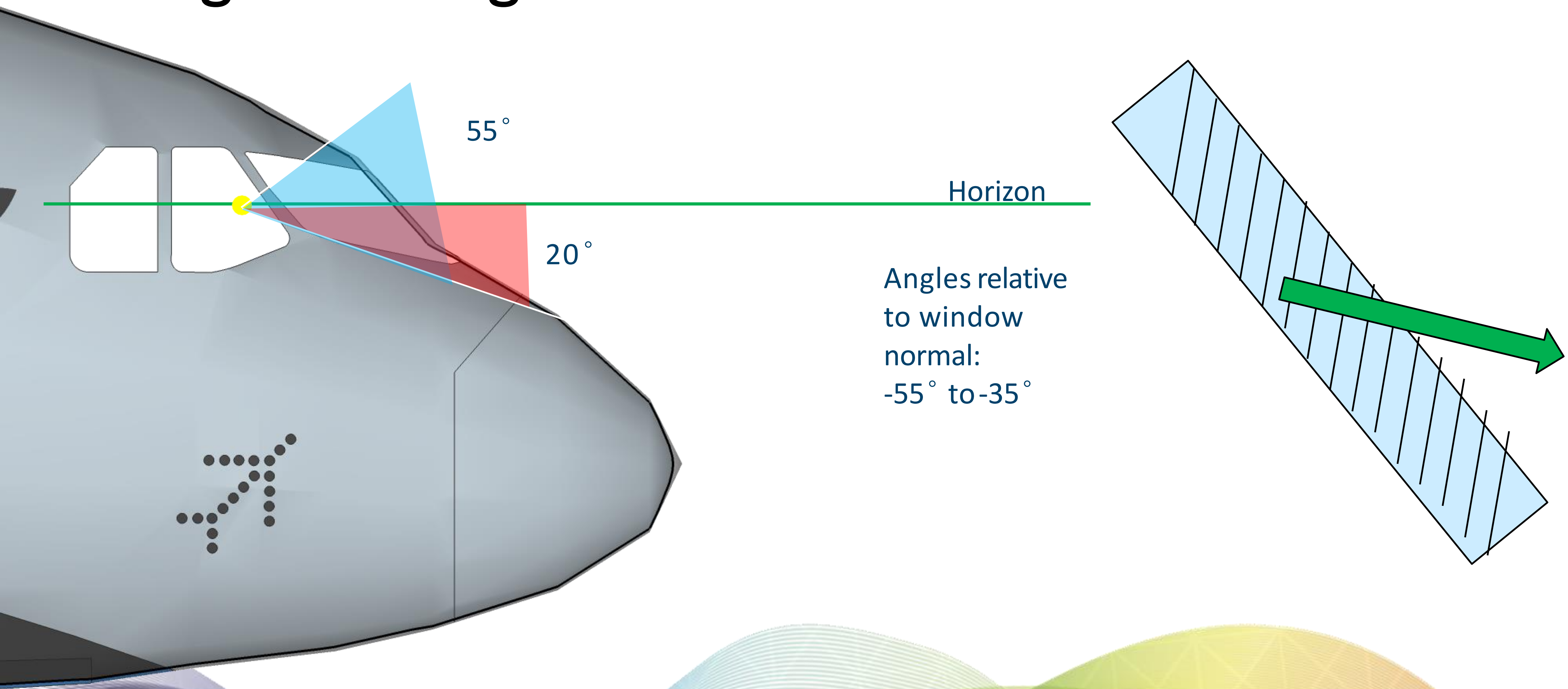
Binocular Visibility Through Windows from Captain Eye Position
FIGURE-4-4-0-991-005-A01

N_AC_040400_1_005

CAPTAIN FIELD OF VIEW SHOWN.
FIRST OFFICER FIELD OF VIEW SYMMETRICAL.

EXAMPLE: WHEN CAPTAIN TURNS HIS HEAD BY 80° LEFT, VISIBILITY WILL BE 35° UP AND 25° DOWN THROUGH THE SLIDING WINDOW FRAME.

Design Challenges

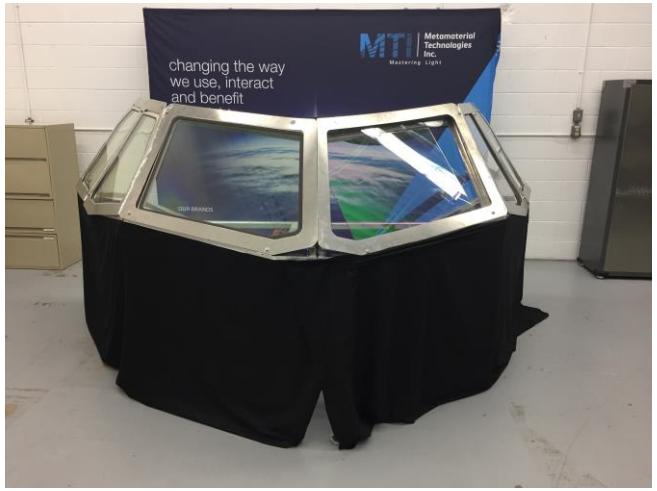


Large Scale Manufacturing

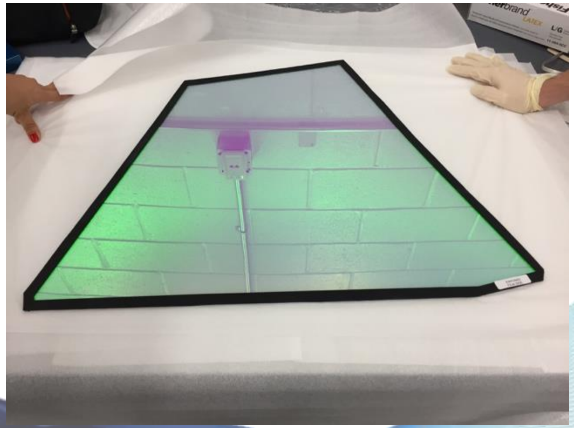
Aircraft Windows

metaAir on sliding window of Airbus A319 (binocular view)

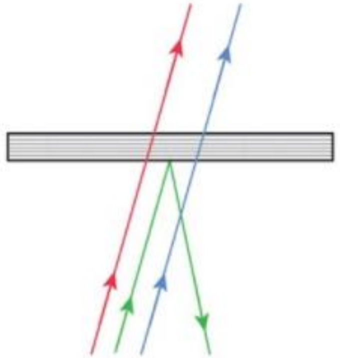
metaAir on 6 windows on Airbus A320 cockpit mock-up



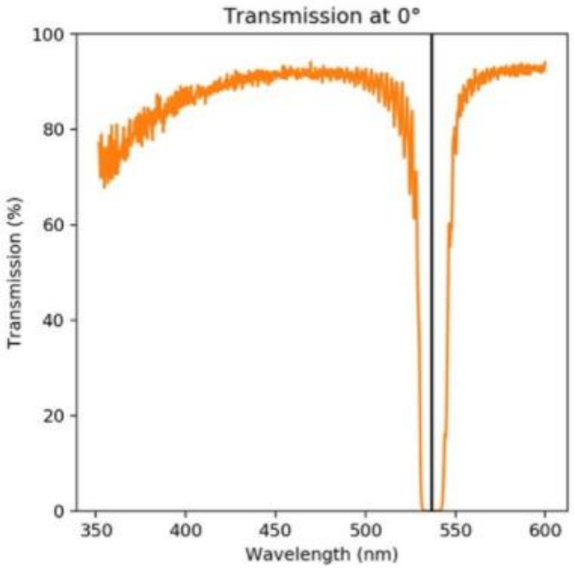
metaAir for A320 sliding window



metaAIR® Laser Glare Protection Eyewear



	Notch Center (nm)		
	447	532	635
SBW (nm)	7	13	11
OD (log)	>2	>4	>2



Evolution

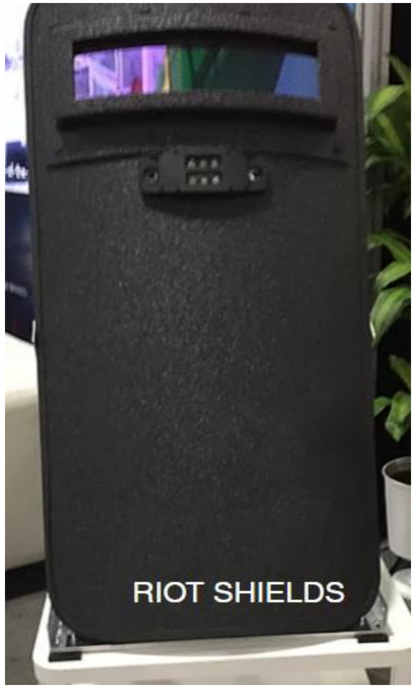
2013

2019

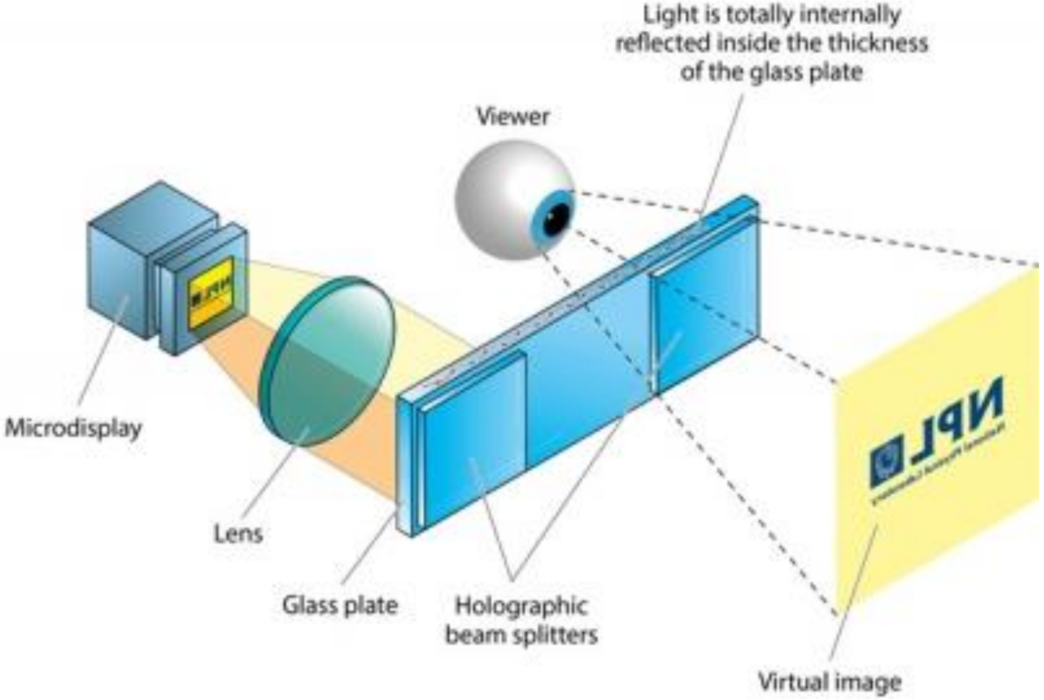
META Applications

Functional Films for the People

More Laser Protection



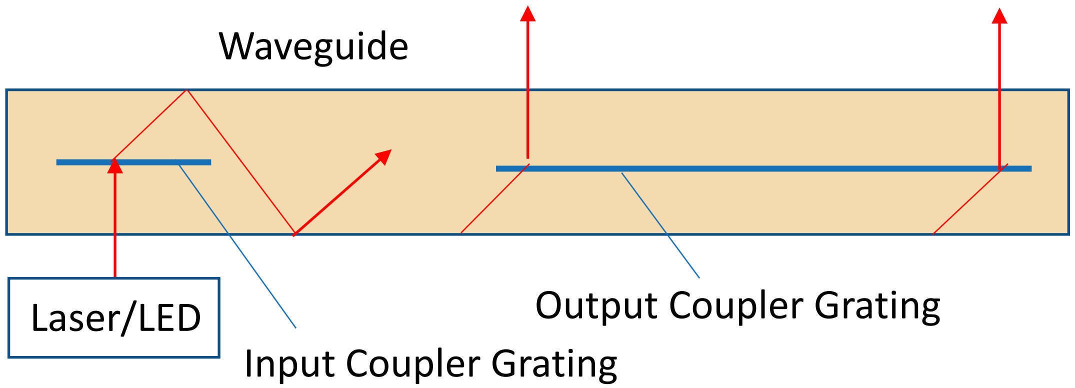
Augmented Reality



Source: [NPL]

Augmented Reality: ARfusion™ & holoOPTIX™

META®

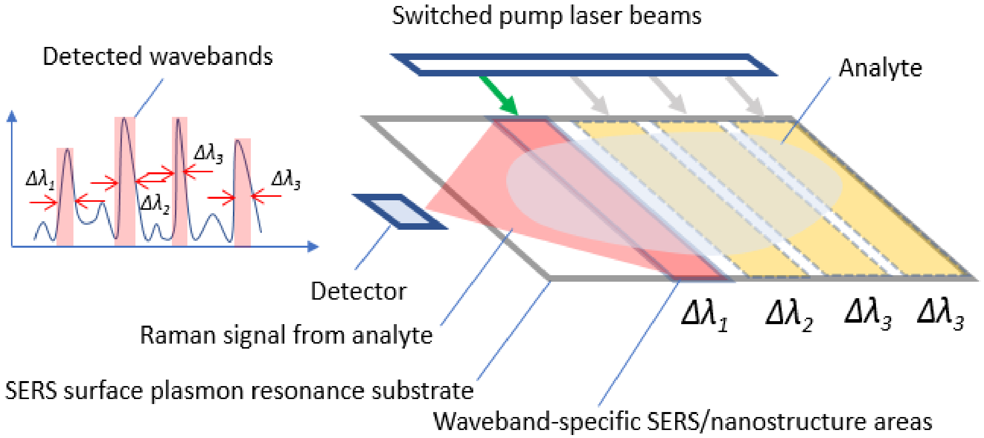


- Illumination expansion
- Beam geometry shaping
- Illumination structures: diffuse, uniform, structured light, etc.
- Polarization control
- Optical power for light condensing and collection
- Wavelength diversity
- Angular diversity
- Multiplexed optical functions
- Switchable optical functions
- SERS integration: pump beam management and signal collection

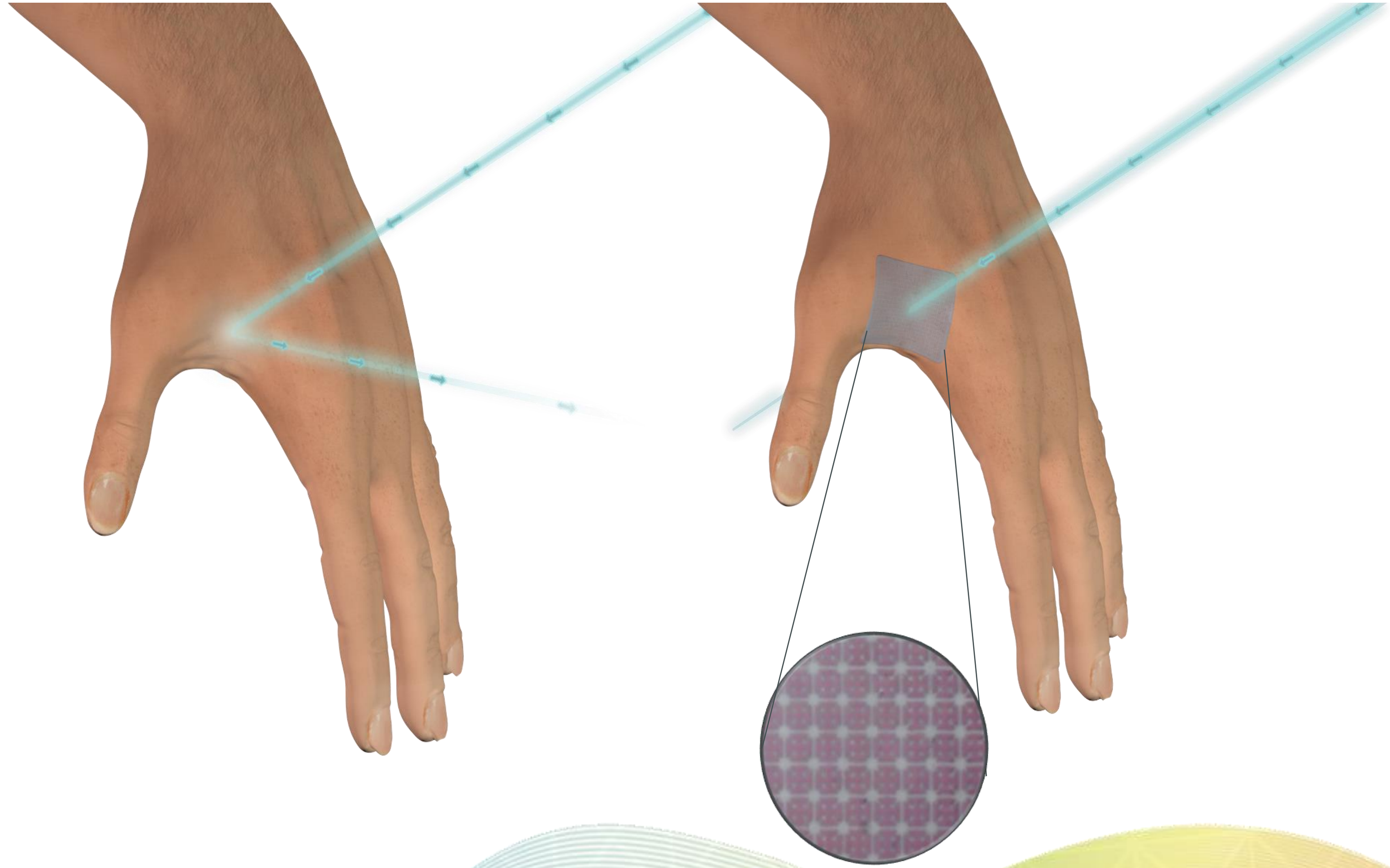
Films in Casted Lenses

Source: NPL

Biosensing: Raman Spectroscopy for Infectious Diseases

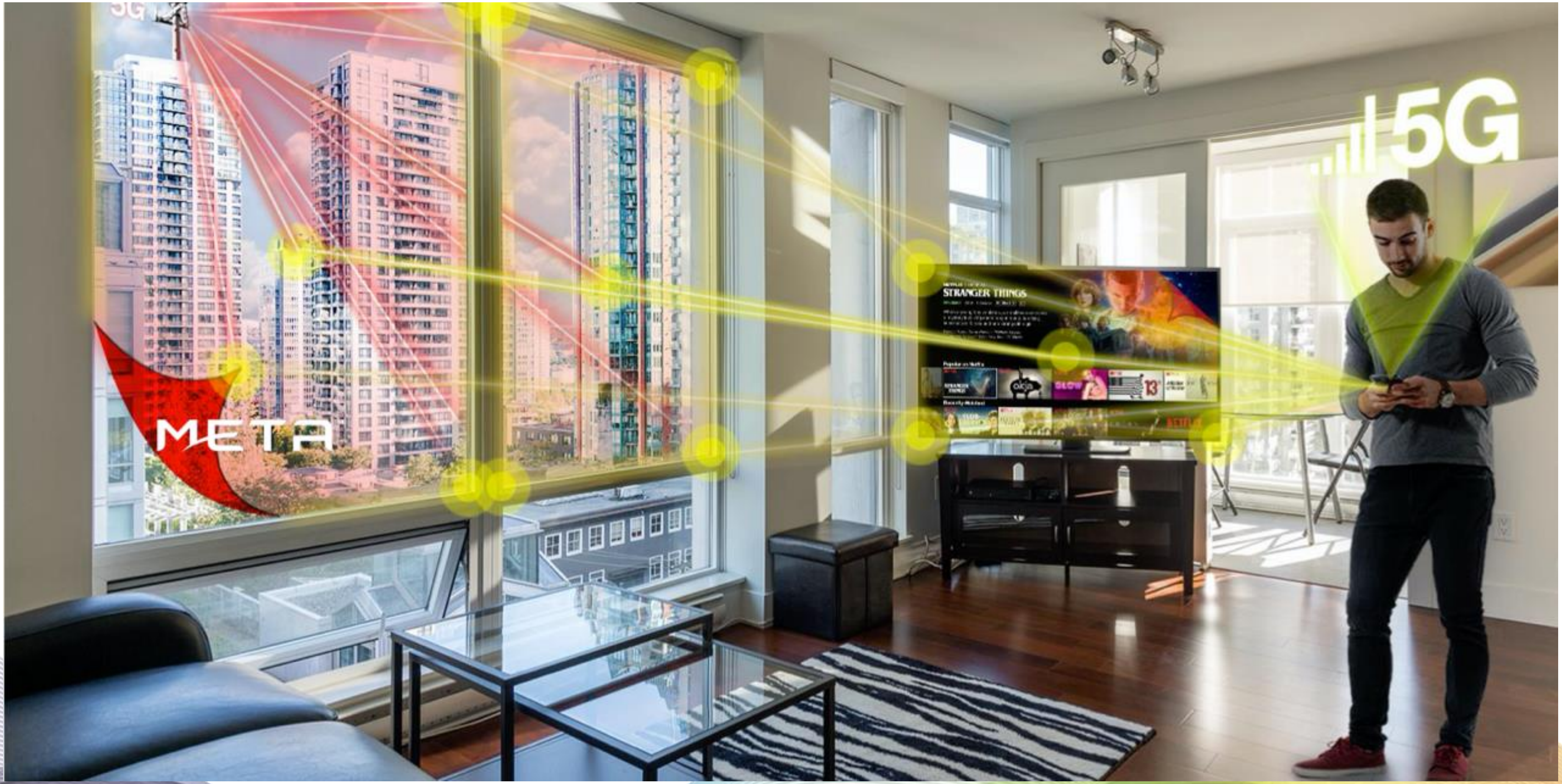


Biosensing w/ Impedance Matching

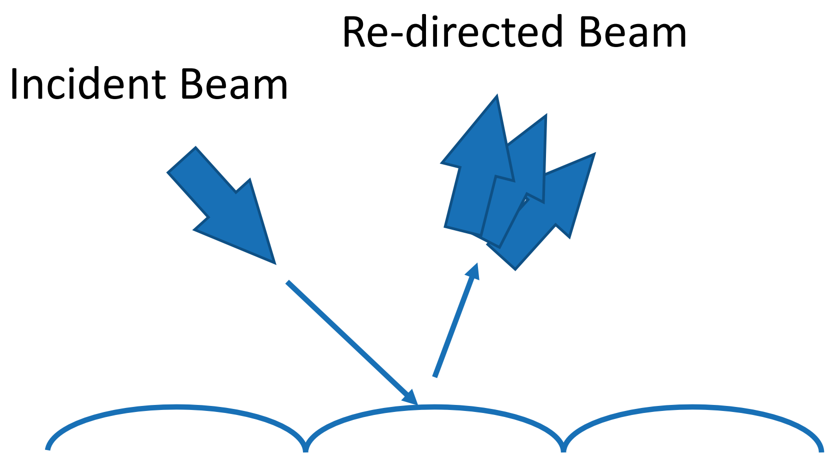


Outdoor 5G Coverage Enhancement

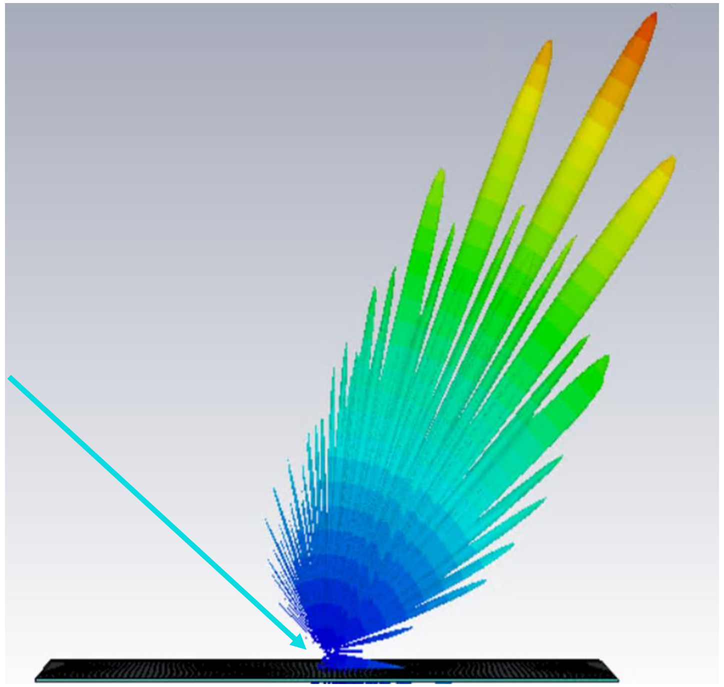
Indoor Coverage Enhancement



Geometric Optic Analogue of a Beam Disperser



Mirror array Implemented using
Transparent Metamaterial



NANOWEB® metamaterial

Transparent Microwave Doors

EMI Shielding & Nano-heater to Protect Sensors - Transparent to RADAR and LIDAR Simultaneously

42

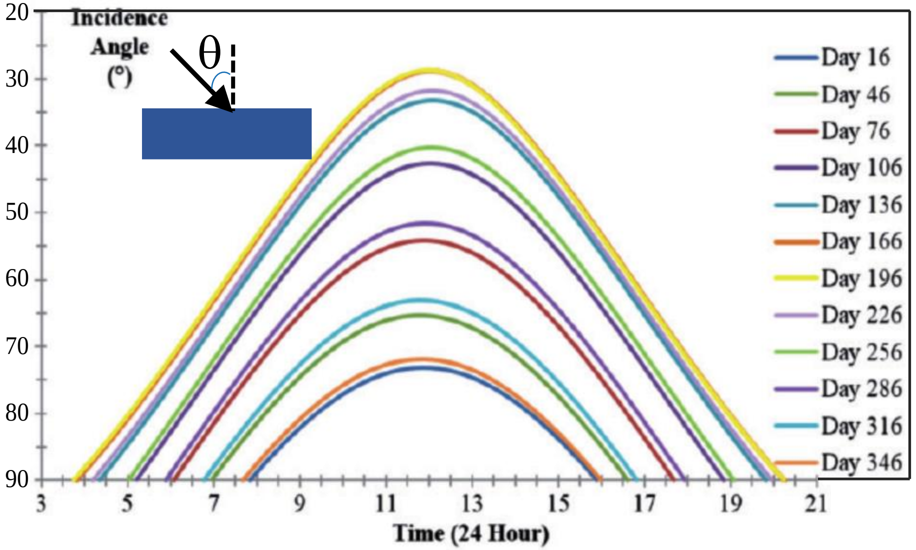
Ultralightweight Solar Cells

- Develop lightweight high-efficiency solar module for high altitude aircrafts (e.g. Stratobus, Zephyr HAPS, HALED etc)
- Develop antireflective and light trapping films suitable for ultra-thin crystalline silicon PV device technology and develop the process to deposit them uniformly over large areas

Challenges for Ultralightweight Solar Cells

I. Low solar performance in mobile PVs due to reflection at highly oblique solar angles

Sun incidence angle throughout the year at 50° latitude



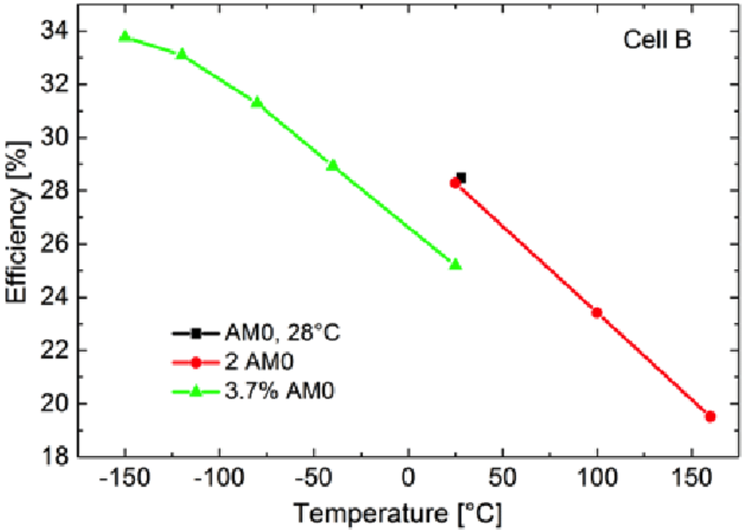
Solar light incident at oblique angles most of the day

Goal 1: to increase transmission at oblique incident angles

Goal 2: to develop high emissivity layers for thermal management

II. Module efficiency degradation at high temperatures

Module efficiency vs. temperature under different illumination



70% of incident solar power converted to heat degrading the module performance at high altitudes

DOI: 10.1051/e3sconf/20171604005

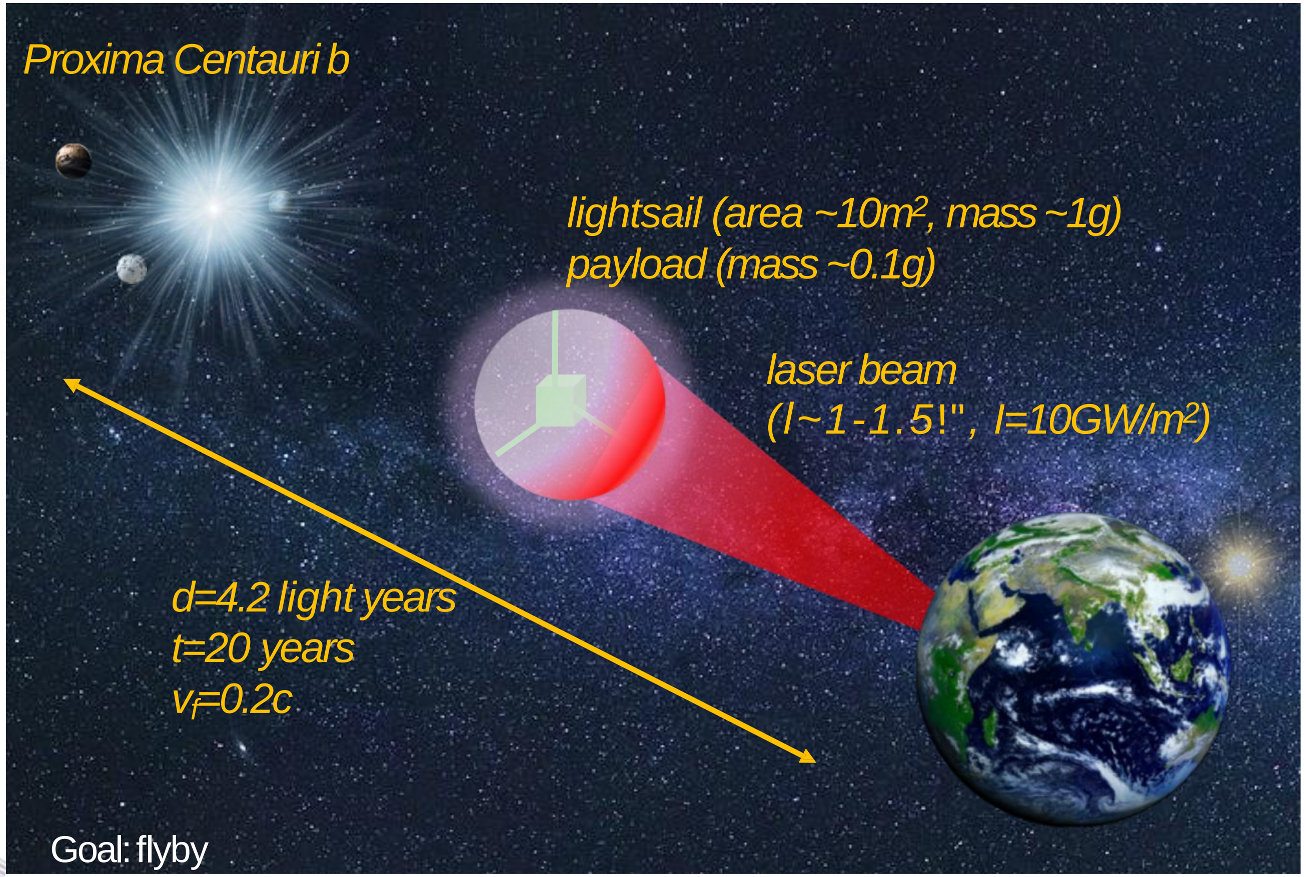
Secure Currency & Brand Protection

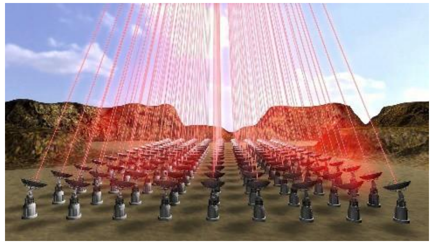
- Produce motion, depth and color without inks or dyes.
- Full color, nearly impossible to reproduce.
- Engaging security features with RGB color, 3D images, and movement.
- Developing new security feature for a confidential top-10 central bank.

UEFA Euro Cup Tickets

Starshot Lightsail – Nanostructured Reflectors

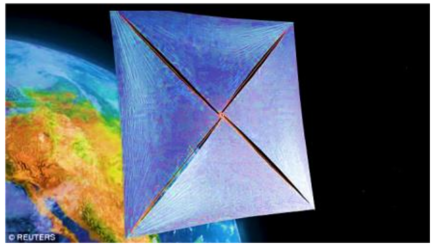
META®





Nanocraft

Light sail

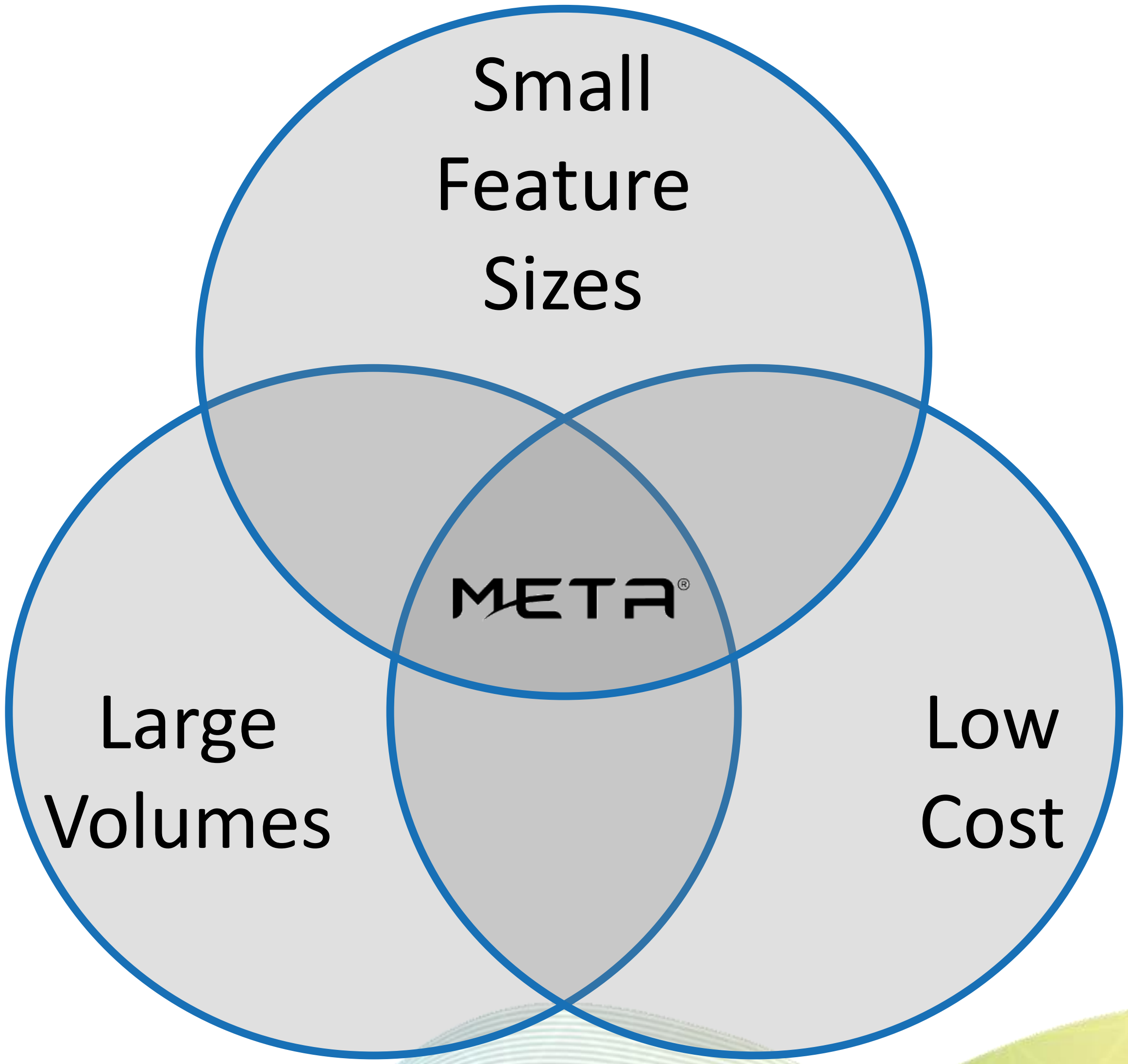


BREAKTHROUGH INITIATIVES

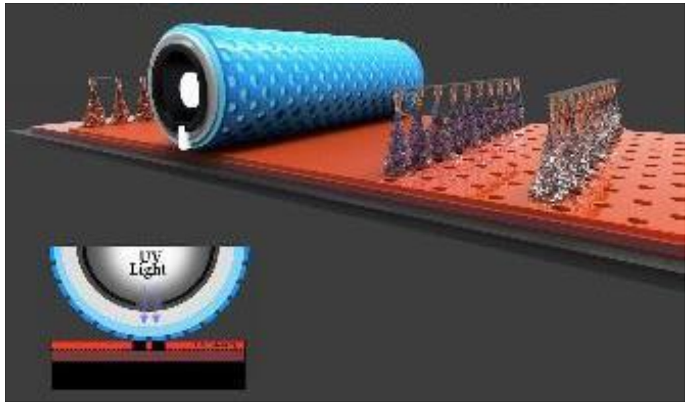
https://breakthroughinitiatives.org/concept/3

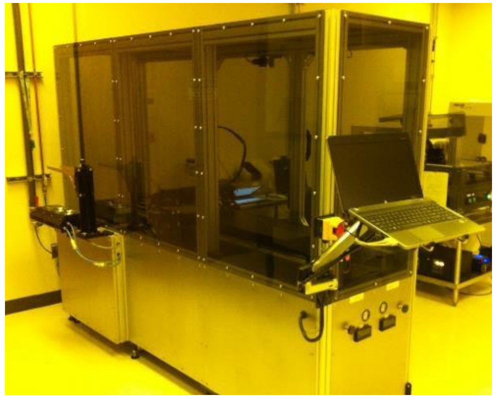
Manufacturing at Scale

META®
Go Beyond.


Small
Feature
Sizes
Large
Volumes
Low
Cost

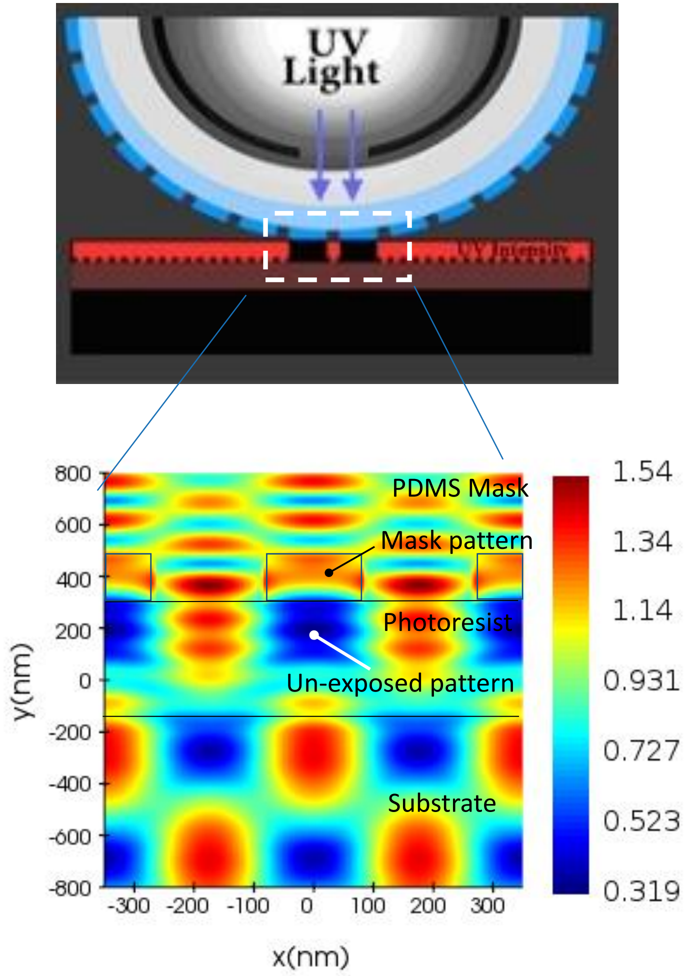
Rolling Mask Lithography (RML®)





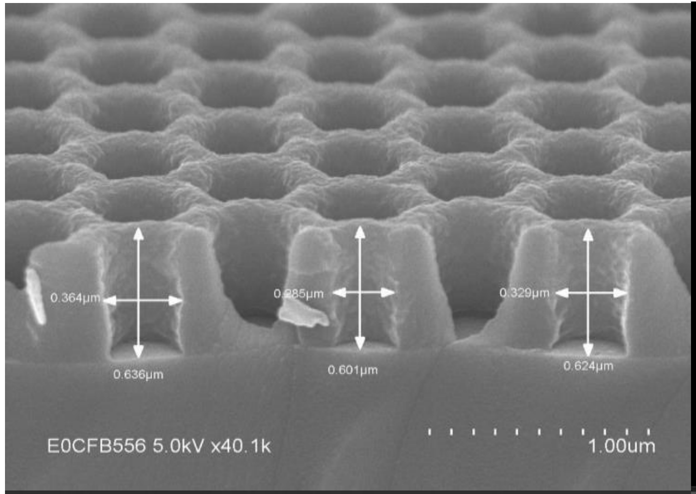
- Continuous and scalable
- Inexpensive
- Ultra-fast fabrication
- Phase lithpgraphy

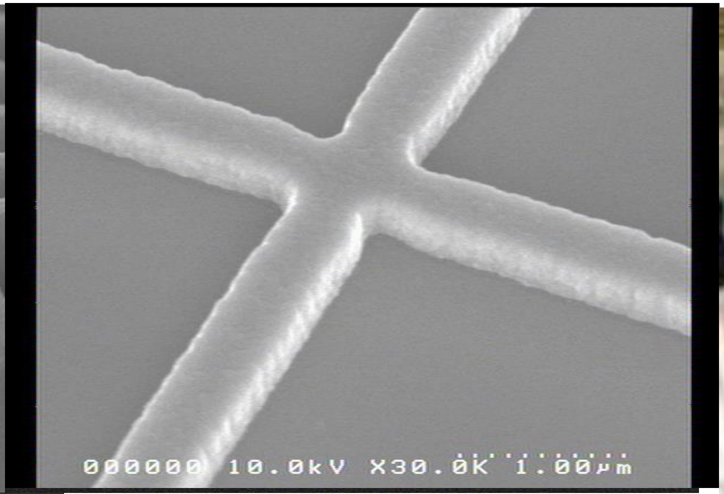
- RML® proprietary tool substrate size: 1m x 0.3m
- Resolution: 150nm
- Capacity: 3m/min

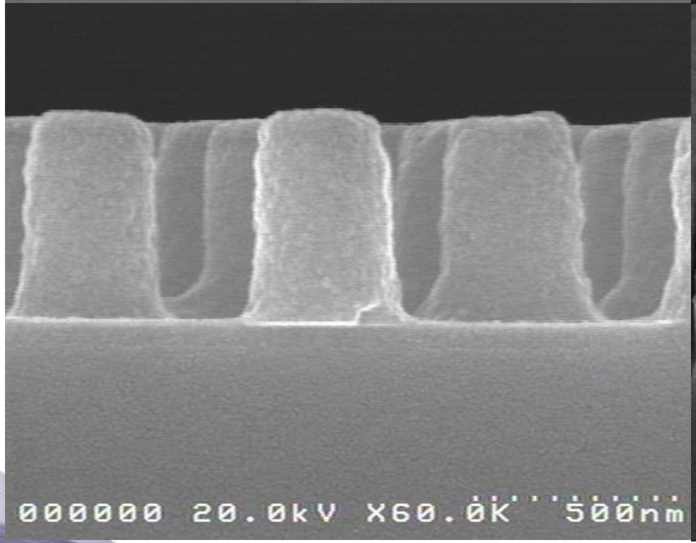


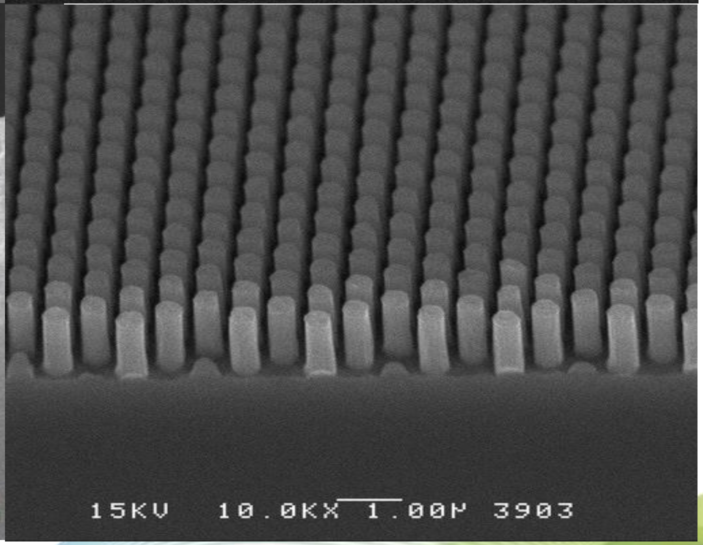
- vs. amplitude lithography: smaller feature sizes
  - Diffraction limited, 5um for far field (at volume)
- vs. NIL: no residuals, enables liftoff/additional layers (at larger feature sizes)

Made with RML®

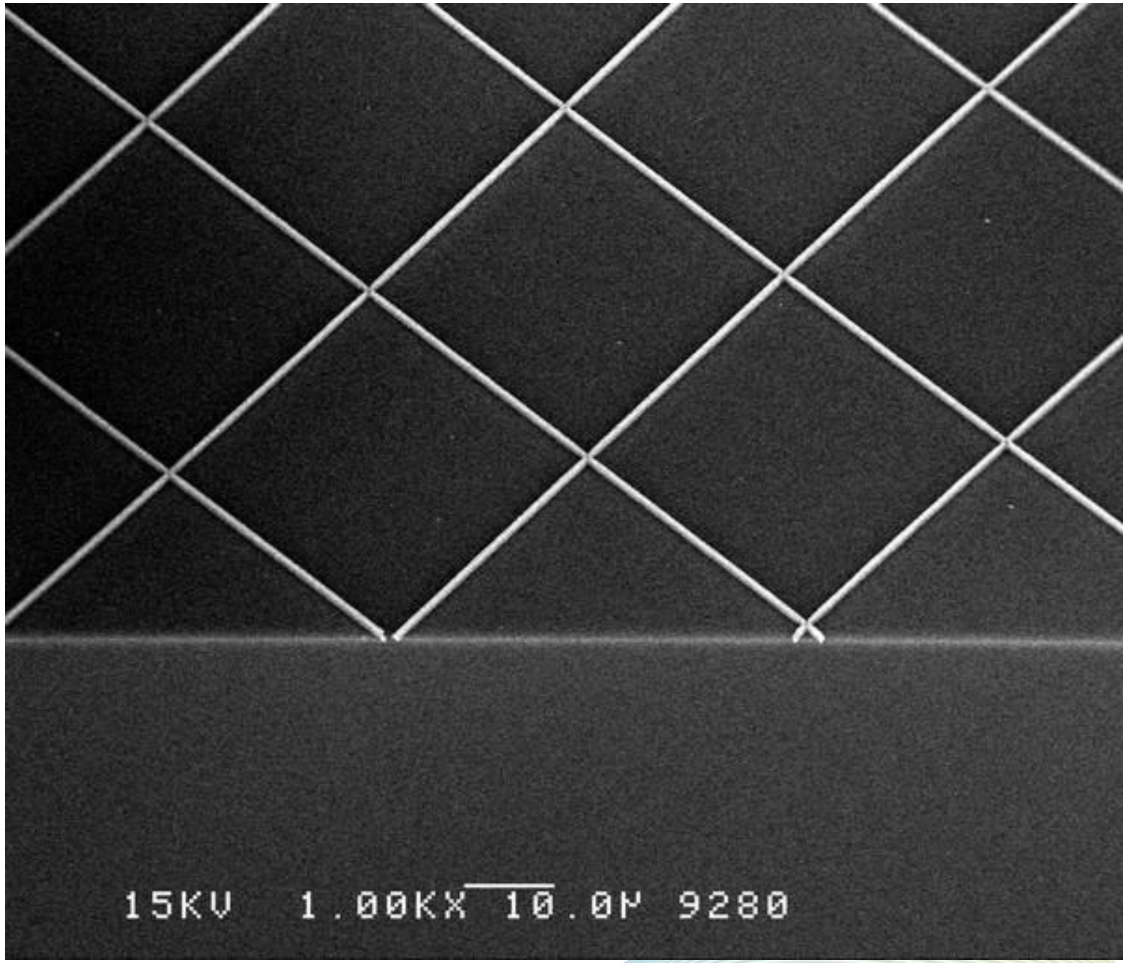


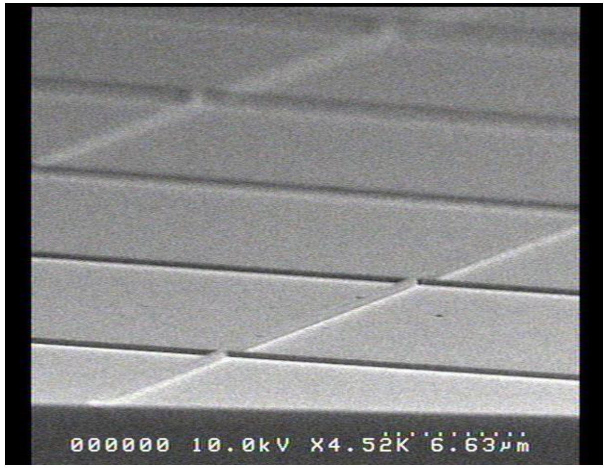


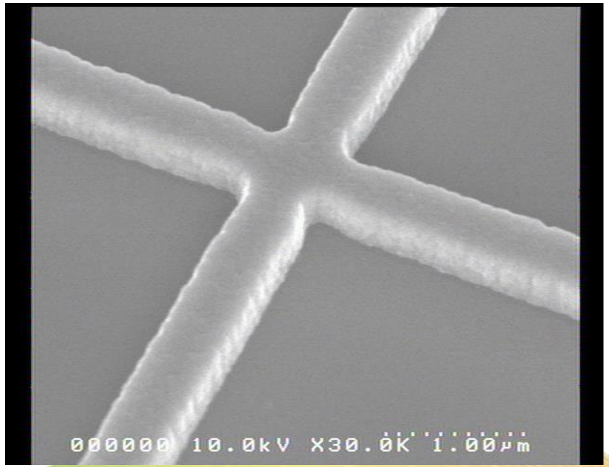




NANOWEB® – Transparent Conductive Mesh

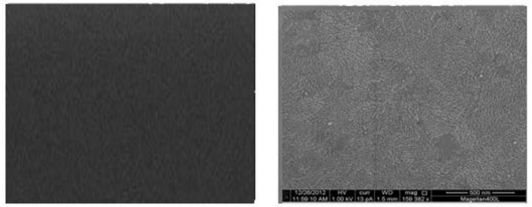






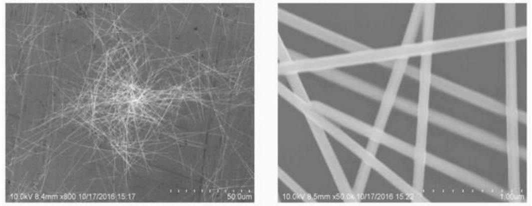
META®

ITO

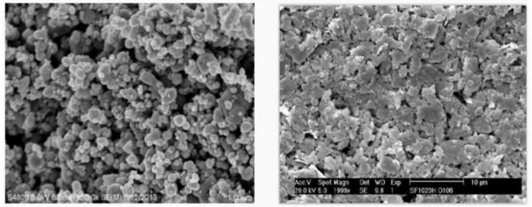


- ✗ Low Transmission
- ✗ Low Conductivity
- ✗ Not flexible
- ✗ Not suitable for large surface areas

Silver Nanowires



Silver flakes

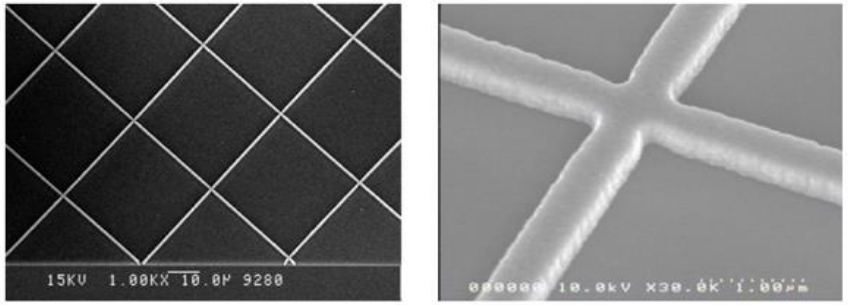


- ✗ High Haze
- ✗ Low Transmission
- ✗ Low Conductivity
- ✗ Low precision/control

VS.

RML® NANOWEB®

Sub-micron, high transparency, super conductive metal mesh



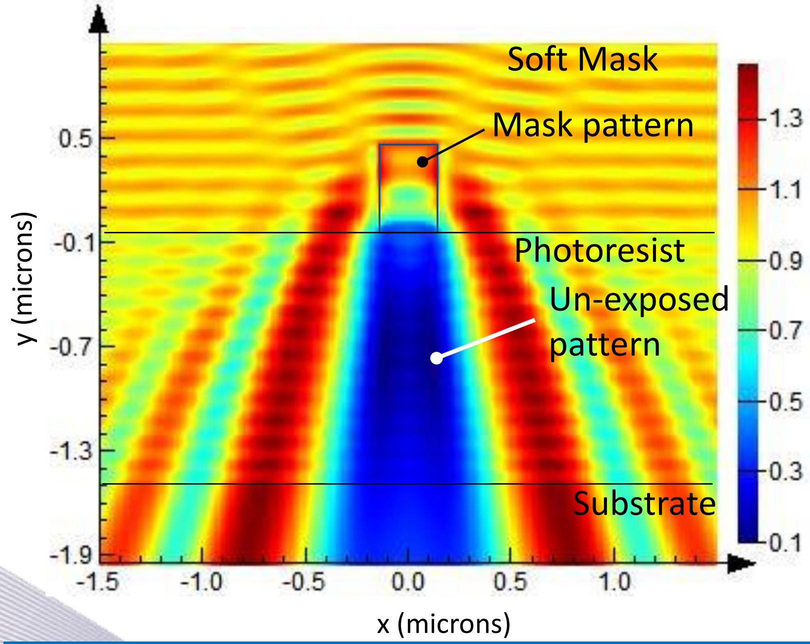
- ✓ High Transmission
- ✓ High Conductivity
- ✓ Lower Haze
- ✓ Hi Resolution & Control

Optimizing NANOWEB®

Translate requirements into designs, develop new masks tailored for optimum performance of target applications.

Linewidth Pattern optimization

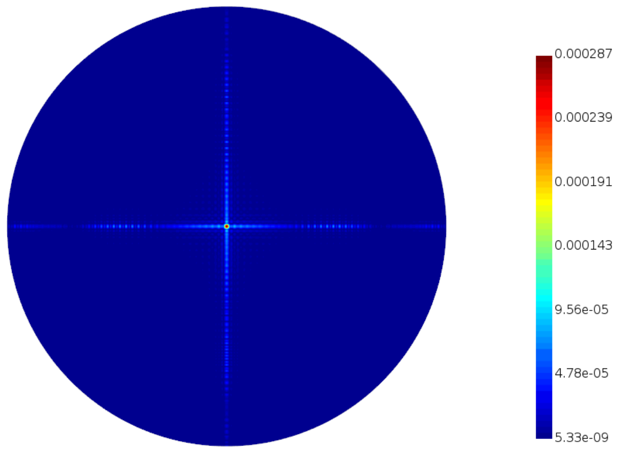
Colormap for the E-Field Distribution



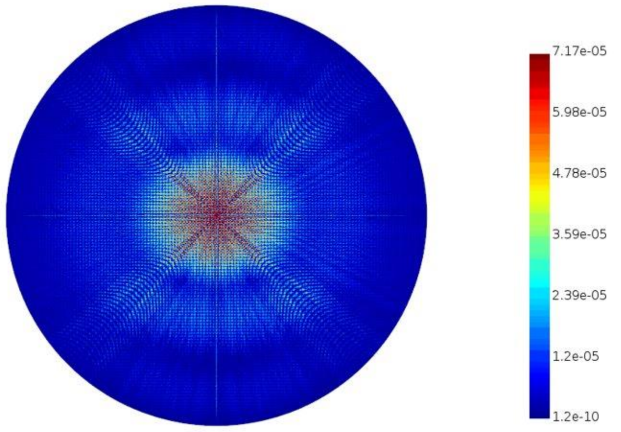
High contrast enables high uniformity and yield

Haze and Transmission optimization

Polar maps for the scattered field



Rectangular mesh

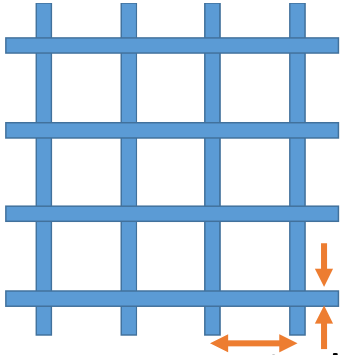


Optimized mesh

Haze, diffraction and transmission can be optimized for each application

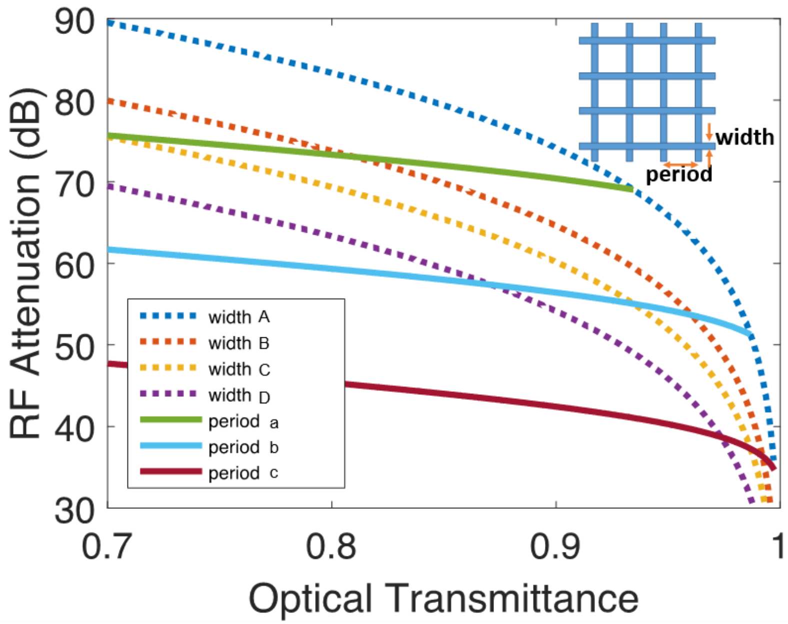
EMI Shielding - Optimum set of design parameters

Analytical Model for the RF Transmission



$$T \cong \frac{4g^2}{\lambda^2}\left[ln\left(\sin\frac{\pi a}{g}\right)\right]^2$$

RF attenuation at 3 GHz vs. Optical Transmittance



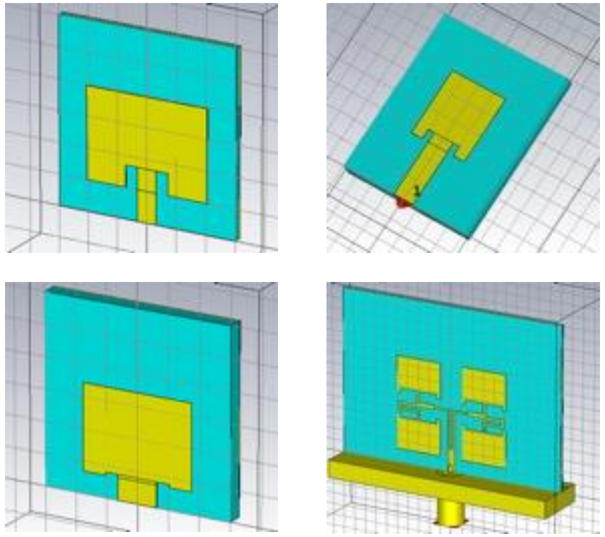
Smaller width has higher EMI shielding

GOAL : Finding optimum width, period and thickness of the Nanowires for largest EMI Shielding

NANOWEB® 5G Antennas

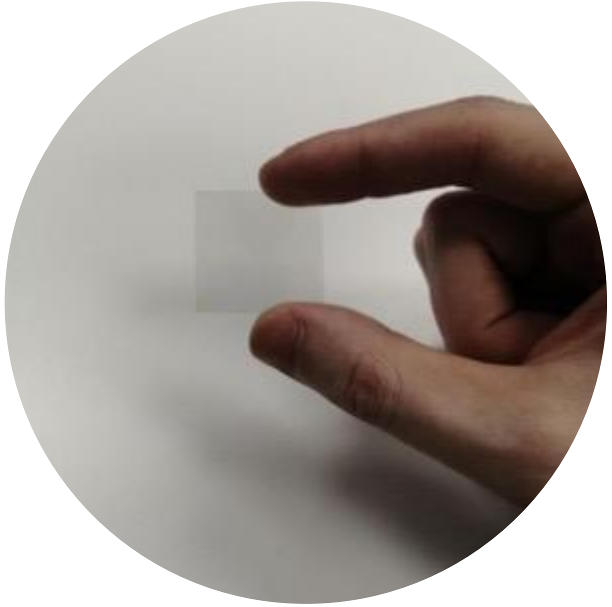
META®

Custom Design & Simulation



Precision Fabrication

High Performance & Transparency



How to Fabricate Fast?

“Interstellar method”

R2R Pilot Manufacturing Process Steps

META®

1 **Loading**
Pre-coated PET film with bi-layer photoresists.

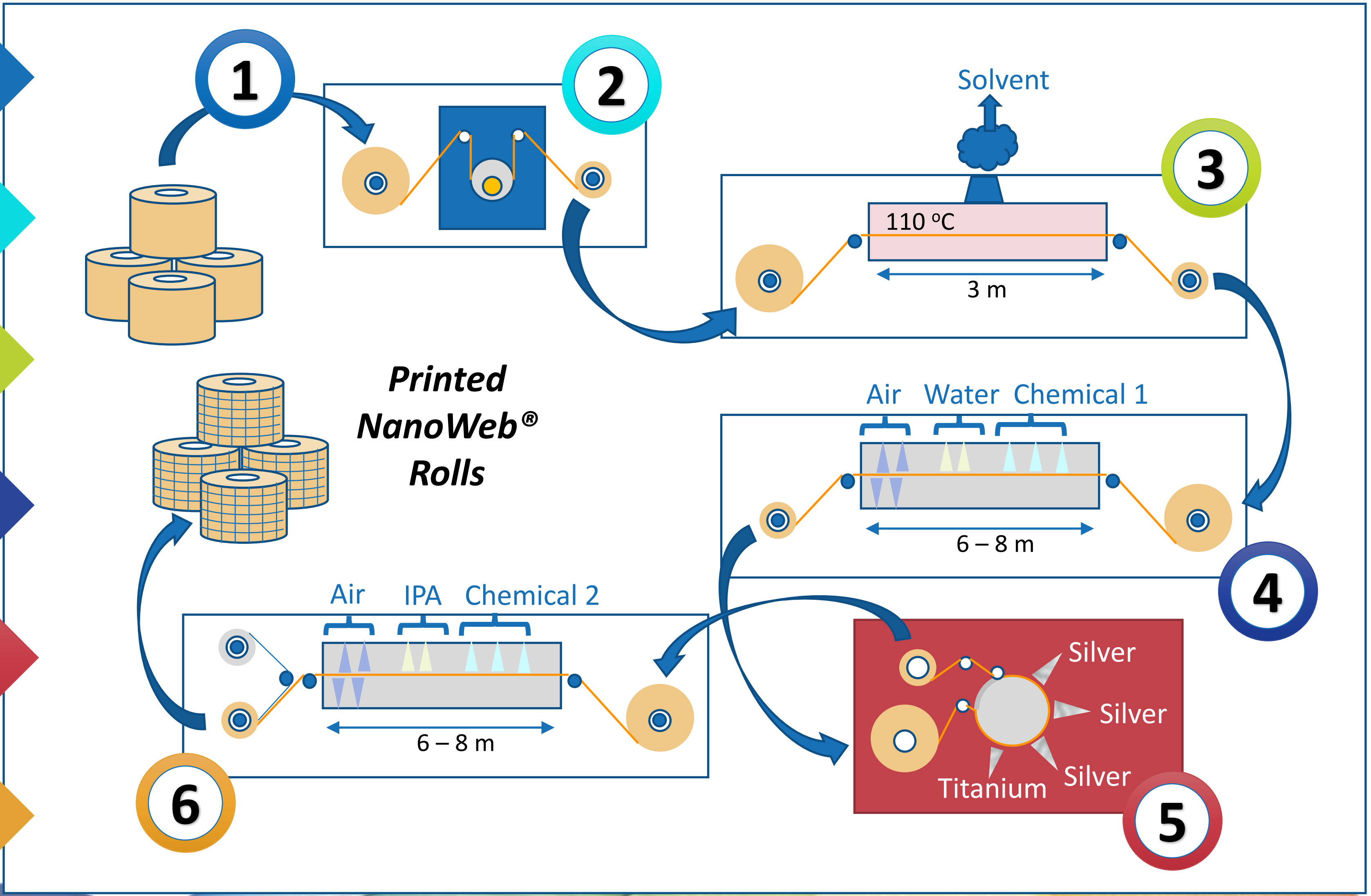
2 **Exposure**
Printing with RML technology using UV-365nm and proprietary mask

3 **Baking**
Stabilizing chemistry of printed design in photoresist.

4 **Development**
Creation of 3D structures in Photoresist.

5 **Metallization**
Metal in deposition to create continuous metal mesh.

6 **Lift off and Protection**
Removal of unwanted material and protection of mesh prior to re-winding.



Production Scale-Up

Today

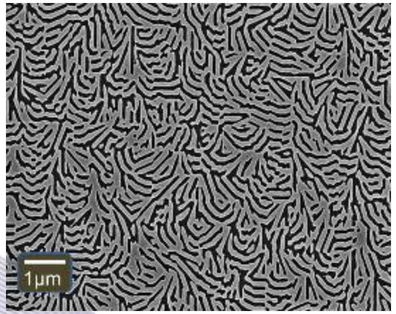
Platform Technologies
- Holography
- Lithography
- Wireless Sensing

High-Volume Markets
- 5G Communications
- Electric Vehicles
- Consumer Electronics
- Clean Energy (+ more)

New HQ Facility
- 68,000 square feet
- New Customer Center
- Retrofit underway

Pilot Scale Production
- 500mm roll-to-roll

Design, Test Samples



Wafer Scale Validation

Highfield Park Facade

R2R Pilot Line

R2R Nanoimprint Lithography

META strengthens the design and lithography expertise with the acquisition of Nanotech Security

Design
- Optical Physics & Nanostructures
- Proprietary Software, 3D Image/Motion Graphics Development

Origination
- High-Resolution Electron Beam Lithography
- Proprietary Nanofabrication Processes and Intellectual Property

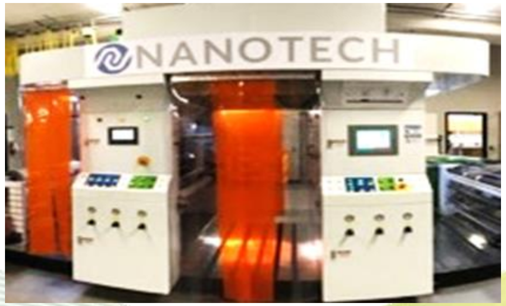
Recombination
- Expertise in recombination of nanostructures to preserve quality and fidelity over large areas

Production
- Decades of experience in high-volume, roll-to-roll web processing
- Secure facility with capacity >7 million m^2

EBL Origination

SR-NIL UV Recombination

R2R UV Casting NIL



R2R Vacuum Deposition

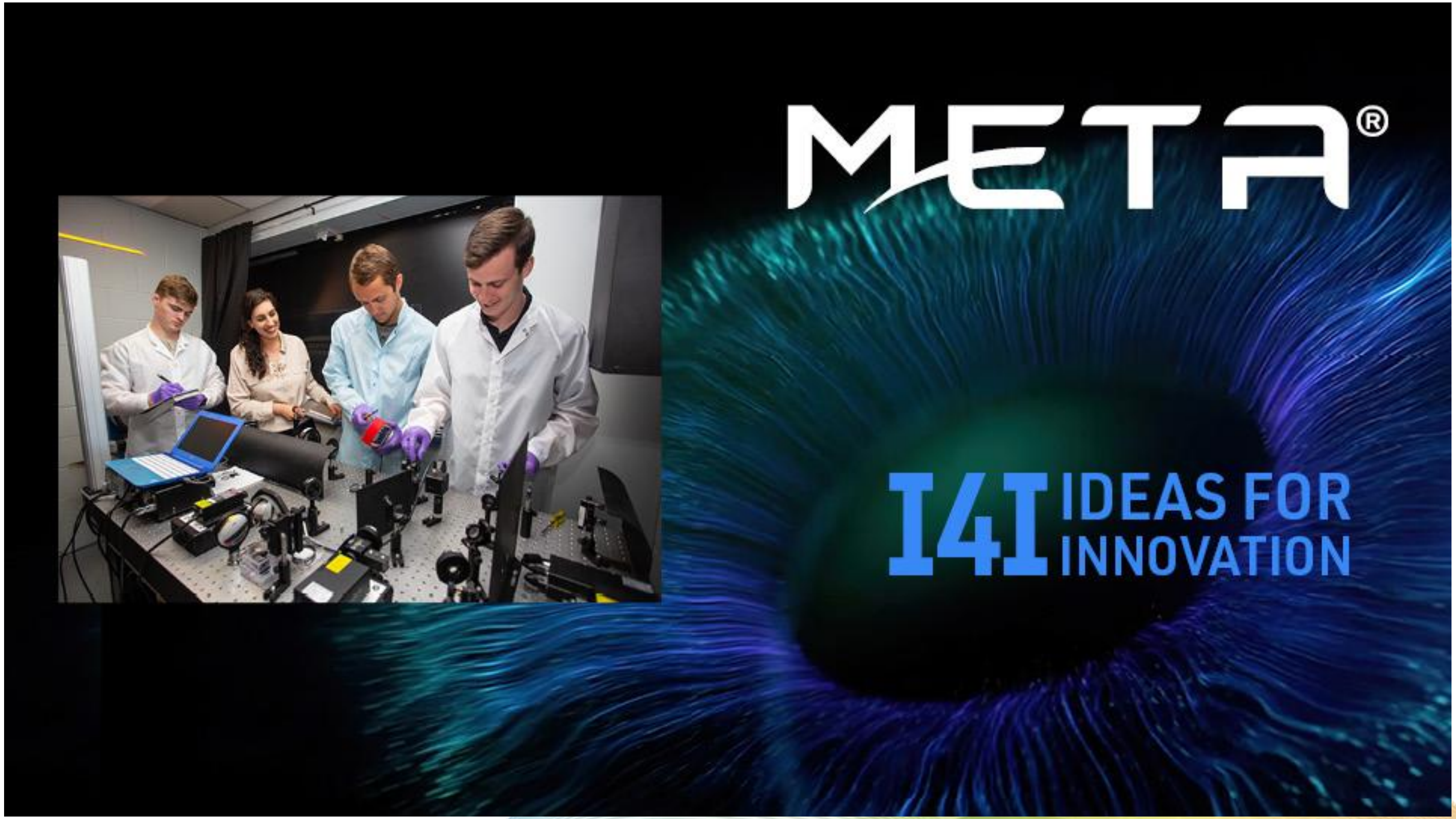
Learnings

Some Lessons

- Wouldn’t be here without cloaking & perfect lensing
- Commercialization takes time & effort
- No need to be a genius
- Look for Game changers:
    - Big enough pain for someone to pay for a solution
- Either improve by an order of magnitude or (ideally:AND) make it cheaper
- Recipe for success:
    - Funding
    - Academia
    - Commercial Partners/Customers

The Future

Go Beyond.


META®
I4I IDEAS FOR INNOVATION

I4I 101

- Programs up to $150k over 12 months
- Annual awards with potential for renewal
- Dates
  - Opens: October
  - Closing: December 15
  - Decision: January
- Reviewed by independent committee members (industry + academia)
- For more information: i4i@metamaterial.com
  https://metamaterial.com/about-us/ideas-for-innovation/

Ideas for Innovation - I4I STREAMS

1. MOBILITY & COMMUNICATIONS
   - Optical Computing and Signal Processing
   - Next-gen Wireless and Optical Communications
   - Advanced LiDAR and RADAR technologies
   - Wireless Power Transfer
   - Smart Home & IoT devices
   - Novel Antenna Concepts
2. IMAGING & DISPLAY
   - Next-gen Imaging and Sensing Concepts
   - Flat and Tunable Optics
   - OLED/LED Light Extraction
   - 3D Imaging and Stereoscopic Displays
3. ENERGY & ENVIRONMENT
   - Solar Power and Light Management
   - Thermal Radiation Control
   - Energy Storage (Batteries, Supercapacitors)
   - Energy Harvesting (Geothermal, Thermoelectric)
   - Smart City Applications
4. HEALTHCARE
   - Medical Imaging
   - Smart Bio-Sensors
   - Wearable Devices
   - Neuro-Sensing
5. AEROSPACE & DEFENSE
   - Tunable Optics (e.g., Electro-optics)
   - Directed Energy and Countermeasures
   - Thermal Imaging and Signature Control
   - Safety and Protection
6. WAY BEYOND TECH (define-an-app)
   - New metamaterial concepts
   - Extreme EM parameters (e.g., ENZ, hi-μ)
   - Extreme spatial dispersion
   - Anomalous EM behavior
   - Topological metamaterials
   - Time-switched metamaterials
   - Quantum metamaterials . . . *and more…*

Thank You

themos.kallos@metamaterial.com

META®
Go Beyond.

Backup Slides

Go Beyond.

metaOPTIX™ HOEs for illuminators

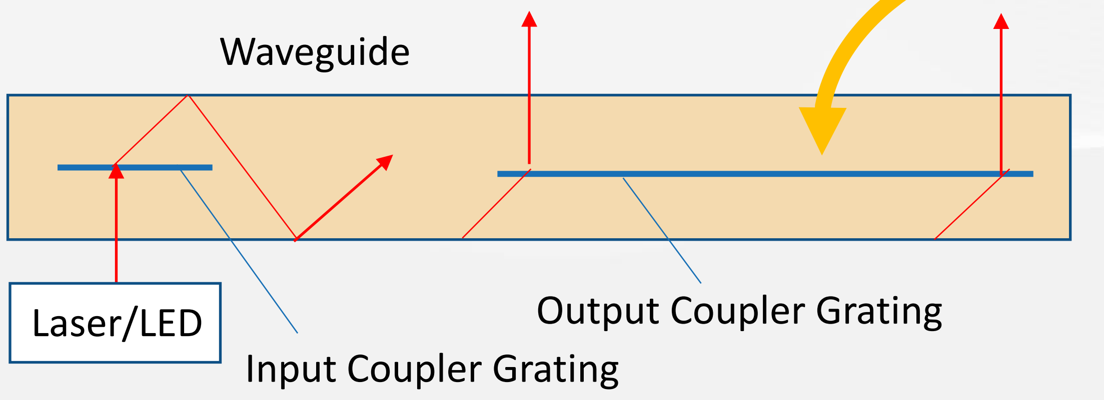
Problem

- Imaging instrumentation is widely used in fields as diverse as medicine and industrial process monitoring.
- Diverse applications such as optical microscopy, machine vision, fluorescence imaging, and Raman imaging require optimal illumination of the subject. Issues
  - ➢ Optical and mechanical complexity resulting from diverse illumination paths
  - ➢ Optical access (illumination and imaging) limitations set by bulky light sources and optics
  - ➢ Form factor , reconfigurability, manufacturability and cost.

Solution

Waveguides incorporation metaOPTIX™ HOEs and nanostructures offer a transparent, thin, low cost illumination solution for light management in a diverse range of imaging applications.

Basic Concept



Optical Functions

- Illumination expansion
- Beam geometry shaping
- Illumination structures: diffuse, uniform, structured light, etc.
- Polarization control
- Optical power for light condensing and collection
- Wavelength diversity
- Angular diversity
- Multiplexed optical functions
- Switchable optical functions
- SERS integration: pump beam management and signal collection

Prescription Cast Lenses for AR Displays

metaFUSION™ Technology

- metaFUSION™ combines META functional metasurface technology with precision high-volume automated cast lens technology and speciality substrates/foils .
- metaFUSION™ lenses are directly cast into the final correction using a library of >2,000 prescription molds. This requires significantly less material, energy and water than conventional production, which involves milling and grinding an oversized lens blank.
- The metaFUSION™ process requires a fraction of the energy. Typically, a corrective lens is cured in about 50 hours at >100C ; metaFUSION™ technology needs just10 seconds.
- Since metaFUSION™ lenses are poured and do not need grinding, no water is required in the production process. The metaFUSION™ coating process, based on plasma enhanced chemical vapor deposition (PECVD), is environmentally friendly and achieves superior scratch and abrasion resistance without using wet chemistry.
- metaFUSION™ enables a diversity of AR glasses applications by encapsulating functional metamaterial films within a prescription lens.





$1.5B Augmented Reality Eyewear Market

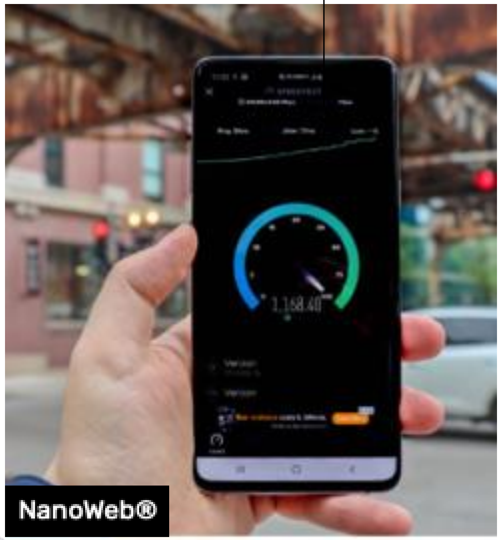
Source: BCC Research

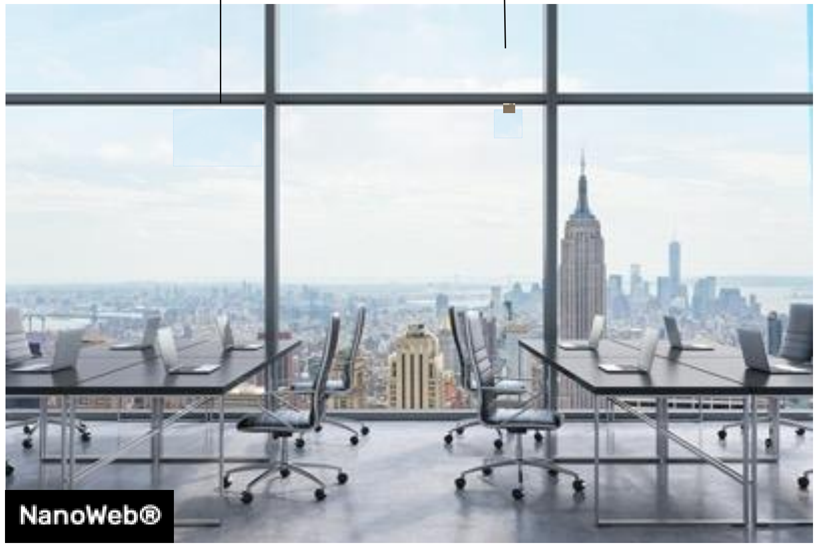
Increased performance through
low sheet resistance <10 Ohm/sqr

On most substrates
e.g. PET, Glass, Sapphire

Flexible films adapt to
different shapes

Up to 98% Transparency





META NanoWeb® Anti-Fogging Film

- **PROBLEM** - Masks and eyewear often become fogged disrupting the wearer's vision. The problem is acute in dive and gas masks, which are not quickly removable.
- **SOLUTION** – Apply META's Nanoweb film to eyewear inner surfaces to eliminate temperature gradients between the lenses and surrounding air near the face. Now moisture cannot condense; fogging disappears.
  - A NanoWeb® ~500 nm diameter wire mesh can carry electricity, which converts into heat on the lens via Ohm's Law.
  - The defogging performance depends on the amount of heat that can be deposited. While Nanoweb cannot change the amount of heat need to defog, it can carry high heat density, > 10,000 W/m2, enabling faster defogging.
  - NanoWeb® remains highly transparency; user's vision is not impaired.

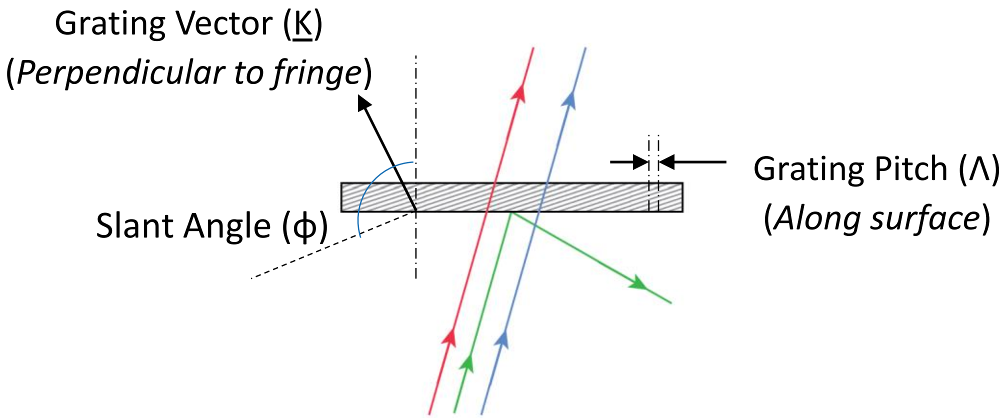
META Nano-heater to Protect Sensors - Transparent to RADAR and LIDAR Simultaneously

PROBLEM - ADAS and Autonomous vehicles depend on an array of cameras and sensors to "see" and understand their surroundings

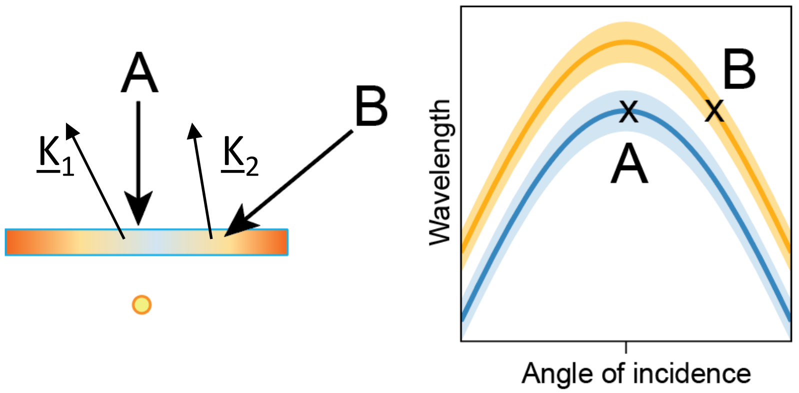
SOLUTION - META's NANOWEB® transparent conductive film provides de-icing and defogging without blocking the camera/sensor functions

META Spatially-Varying Holographic Conformal Filters

Slanted Grating Reflection Filters



Spatially Varying Reflection Filters



- HOE diffractive properties depend primarily on pitch (Λ) and slant angle (ϕ), one or both of which may vary across the HOE.
- Reflection directions are determined by the local grating vector(K).
- A uniform conformal filter will not diffract rays of the same wavelength efficiently at all angles of incidence.
- META spatially-varying reflection filters can be optimised to provide narrowband high OD blocking and high out of band transmission and can be formed on large area polymer films.