Metamaterial Technologies Inc.

Mastering Light

Laser Filtering, Metamaterials, and Commercializing Through the Lens of the Mythical Person Month

Themos Kallos

Co-founder

Chief Science Officer

Outline

- About MTI
- Laser Filtering
  - Problem
  - Solution
  - Technical Challenges
- Rolling Mask Lithography
  - Nanoweb
- How much effort to commercialize an optical metamaterial?

About MTI

HALIFAX, NS

MTI head office

LONDON, UK

R&D and EU Sales Office

PLEASANTON, CA

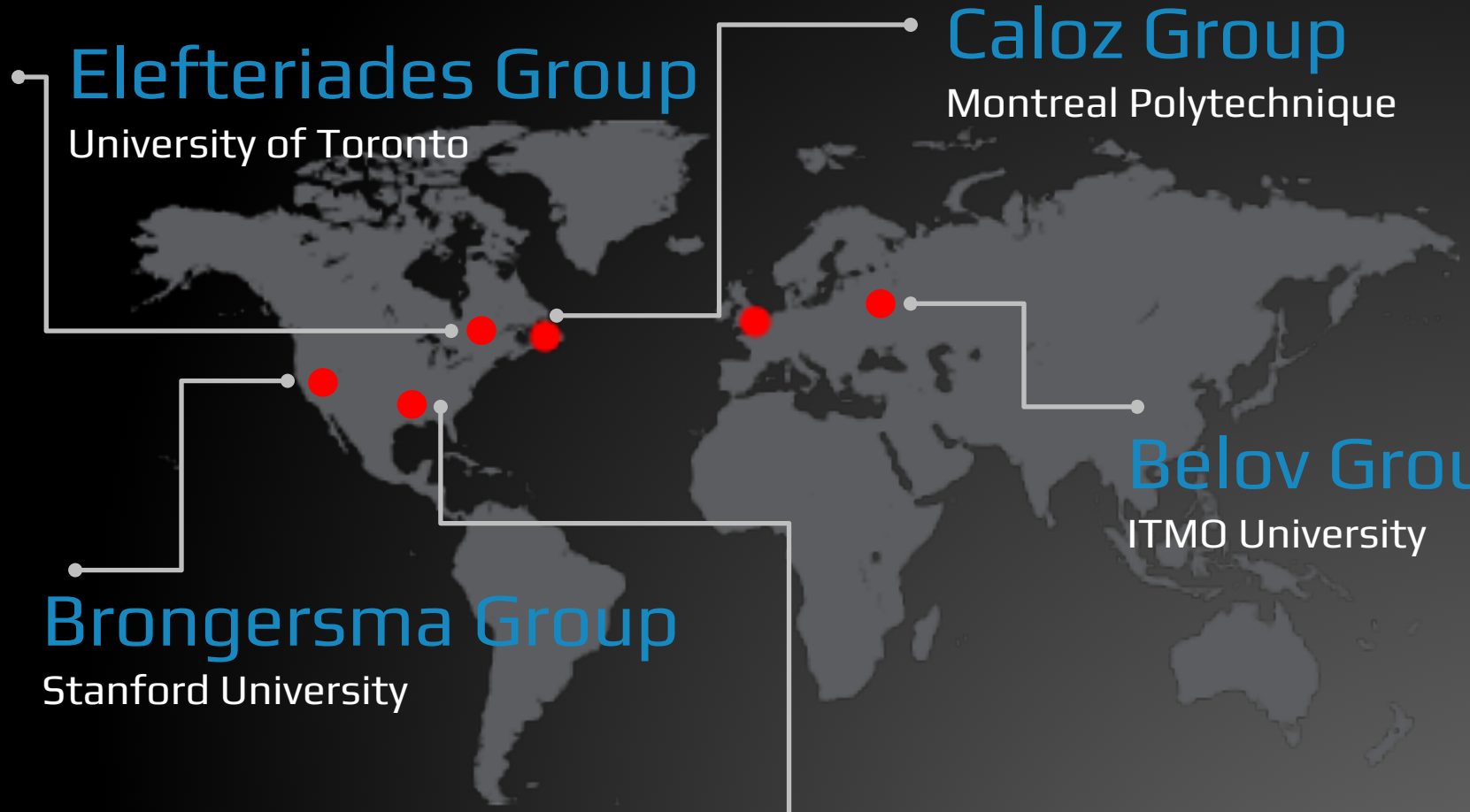
Rolling Mask Lithography Center

Founded in 2010

21 People

19 Patent Families

metamaterial.com



Elefteriades Group
University of Toronto

Caloz Group
Montreal Polytechnique

Belov Group
ITMO University

Brongersma Group
Stanford University

Alù Group
University of Texas at Austin

THE UNIVERSITY OF TEXAS AT AUSTIN

ITMO UNIVERSITY

Stanford University

POLYTECHNIQUE MONTRÉAL

UNIVERSITY OF TORONTO

The Core Team

George Palikaras,
Founder & CEO
-Ph.D in Metamaterials
-Goldman Sachs Award
-Founder two-startups
-28 patents

Themos Kallos,
Co-Founder & CSO
-Ph.D in Plasma Physics
-IEEE Plasma Physics Thesis Award
-28 patents

Boris Kobrin, CTO
-Founder and CEO-Rolith Inc.,
-30 patents.
-Ph.D. in Solid State Physics
-Serial entrepreneur

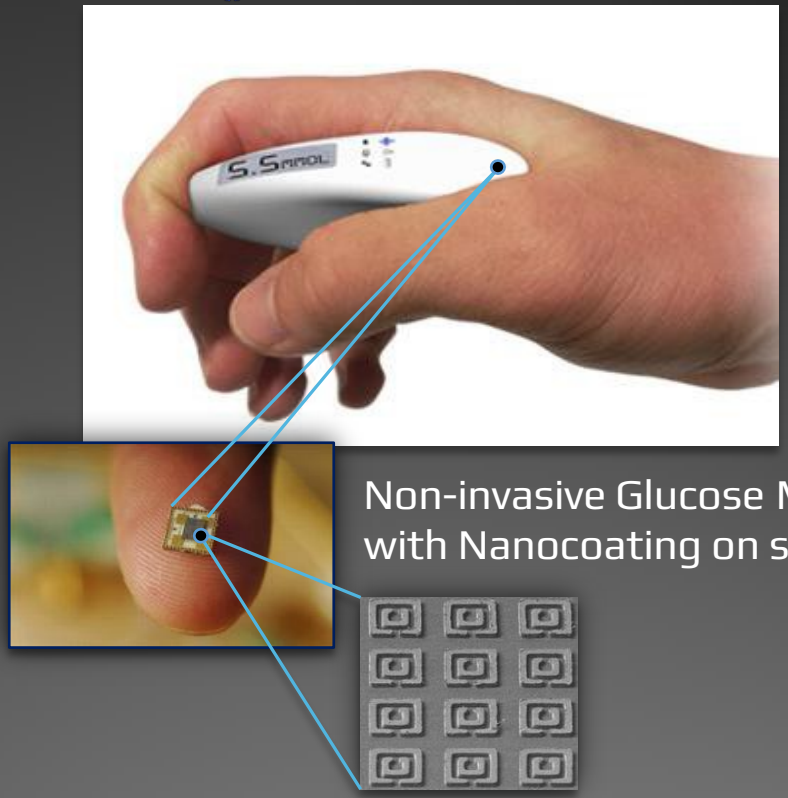
Prof. Mark Brongersma,
Stanford University
-Co-founder-Rolith Inc.,
-Ph.D. in Materials Science/Applied Physics
-NSF & Multiple science awards
- 16 patents, 170 Publications

Maurice Guitton, Chairman
Veteran Aerospace businessman. Former **President & CEO of Composites Atlantic** (Airbus Group). Maurice built 6 Aerospace qualified factories, launched and delivered over 10,000 aerospace parts to all major OEMs. Recipient of the French Legion of Honor, the French Order of Merit and the James Floyd Aeronautic Award of Canada.

Films to Increase
Solar Cell Efficiency

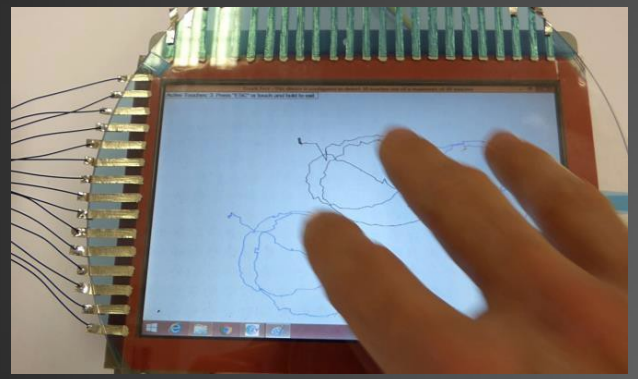
Films to Make LED"s
Brighter

glucowise



Non-invasive Glucose Monitor
with Nanocoating on sensor

Anti-counterfeiting
technology



Touch Sensor – increase image
quality and responsiveness

Software

It ‘s not a question whether you can make it;

Will anyone buy it?

Hardware

It ‘s not a question whether anyone will buy it;

Can you make it?

Applied Research

Make problem simpler;

Solve problem

Pure Research

Make problem harder;

Write paper

It is much easier to get a result than to get an answer

Laser Filtering

What’s the Problem?

Legitimate use: Amateur Astronomy

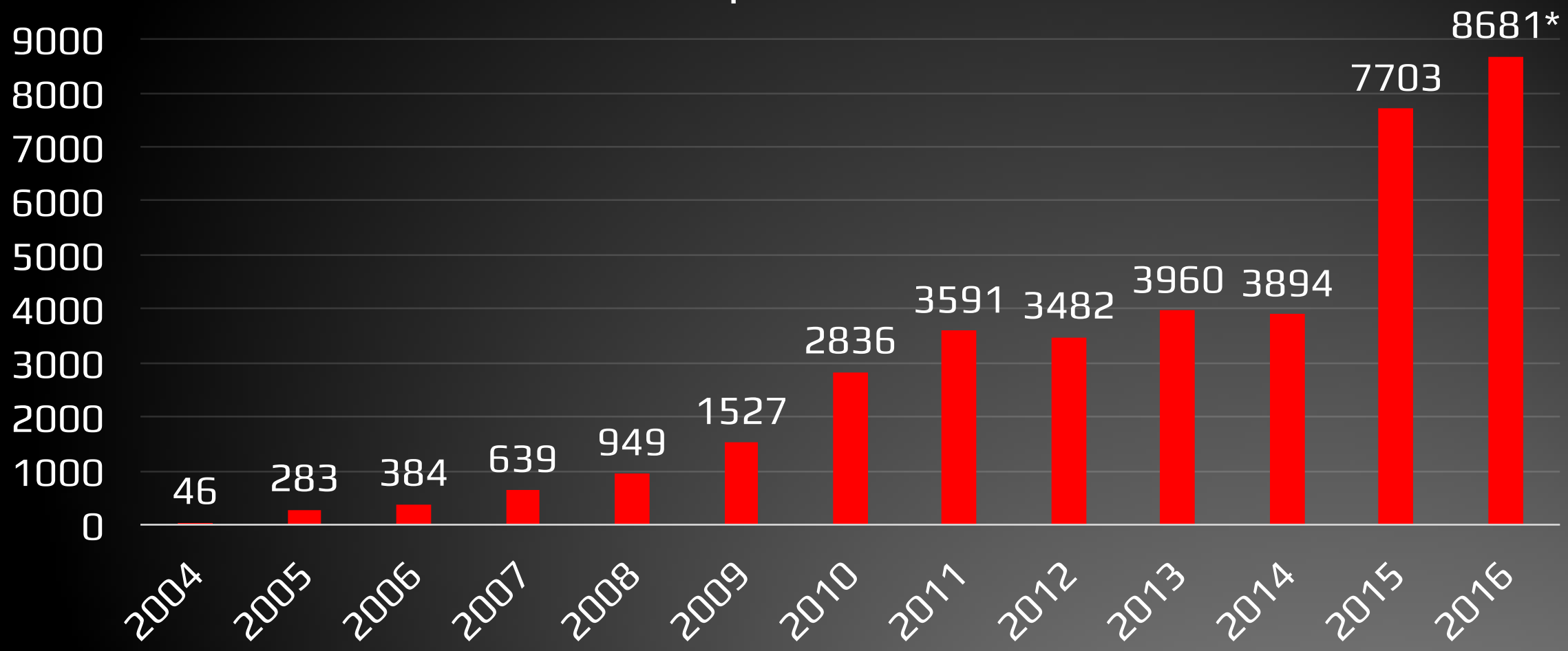
Laser Attacks in Aviation

- Health risk for pilots
- Security risk for aircraft
- Safety risk for passengers
- Economic risks (go-arounds, missing flights)

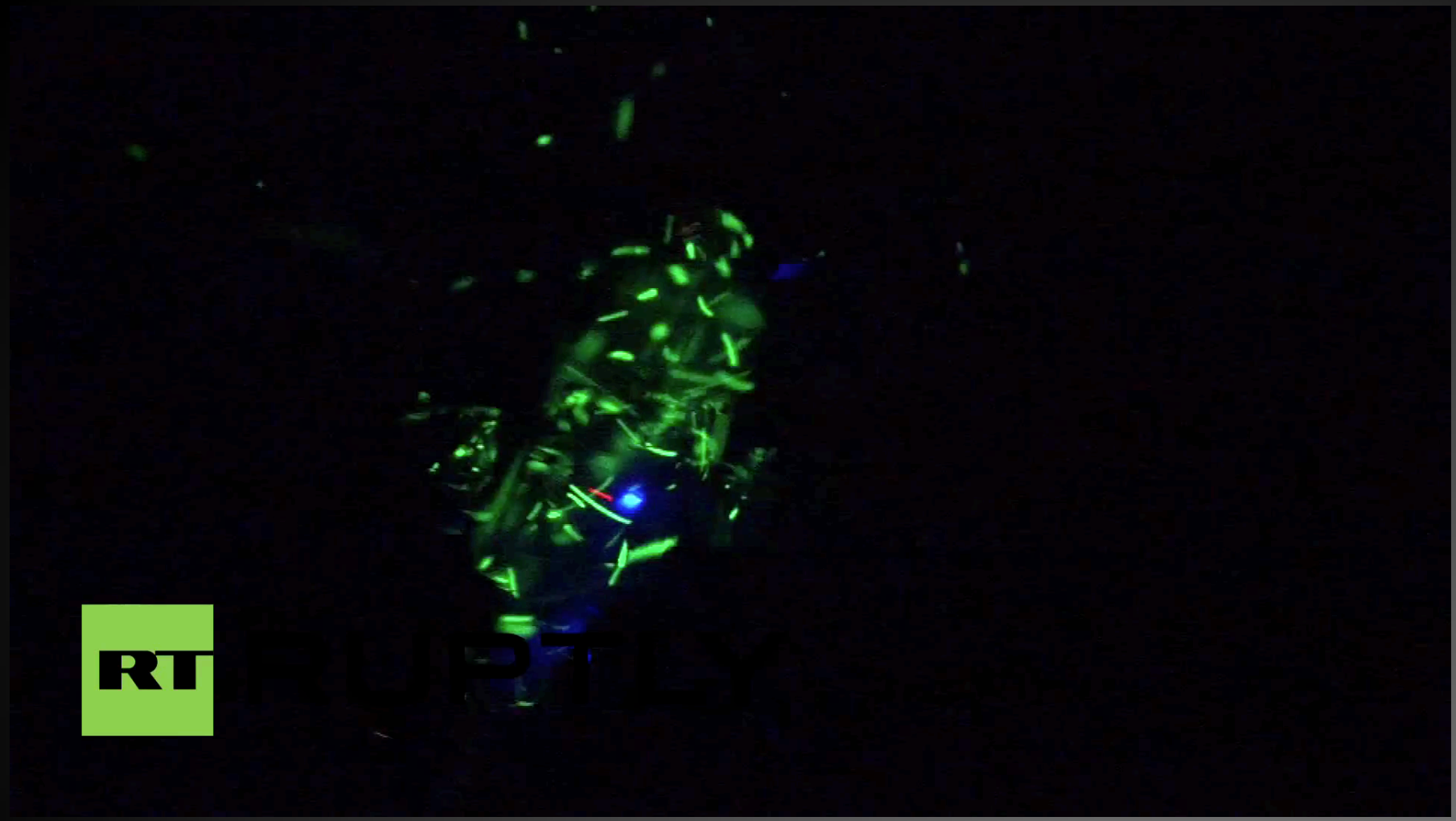
Image Source: FAA

Sources CNN , May 2015

Laser illuminations reported to FAA, annual total

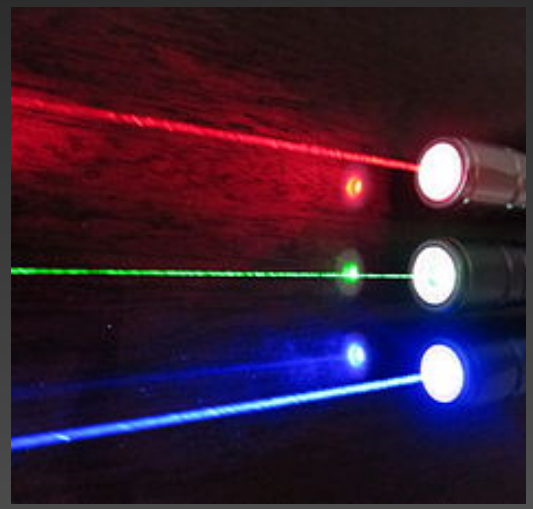


Sources: FAA, Laserpointersafety.com

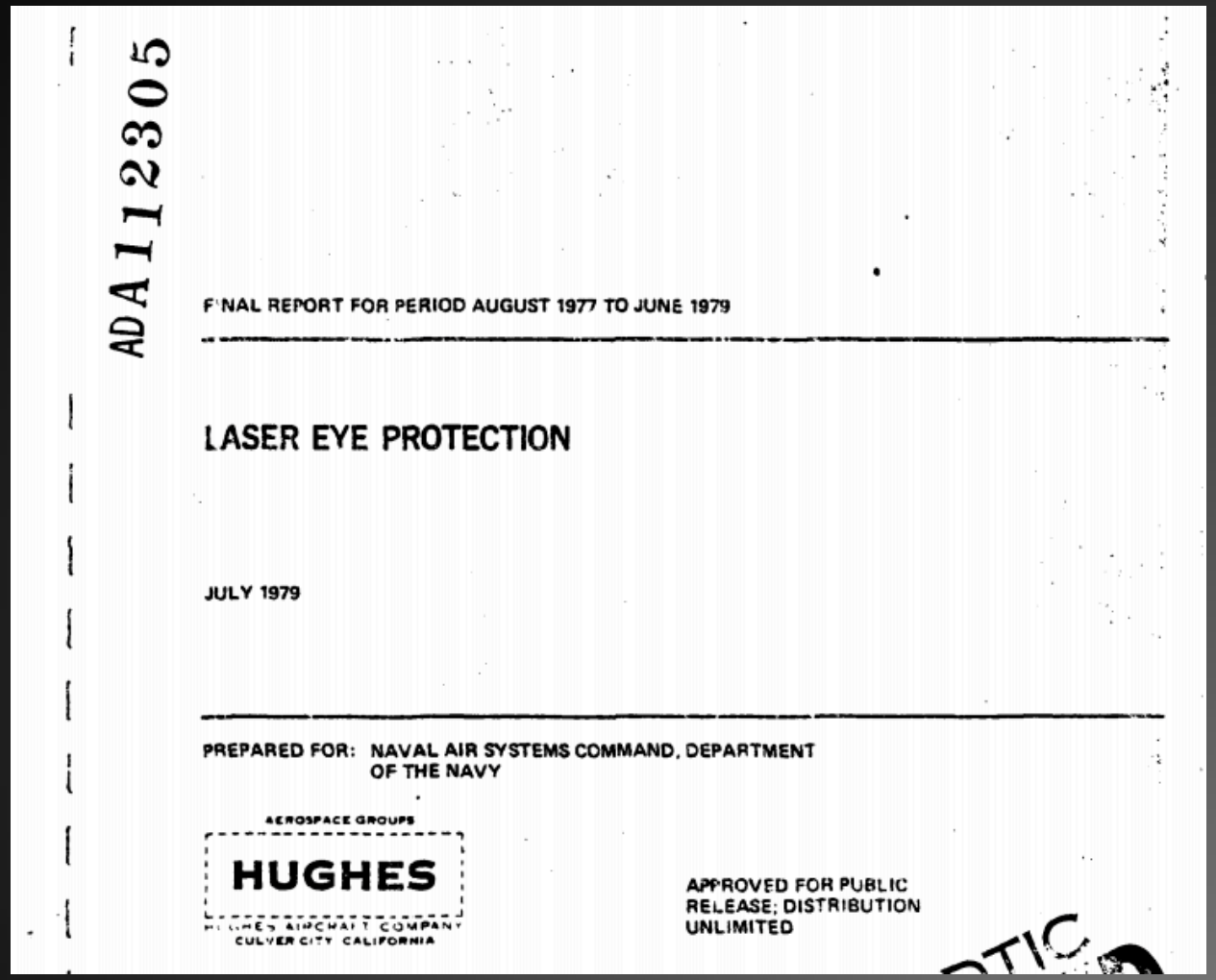


Why is this a Growing Problem?

- High Laser Availability
- Reduced Cost
  - Handheld 2W for <$99
- Post-telecom Boom Effect



"Nanostructured Thin Film Laser Protective Filters for the Aviation Market: A Market Study", BGA Associates, Sep 2012



AD A112305

FINAL REPORT FOR PERIOD AUGUST 1977 TO JUNE 1979

LASER EYE PROTECTION

JULY 1979

PREPARED FOR: NAVAL AIR SYSTEMS COMMAND, DEPARTMENT OF THE NAVY

AEROSPACE GROUPS

HUGHES

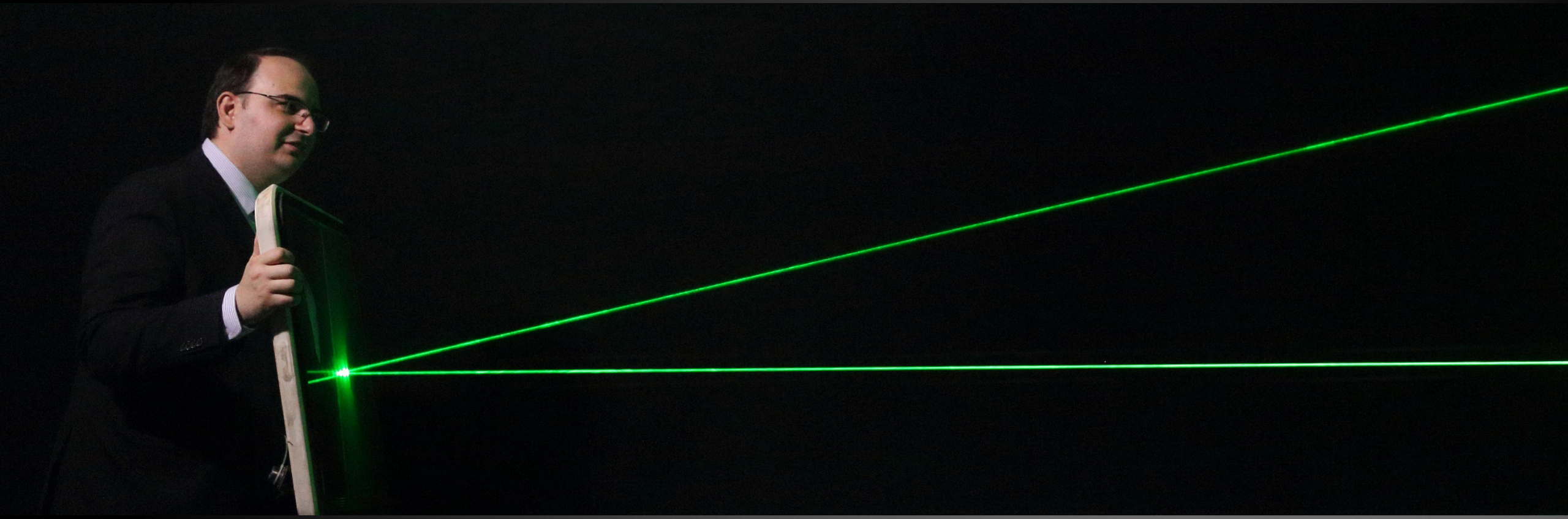
HUGHES AIRCRAFT COMPANY
CULVER CITY, CALIFORNIA

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

DTIC

What’s the Solution?

metaAIR

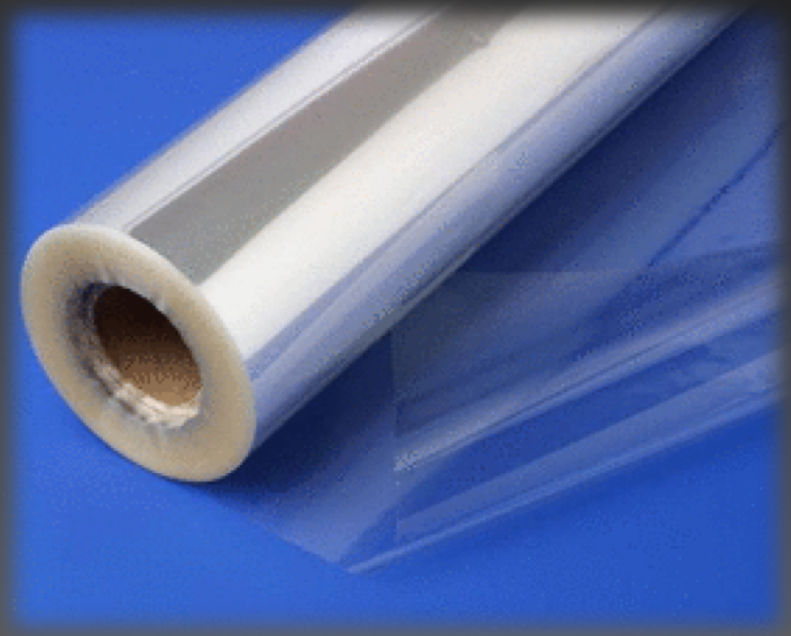


metaAIR

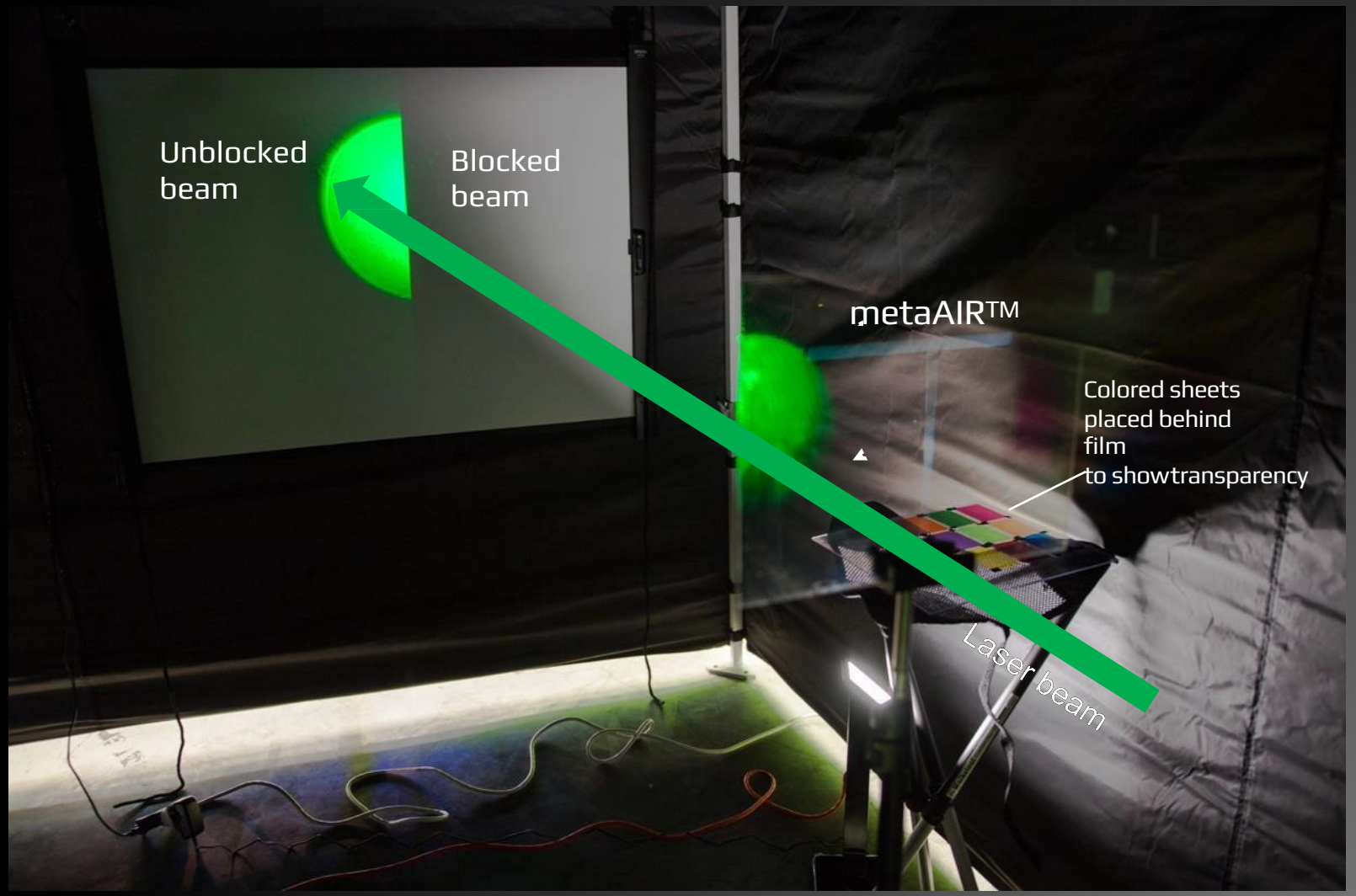
Meter-scale
holographic notch filter films
for aircraft

Basic Optical Requirements

- Optical Density > 2.0
- Bandgap FWHM < 20nm
- Angular bandwidth > ±45°
- Visual Light Transmission (VLT) > 50%
- Surface area ~m^2
- Neutral Color



metaAIR ™ - Blocking Harmful Laser Light



metaAIR™ - Ultimate Clarity

Multiple Industry Applications

Transportation

Law Enforcement

Aviation

Protective Eyewear

Defence

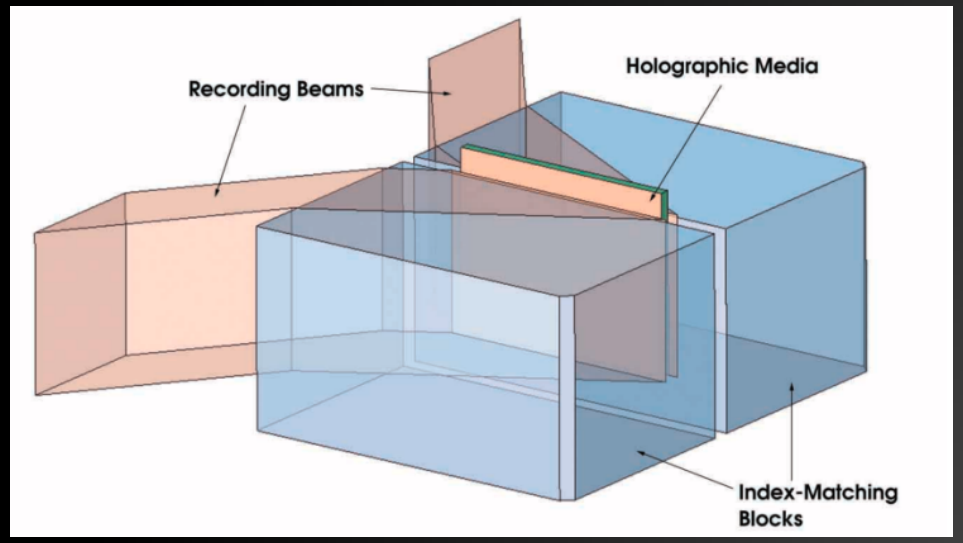
Self-driving car sensors and HUDs

Military

Night Vision Goggles

Technical Challenges

The Advantages of Holography

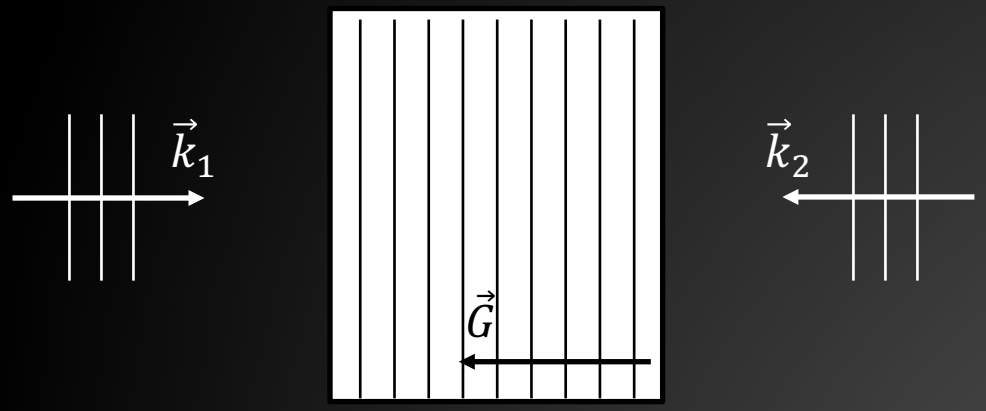


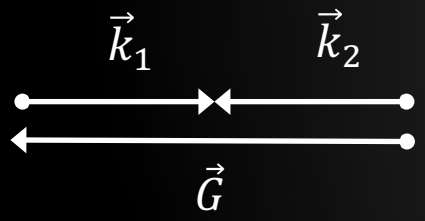
- Faster manufacturing compared to deposition/dye tech
- Scalable to over meter-wide surfaces
- Roll to roll production compatible
- Bendable film solutions due to the use of polymer materials
- Capable of recording complex gratings

Image Source: Ondax Inc.

Basic Reflection Gratings

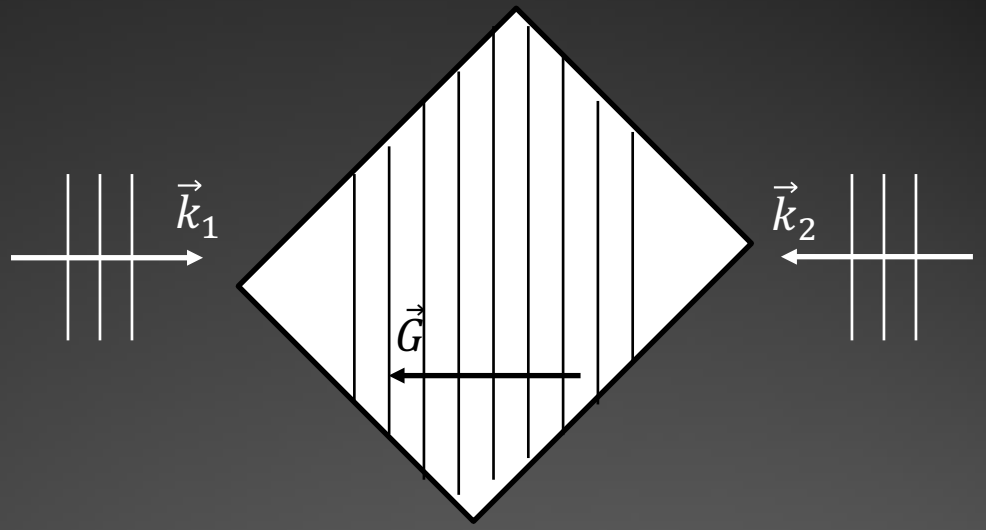
Conformal

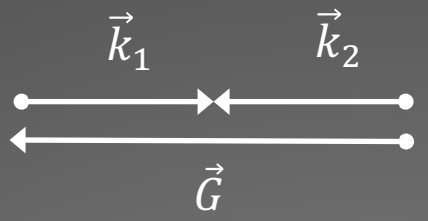




- k = 2π/λ
- G = 2π/Λ
- Λ = fringe spacing

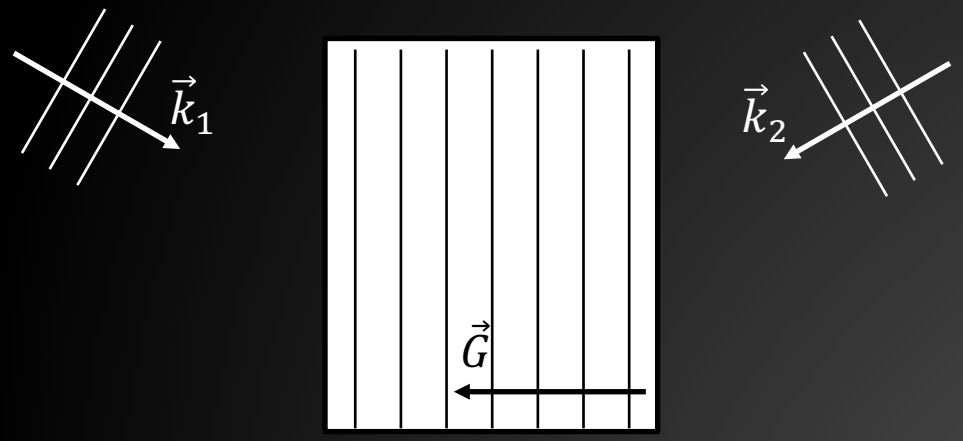
Fixed Slant (45º)

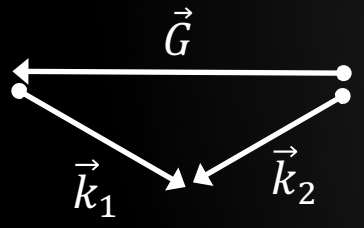




Other Reflection Gratings

"Chirped" Conformal

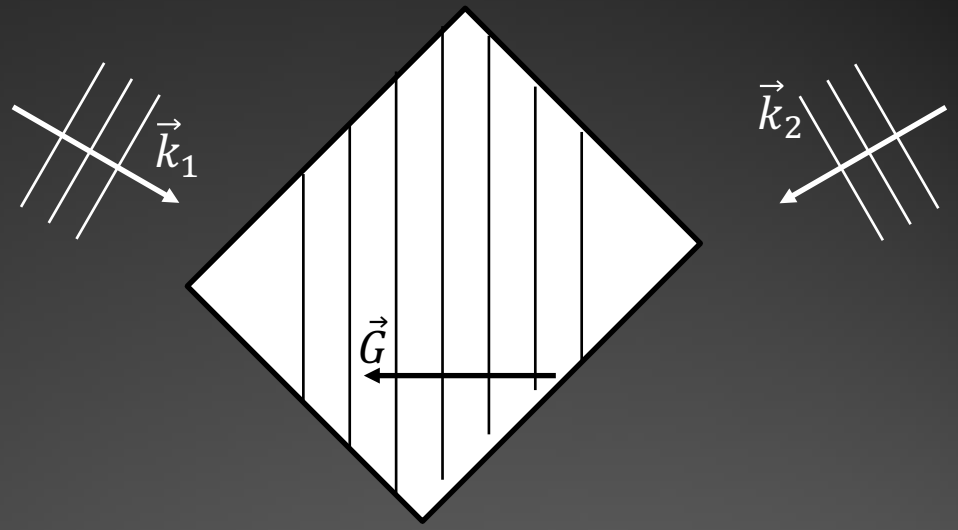


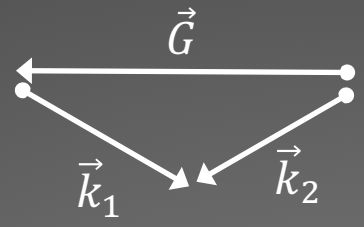


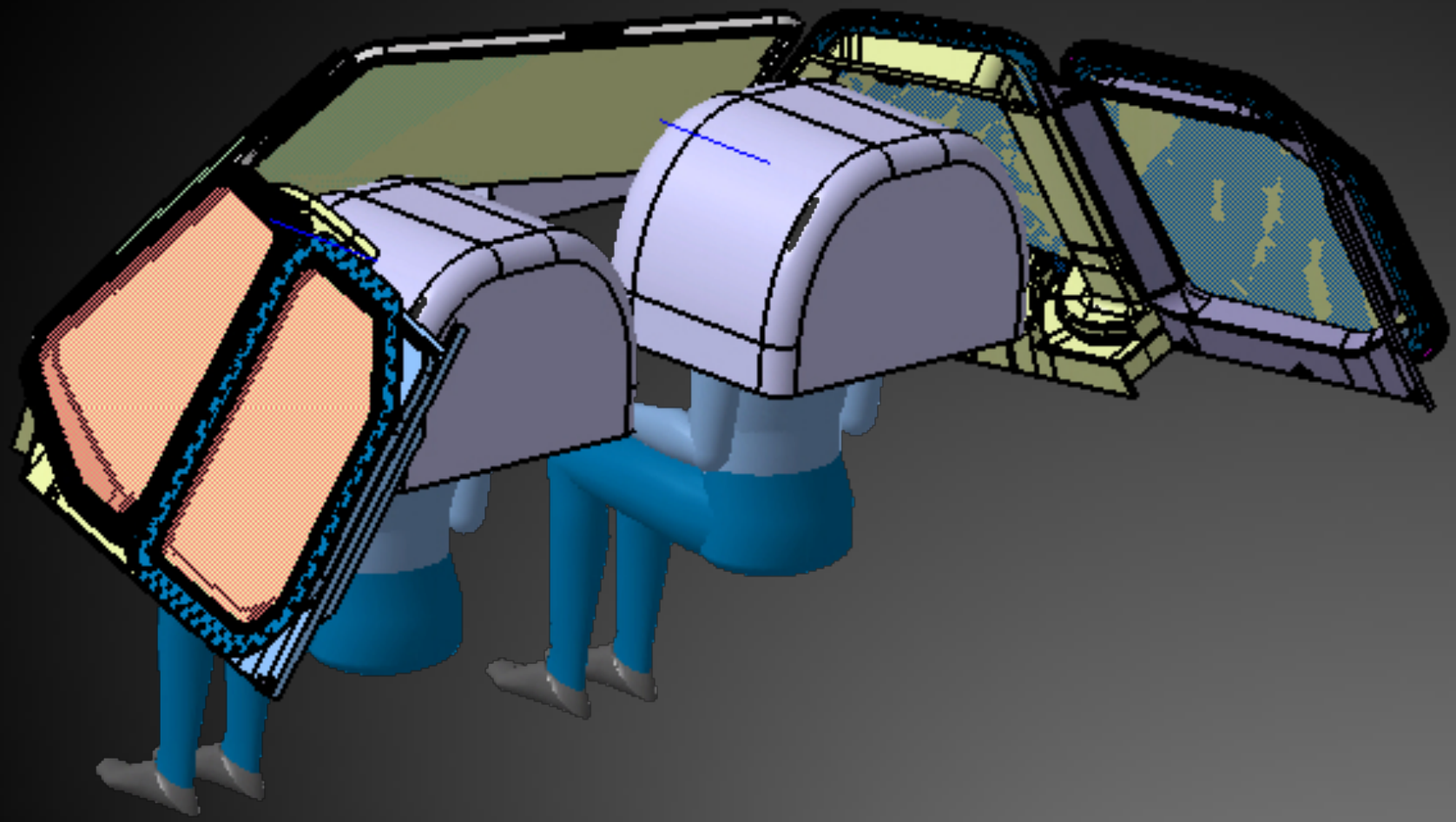
- G of chirped conformal < G of conformal
- (fringe spacing Λ is longer)
- G=2π/Λ

- Smaller angular bandwidth vs. conformal & fixed slant

"Chirped" Slant (45°)

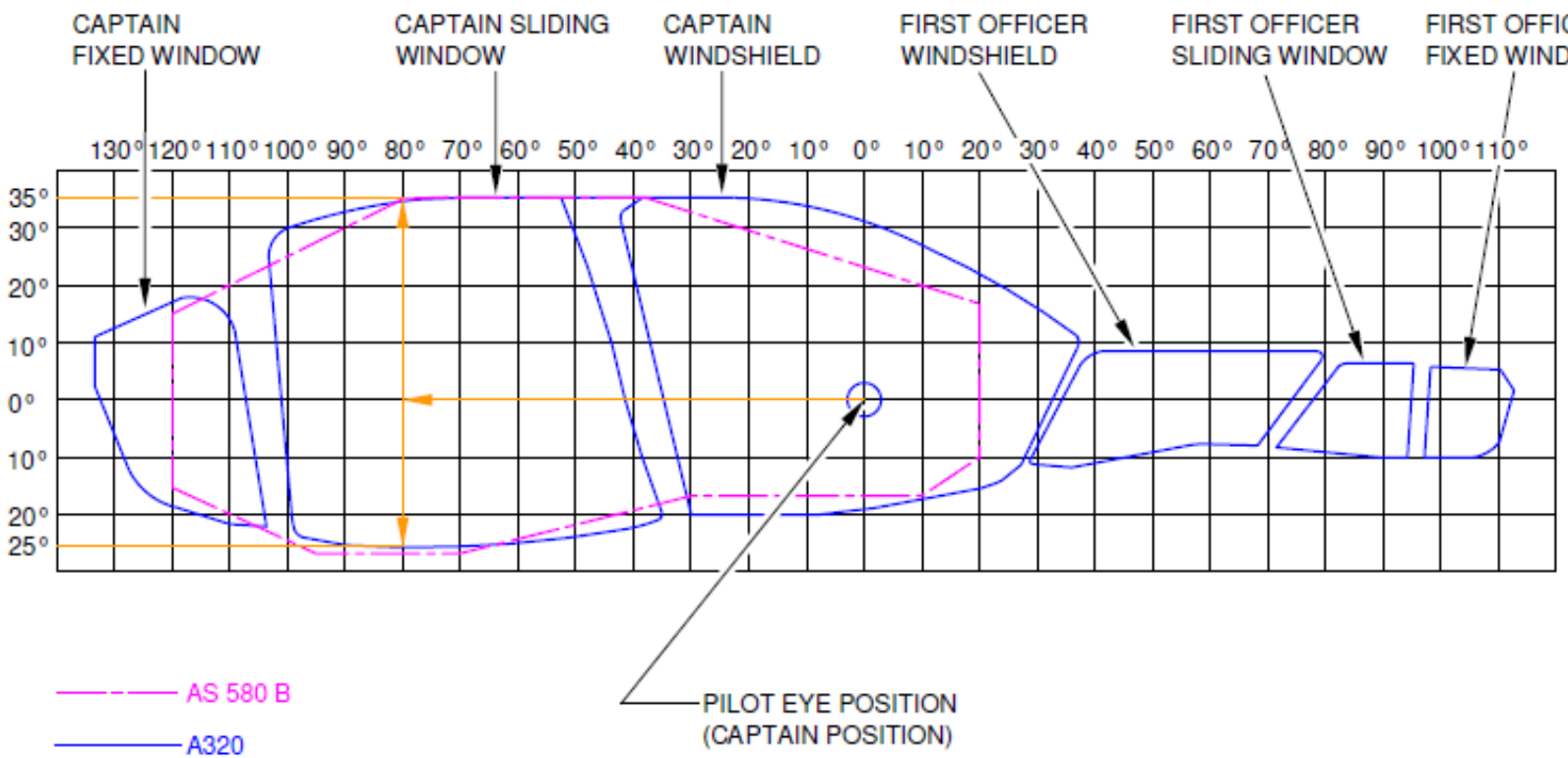






Binocular Visibility Through Windows from Captain Eye Position

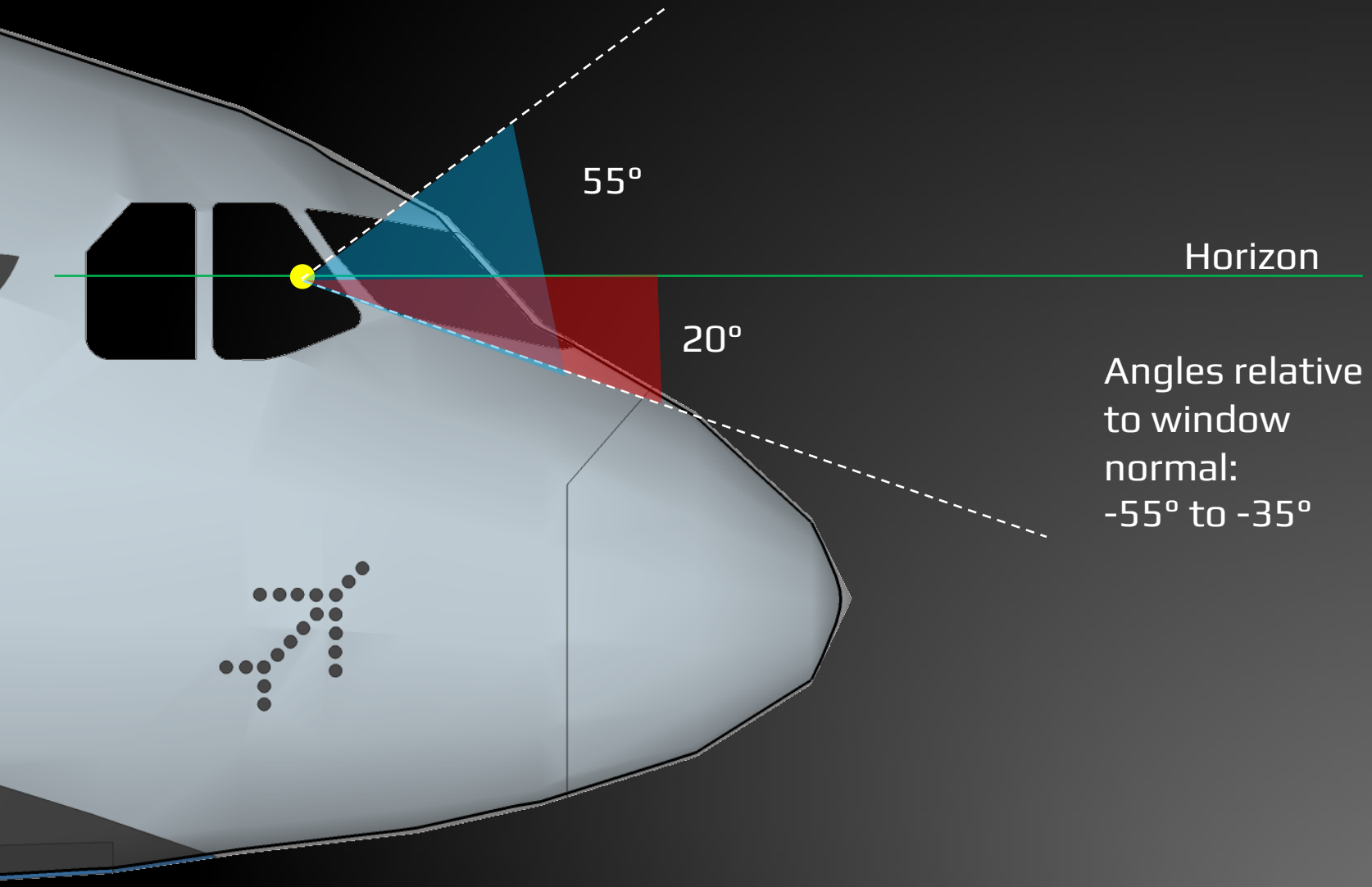
FIGURE-4-4-0-991-005-A01



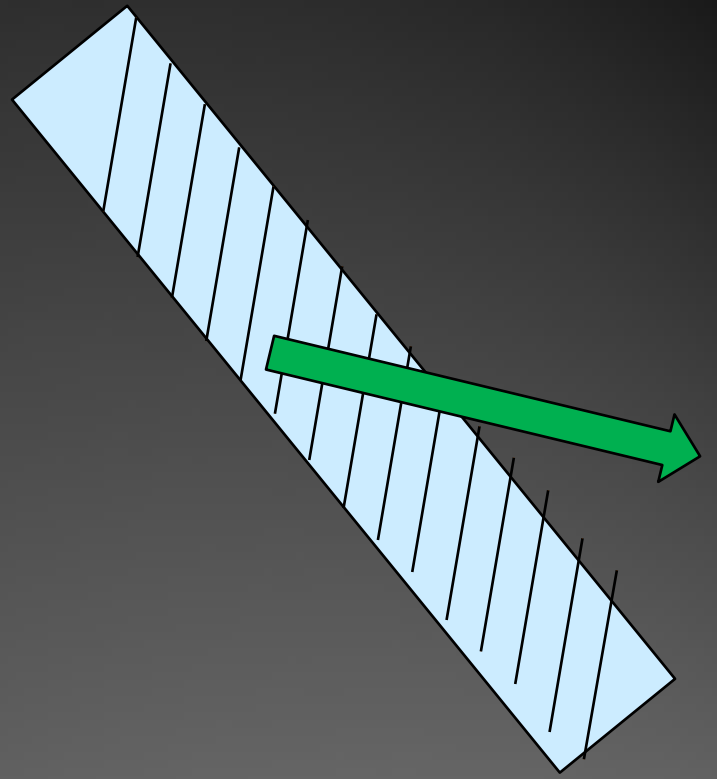
CAPTAIN FIELD OF VIEW SHOWN.
FIRST OFFICER FIELD OF VIEW SYMMETRICAL.

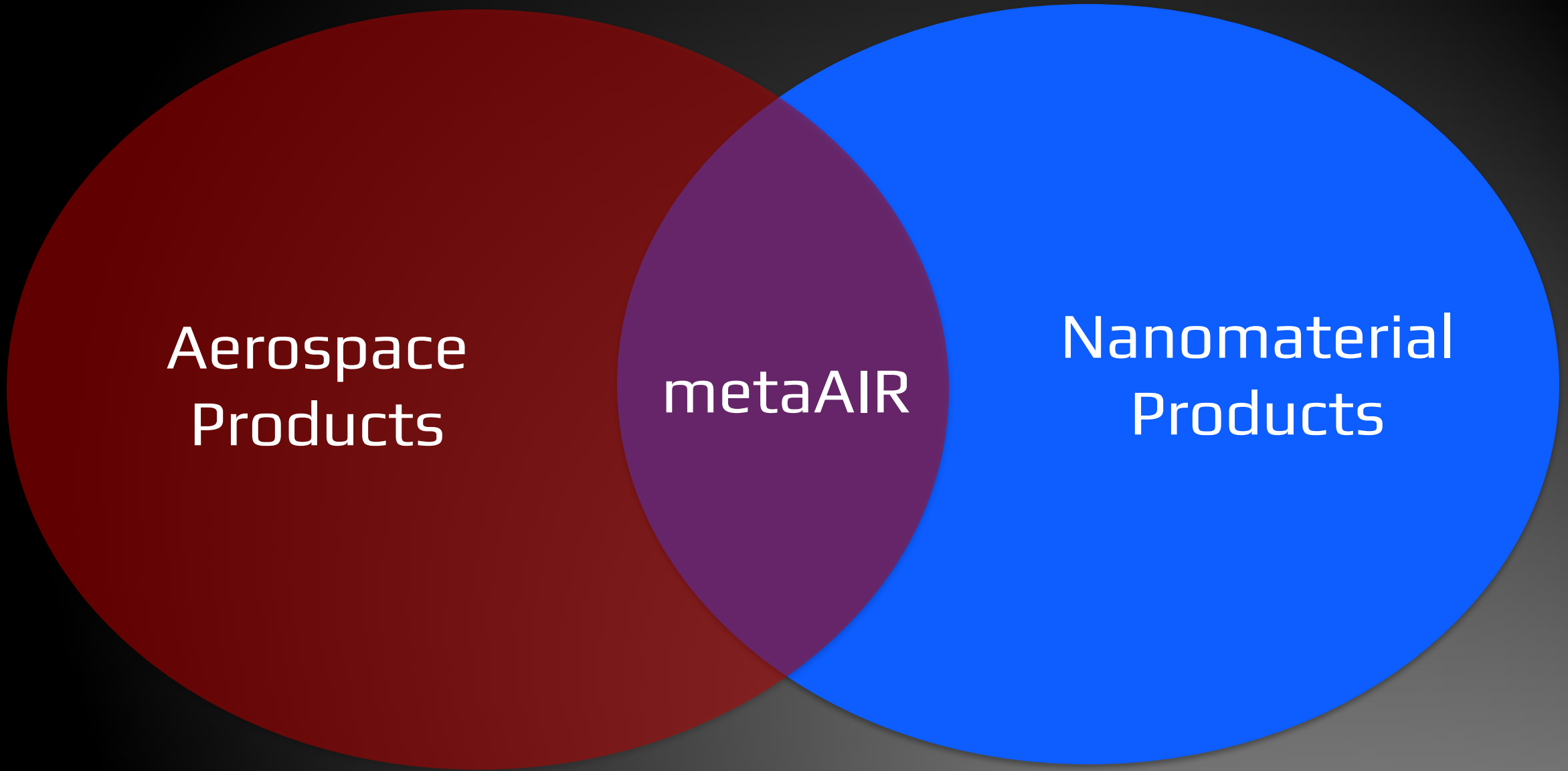
EXAMPLE: WHEN CAPTAIN TURNS HIS HEAD BY 80° LEFT, VISIBILITY WILL BE 35° UP AND 25° DOWN THROUGH THE SLIDING WINDOW FRAME.

N_AC_040400_1_005



Angles relative to window normal:
-55° to -35°



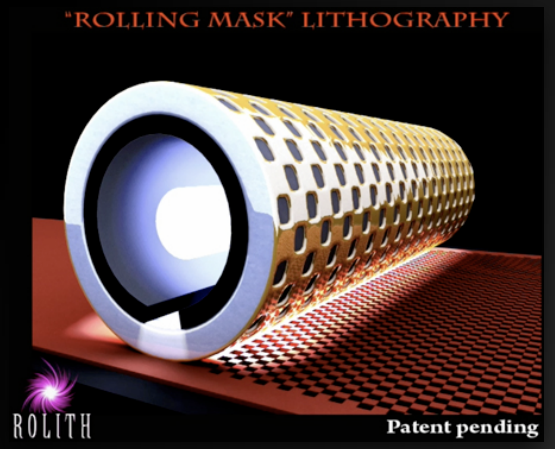


The Challenges for Metamaterial Fabrication

- Transparency for visible applications
- Large scale nanofabrication
  nm accuracy over meter surfaces
- Cost-effective fabrication
  $1-10 per cm^2 on volume production

Rolling Mask Lithography

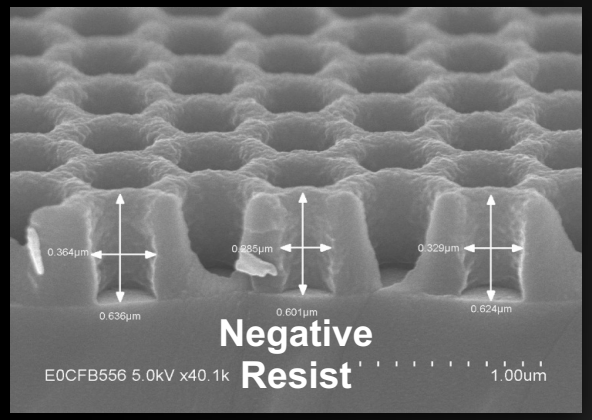
Metafabrication Platform: Rolling Mask Lithography - RML®

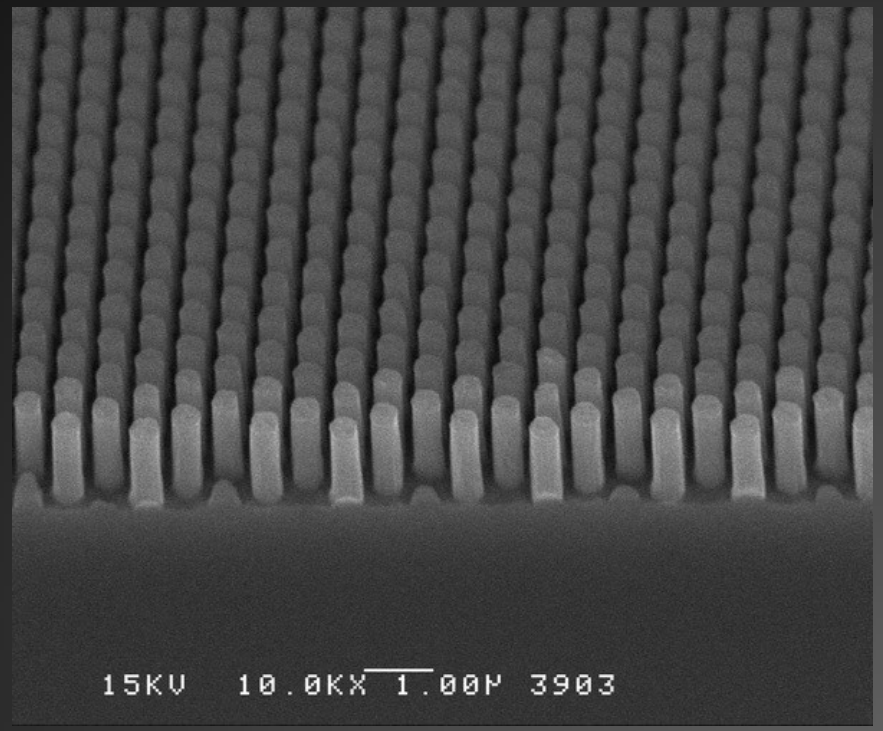


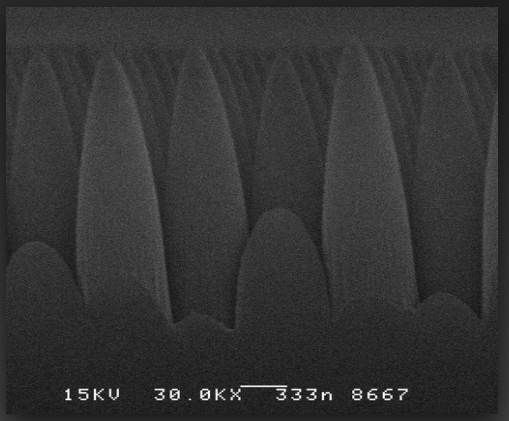
2nd Gen RML® Tool

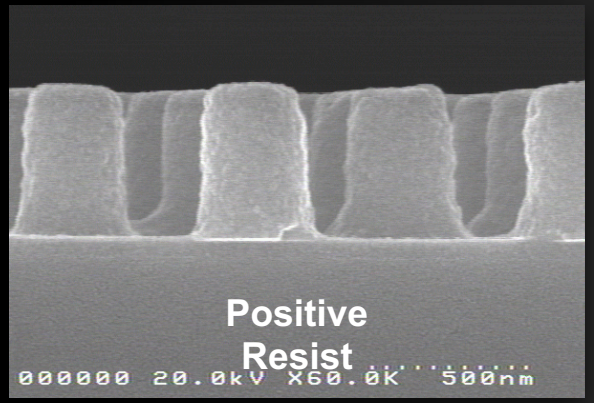
- "Rolling Mask Lithography" (RML®) - low cost, high resolution and large area nanopatterning
- Any substrate material (glass, semiconductors, flexible polymer, metal or glass films)
- Scale: up to 1m x 0.3 m (2nd Gen) and R2R continuous 1 m wide web (3rd Gen)
- Resolution: down to 150nm (2nd- Gen); 50 nm (3rd-Gen)
- Inexpensive (<$1M/tool) versus competition
- Throughput: up to 40m²/h (3rd-Gen)
- Cost target: $5/m² (3rd-Gen)

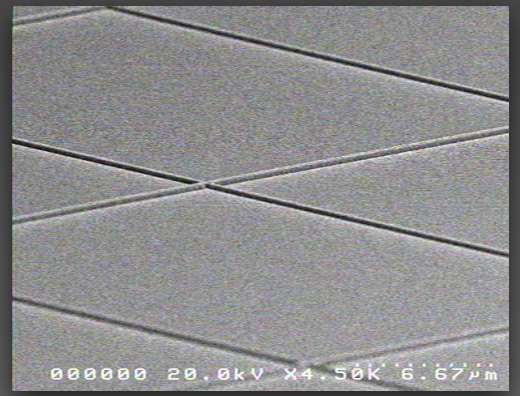
Examples of nanostructures - RML®









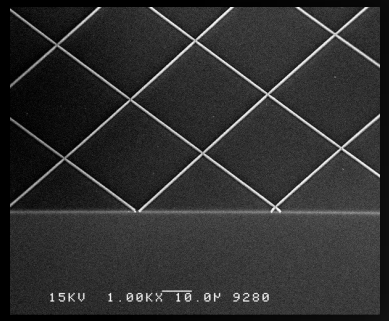


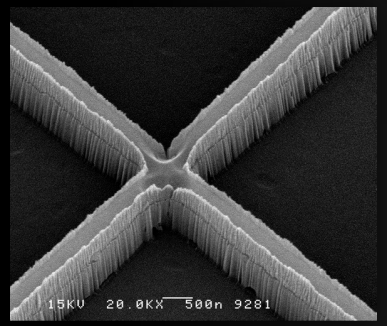
Nanoweb

Meter-scale
high-conductivity transparent
metal mesh

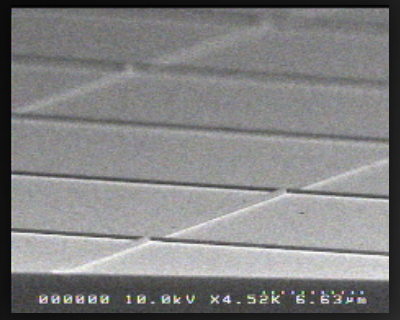
NanoWeb® Transparent Metal Mesh

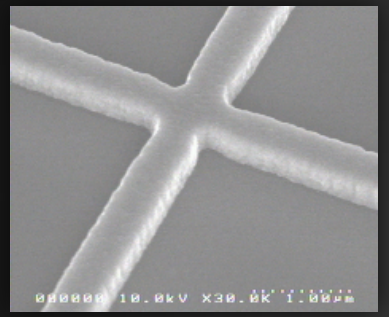
Al on Glass
(by RML™ + etching)



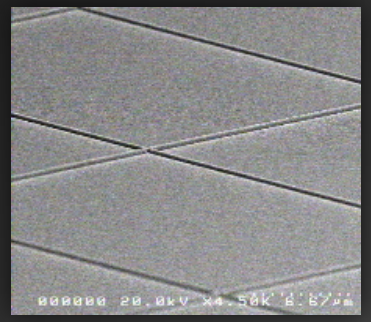


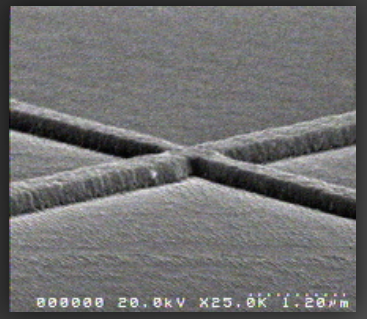
Ag on Glass
(by RML™ + lift-off)





Ag on PET Film
(by RML™ + lift-off)

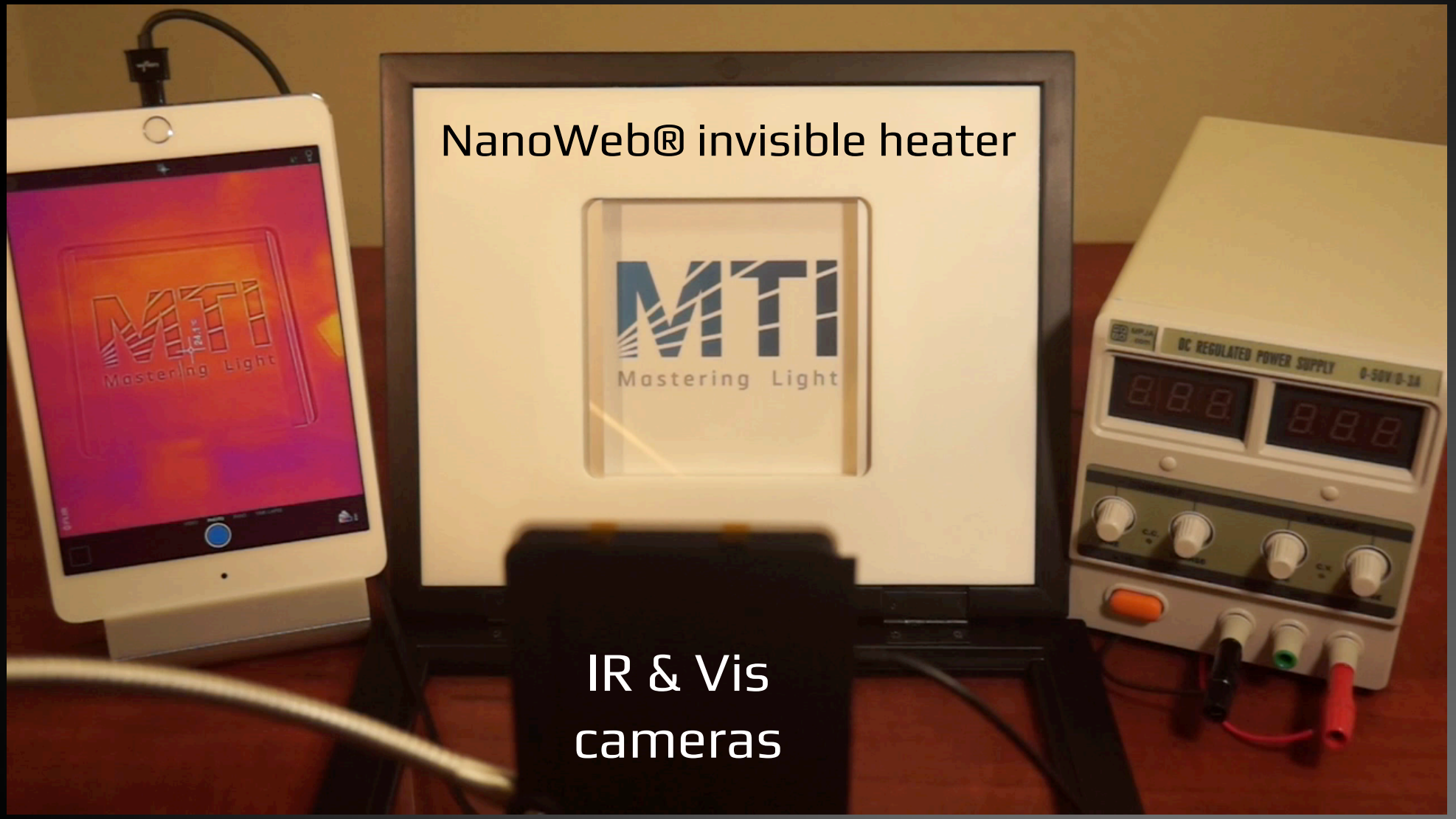




Low power & invisible anti-ice/fog solution

- **Fabrication: RML® lithography+metal deposition+photoresist lift-off**

- **Advantages against competition:**
  - Higher conductivity (lower power requirements)
  - Higher transmission
  - No coloration/tint
  - Compatible with flexible films
  - Compatible to any substrates
  - Available with any metals
  - **Invisible to the human eye**



How Much Effort?

Person – Month

Person – Year

1995

the mythical man-month

Essays on Software Engineering

Frederick P. Brooks, Jr.

Question

How much effort is needed to achieve something?

Get tenure

Write a fundable proposal

Reach first sale

Commercialize an optical metamaterial

Idea

More or less the same

(for similar target goals)

How many person-years of effort are required to commercialize an optical metamaterial?

Defines company size

Better planning of resources

Budget

How many person-years of effort are required to get tenure?

How many person-months of effort are required to publish a paper?

1 author, 1 paper in 1 year : 12 person-months

1 author, 2 papers in 1 year : 6 person-months

2 authors, 1 paper in 1 year : 24 person-months

2 authors, 2 papers in 1 year : 12 person-months

How many person-months of effort are required to publish a paper?

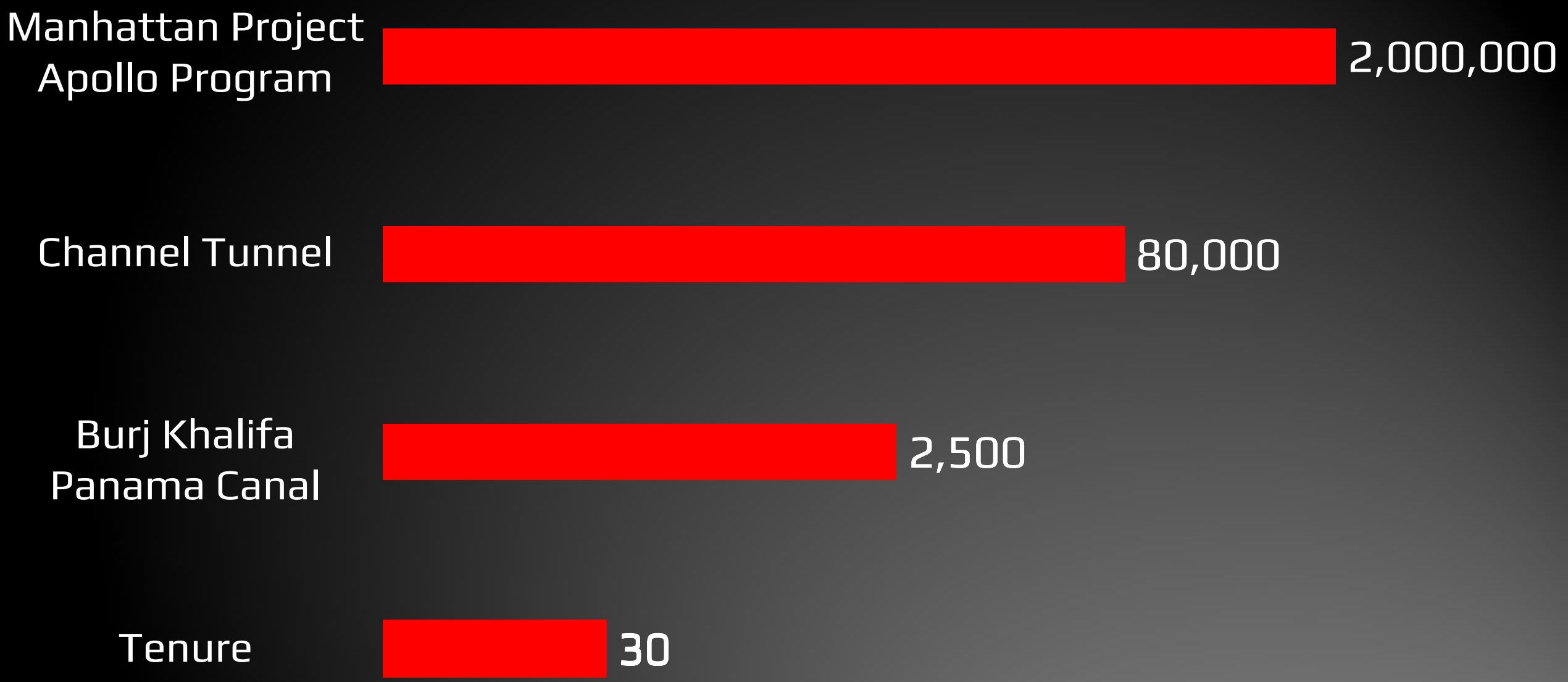
2.1 ± 1.0 *

* Equal author contributions;

How many person-years of effort are required to get tenure?

29 ± 2


How About Companies?



How many person-years of effort are required for a hardware company to reach first sale?

nest®

Started: April 2010
First Sale: October 2011
@ 75 employees
(1.5 year)

105 person – years

Started: June 2005
First Sale: June 2007
@ ~250 employees
(2.0 years)

625 person – years

Started: July 2003
First Sale: February 2008
@ ~250 employees
(4.5 years)

580 person – years

Conclusion

How many person-years of effort are required to commercialize an optical metamaterial?

500

“Themos,
I made marble look like
TRANSPARENT VEIL

You got this”

- Strazza

Thank you

themos.kallos@metamaterial.com