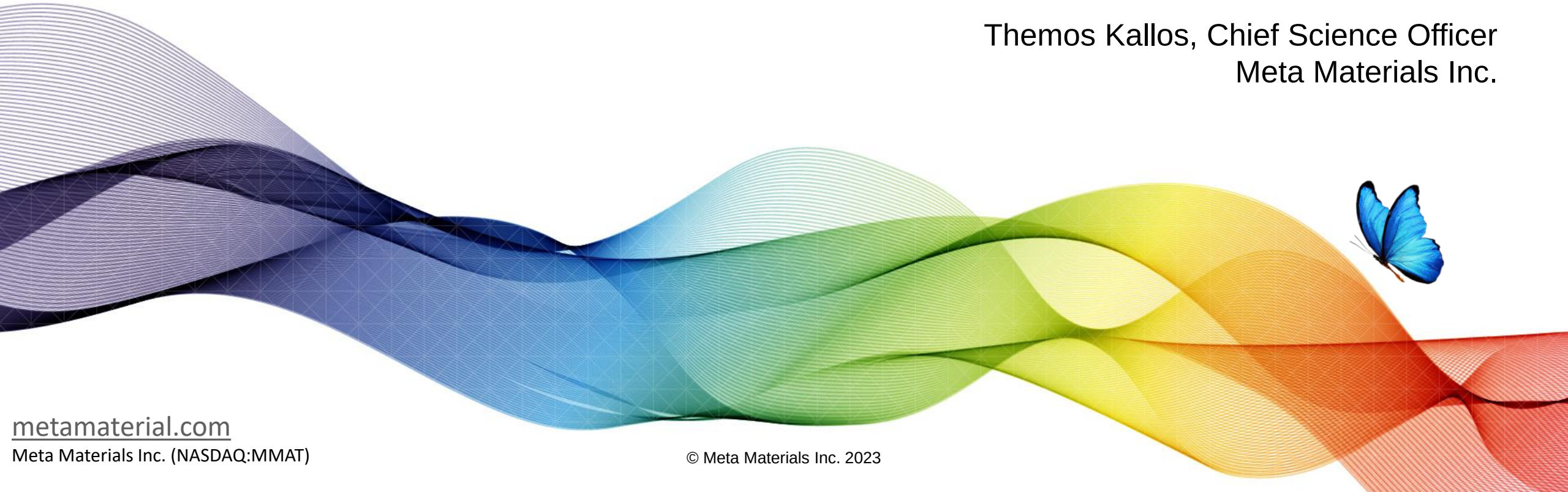
# Design and Manufacturing of Transparent Antennas for Satellite Communications

Themos Kallos, Chief Science Officer
Meta Materials Inc.



# Outline

- About Meta Materials Inc.
- NANOWEB® Platform Technology
- Transparent Antennas
- Manufacturing Techniques

# About META

# The META Timeline

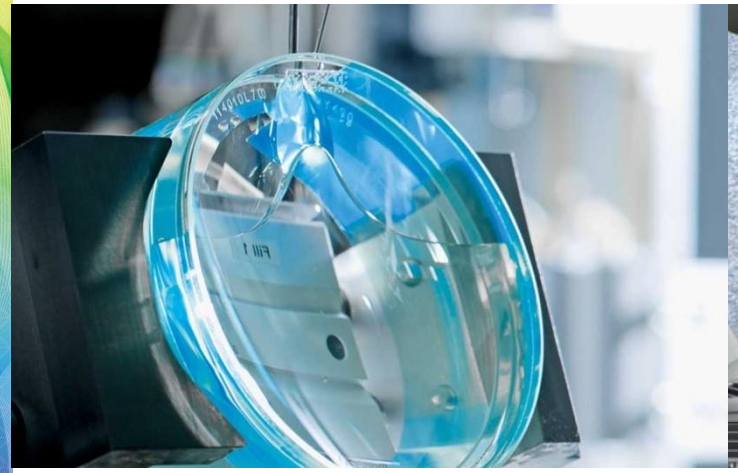
- **2021** — **1st Metamaterial Company on NASDAQ**
- **2011** — **META Founded (London, UK)**
- **2000** — **Negative Refraction Demonstrated**
- **1968** — **Veselago's Paper**
- **1865** — **Maxwell's Equations**
- **1492 AD** — **America Discovered**
- **55 BCE** — **Romans invade Britain**
- **776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

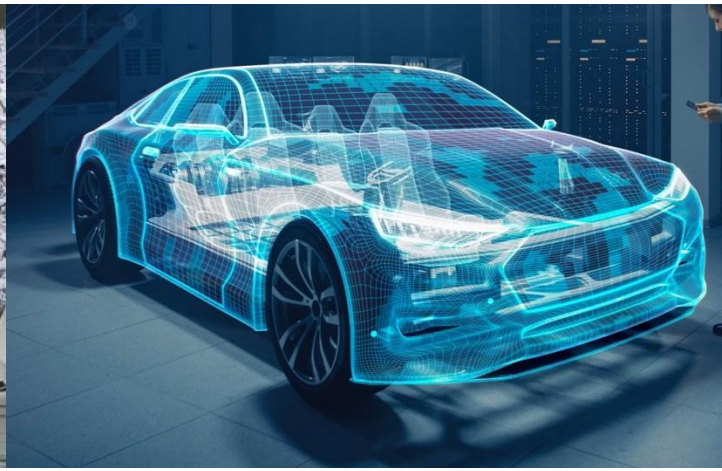


META® Go Beyond.

META®

Go Beyond.

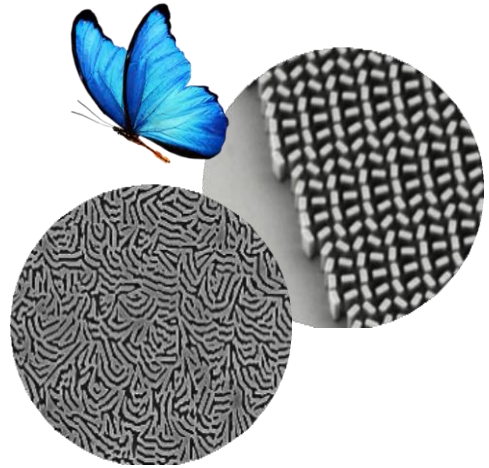




We deliver breakthrough performance, previously thought unattainable, by utilizing nanotechnology and metamaterials to design, integrate, and manufacture sustainable, highly-functional films & intelligent surfaces.

# The META® Core Capabilities

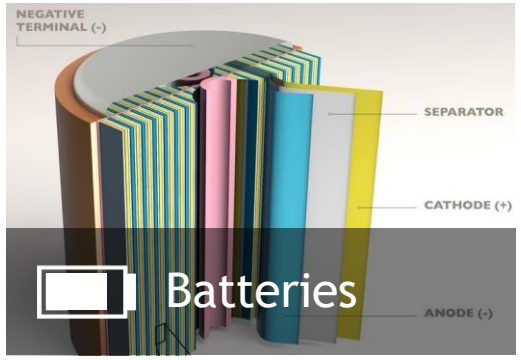
We are a world class designer, integrator and producer of functional films and intelligent surfaces, utilizing proprietary metamaterials that allow us to offer breakthrough technology and solutions across the following industries:















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# The META Design & Integration Advantage

**SPEED**

- META uses AI software to design a library of patterns for different applications and which can typically develop new custom solutions within hours vs months

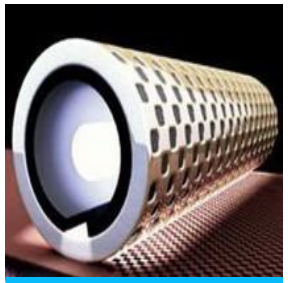
**SCALE**

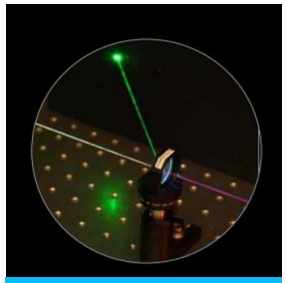
- META is one of the first companies to develop proprietary roll-to-roll production equipment to produce large area, high volume nanocomposites

**COST**

- Increasing the roll-to-roll web width and line speed should drive costs down to a few $/m$^2$

**TECHNOLOGY PILLARS**

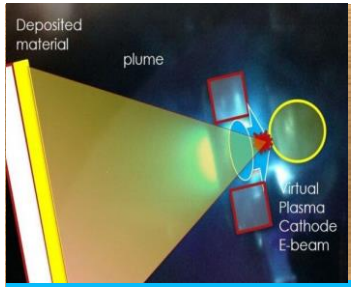

Lithography


Holography


AR Fusion®
Optical Combiner


Vlepsis™
Electro Optics


NPORE® Ceramic
Nanocomposites



PLASMAfusion™
High Speed Coating


Wireless Sensing



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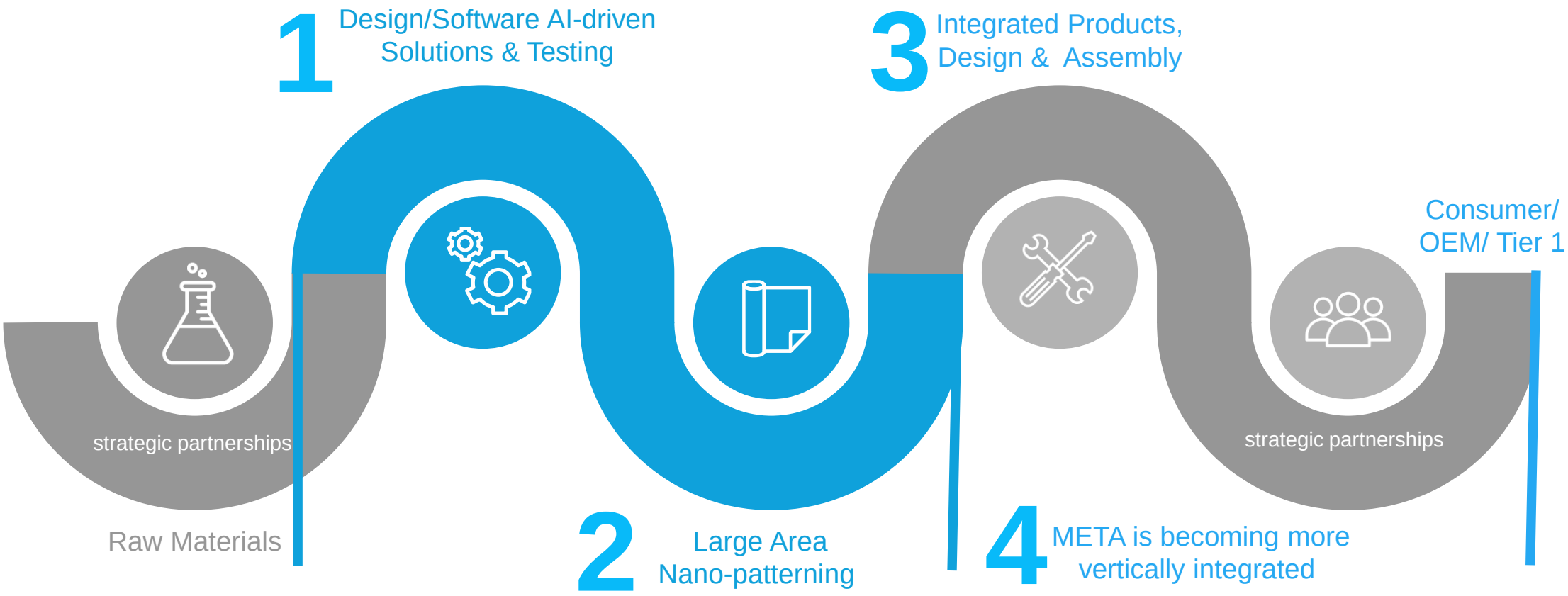
# META Solution Provider in the Value Chain



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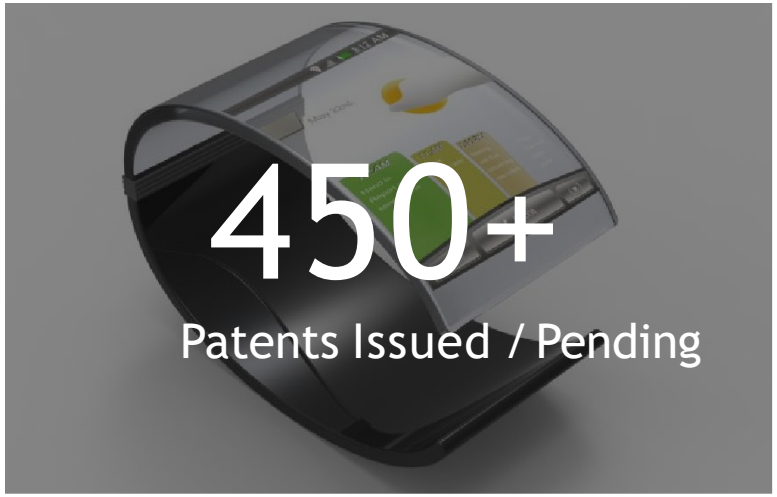
# Our Background





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# Company Timeline

**Algorithm Developed 1st Patent App Filed**

**New Head Office**
Halifax, NS Canada

**NRC & NSERC Grants**

**AIRBUS**
**1st Major OEM Deal** Prototype, Proof of Platform

**MRI & GlucoWise®** begin Human Testing

**Series A and OEM**
Key supply and licensing partnerships with Boeing, Artemis optical & Covestro


**Product Launch** METAAIR®

**BD Partnership**

**Listed to Trade on CSE**

**Partnership with**

**Partnership in 5G with**

**Nasdaq** June 28, Begins

**Acquired** assets & IP of Swiss lens manufacturer **Interglass for ARfusion®**

**Partnership with**

2011-2017 | 2018 | 2019 | 2020 | 2021 | 2022

**University Collaborations**
UNB, UdeM

**Acquisition**
Rolith Inc.
(Pleasanton, CA)
20 Patents families

**Partnership** with Lockheed Martin

**Acquisition**
Mediwise
(London, UK)
28 Patent Families

**SATAIR**
Global Distribution Agreement

**Acquisition**
Nanotech Security Corp. leading developer of Nano-Optic security features

**Acquisition**
Plasma App LTD.
Strengthening our IP portfolio in Battery Materials

**Acquisition**
Optodot Corporation
Over 100 issued or pending Patents

## AWARDS


**NANOWEB®**
IDTechEx
Best Manufacturing Technology Award

**GlucoWise®**
MIT Sponsored Business Award

**Meta Materials**
2019 GLOBAL CLEANTECH 100 Company

**metaAIR®**
Silver A' DESIGN Award + Best Aviation Product / Laureates Aviation Week

**Meta Materials**
LUX Research Innovator of Year 2021 Award

**Future 50**
Fastest growing sustainable companies Award



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# META's Global Presence


**Halifax, Nova Scotia, Canada**
Head Office
Research and Development
Manufacturing facility

**Thurso, PQ, Canada**
Secure Manufacturing Facility

**London & Oxford, United Kingdom**
CoE High Speed Coating-
PLASMAfusion™

**Boston, MA, United States**
CoE Battery Separators - NPORE®

**Pleasanton, CA, United States**
CoE - Nanoweb® applications
USA Sales Office

**Burnaby, BC, Canada**
CoE - Security producs

**Baltimore, MD, United States**
CoE - Electro-Optics Vlepsis™

**Athens, Greece**
CoE Medical & AI Development
EU HQ & Sales

**Minato-Ku, Japan**
Sales Development



META® Go Beyond.

# OEM Partners & Customers: Solving Global Challenges Together

Select Past and Current Co-Development Partners and Customers in Automotive, Medical, Aerospace & Defense, Consumer Electronics and Energy





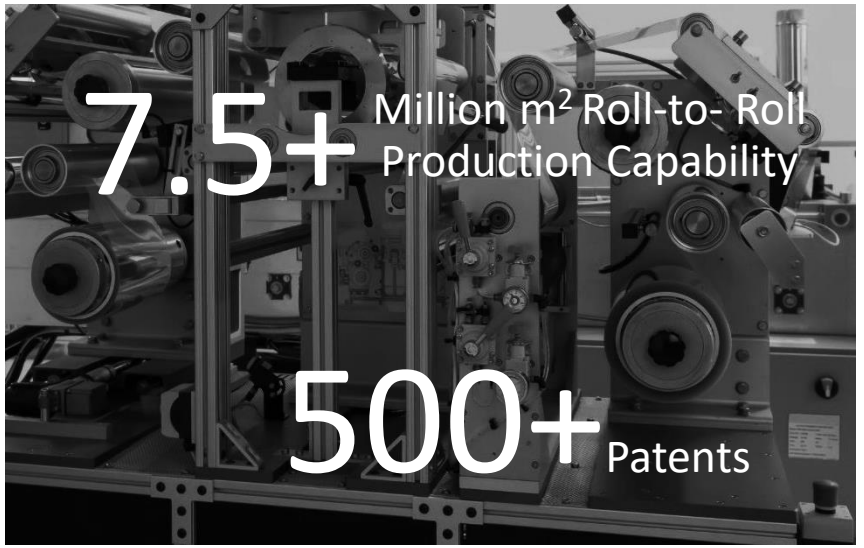

META® Go Beyond.

# Who we are

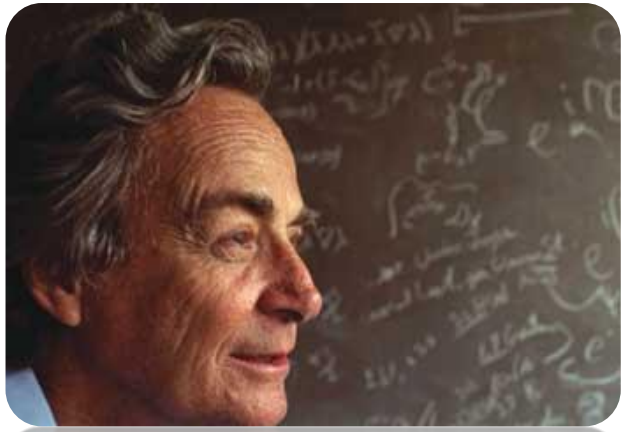
META®
Go Beyond.



META® specializes in designing, originating, recombining, and mass-producing nanotechnology-based films with applications catering to a diverse range of products and markets.

# Solutions



*“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*



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Lithography

# KolourOptik®

## NANO-OPTIC GOVERNMENT AND BANKNOTE SECURITY

KolourOptik®: Sub-wavelength nanostructures that are near impossible to replicate and protect banknotes and government documents from counterfeits.

**Key Differentiators:**

- Ultra thin (< 10 micron),
- combination of movement, depth and multiple colors,
- advanced nanoscale manufacturing processes

**Applications:** Banknotes, passports, ID cards, drivers licenses, birth certificates.


### KolourOptik® Stripe

- Movement
- Multi-colour images
- 3D stereo depth
- “Always on”


### KolourDepth™

- Multiple 3D elements
- Multi-colour images
- Omni-directional movement
- “Always on”

### LumaChrome Foil

- Used in 30+ banknote denominations
- Easy to use
- Striking colour transitions
- Durable



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PARTNERS

AIRBUS SATAIR

INDUSTRIES

# metaAIR®

## LASER GLARE PROTECTION

metaAIR® : Holographic laser protective films that offer professional pilots & law enforcement professionals the best combination of transparency, laser glare protection, and color fidelity.

**Key Differentiators:**

- Tuned nanostructures allow the lens to control how light is deflected and blocked, so dangerous green lasers are neutralized while the rest of the visible light spectrum is unaffected
- Exceptional color recognition, and superior visible light transmission and optical filtering combined

**Applications:** Aviation Eyewear & Law Enforcement self-adhesive film for police riot visors & handheld ballistic riot shields.



AVIATION WEEK Laureates

2018 Winner Best New Commercial Product

A'DESIGN AWARD & COMPETITION — AWARD WINNING DESIGN SILVER A' DESIGN AWARD 2019



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PARTNERS

INDUSTRIES

# holoOPTIX®

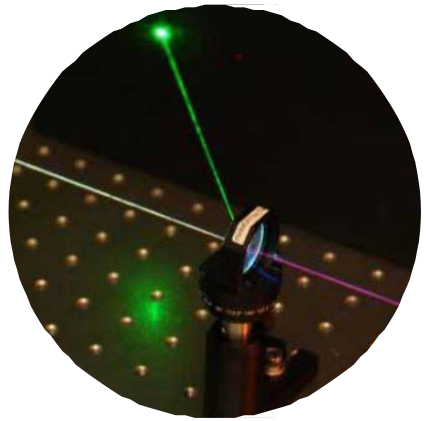
## HOLOGRAPHIC OPTICAL COMPONENTS

META's Holography platform makes it possible to design and fabricate optical components that improve on traditional lenses and mirrors by adding extraordinary optical functions.

**Key Differentiators:**

- holoOPTIX® holographic notch filters enhance surfaces like film and glass with wavelength selectivity — the ability to reject a portion of the light spectrum while transmitting all other wavelengths.
- Achieved through laser created interference pattern - Volume Holographic Gratings (VHG) — that selectively transmit or reflect.

**Applications:** confocal microscopy, multi-photon microscopy, laser-based fluorescence instrumentation, life science applications.



**Available Products:**

- holoOPTIX® FLEX
- holoOPTIX® STRATA 1" diameter form factor for life science applications
- holoOPTIX® SLANT 1" form factor plus unique diffraction characteristics



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PARTNERS

INDUSTRIES

CONFIDENTIAL
OEM's

# ARfusion®

## LENS CASTING - PRESCRIPTION AR EYEWEAR

ARfusion® integrates optical elements for AR (augmented reality) combined with lens casting technology developed by Interglass Technology AG

**Key Differentiators:**

- High volume fully automated lens casting, workstations, tools, test equipment, and technical data
- Proprietary specialty materials/foils supply in cooperation with Covestro AG
- "One stop shop" for prescription lenses and embedded elements such as optical combiners, waveguides, and eye tracking sensors

**Applications:** Complete integrated AR solutions, Cast prescription lenses, Embedded Holograms

Less energy
(10 sec vs 50 hrs curing time)

Zero water usage

Less material usage





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# NANOWEB®

## TRANSPARENT CONDUCTIVE FILM

PARTNERS

Confidential OEM's +

PPG SEKISUI

INDUSTRIES

## Achieving performance never thought possible

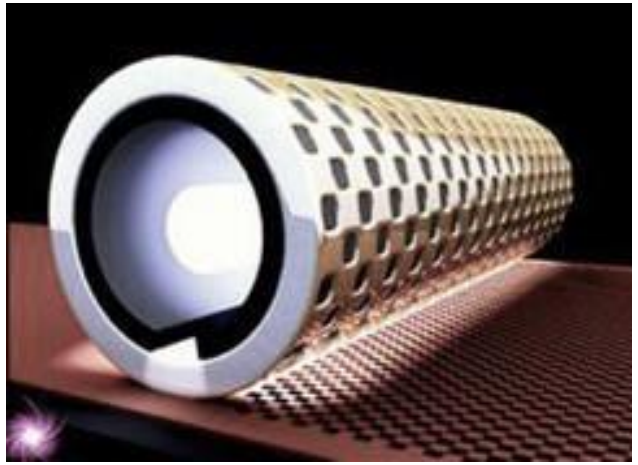
**Key Differentiators:**

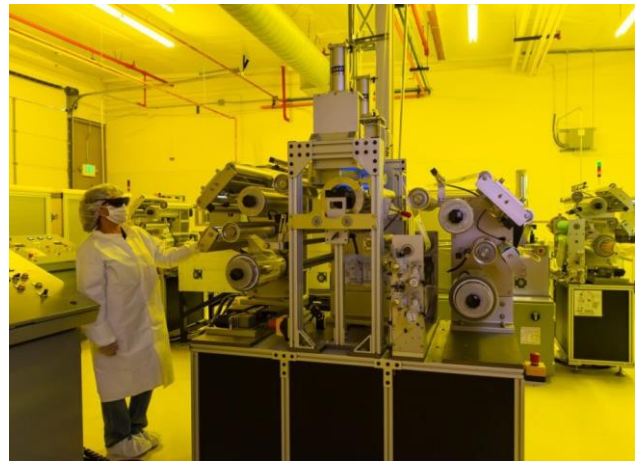
Proprietary RML® technology that can print sub-micron nano-structures directly into any hard or soft substrates.

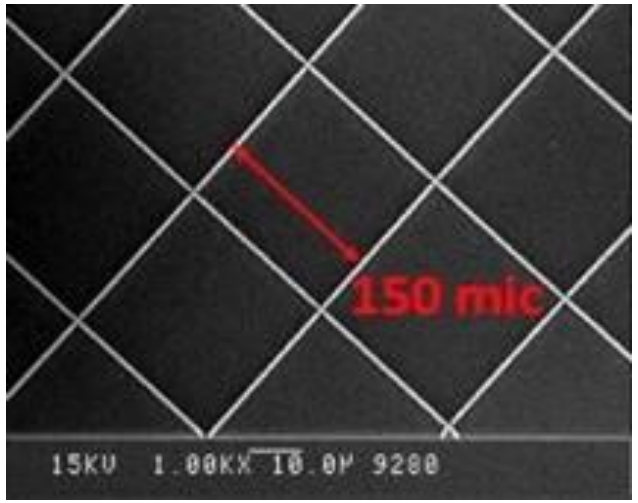
NANOWEB® offers multiplexed patterning, where additional functions beyond de-icing / de-fogging can be incorporated into the vehicle e.g. 5G, 4G, AM, FM antennas

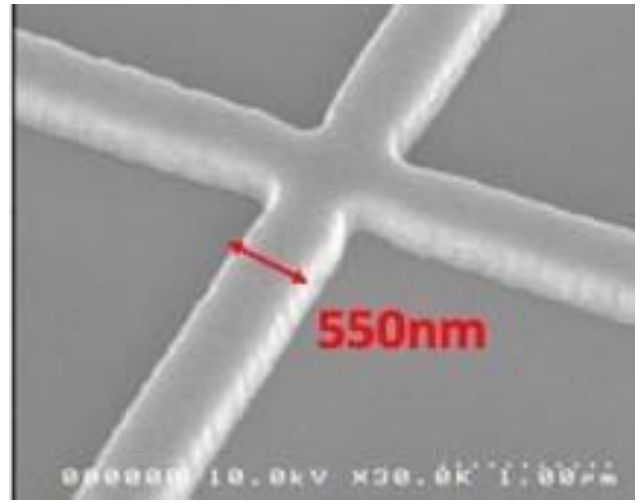
- 99% Transmission (excl. Substrate)
- 10-15 Ω/sq

Custom design per application for maximum performance:
- Pattern (spacing & line width)
- Metal choice (Ag, Au, Al, etc.)










META® Go Beyond.

PARTNERS

Confidential OEM's +

PPG SEKISUI

INDUSTRIES

# NANOWEB®

## Applications

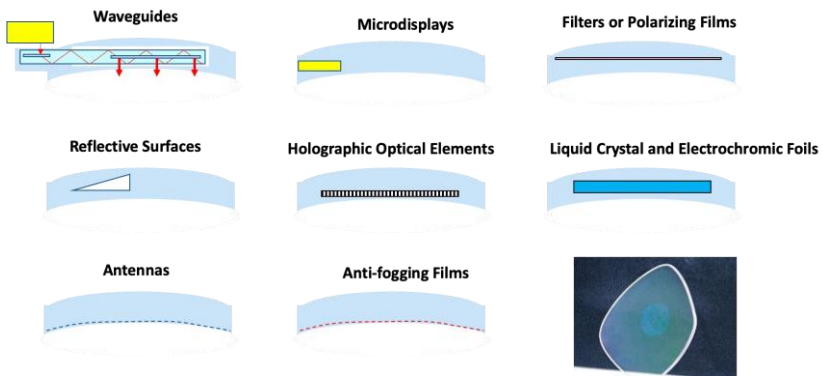
EMI Shielding
- Transparent Microwave Doors
- Automotive LiDAR protection


5G Reflectors / Transmitters

Transparent Antenna
- Glasses
- Automotive
- Mobile Devices


Prescription Lens Optical Combiners
- Augmented Reality Glasses
- Electrochromic lenses

De-Ice / De-fog Automotive & Consumer Product Applications



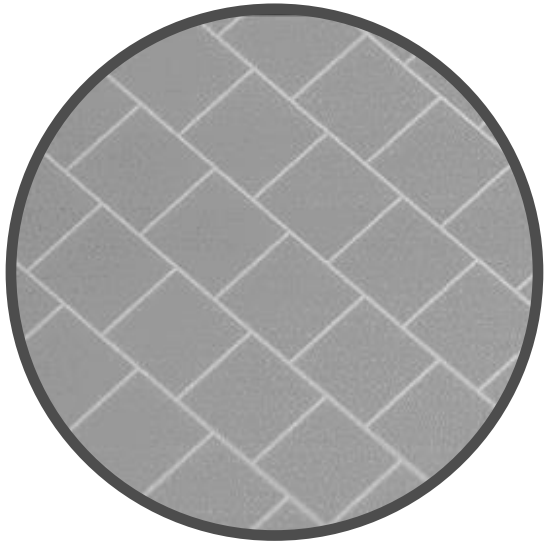

**NANOWEB®**
Best Manufacturing Technology Award

META® Go Beyond.

# Nanoweb

# NANOWEB®

## Transparent conductive film







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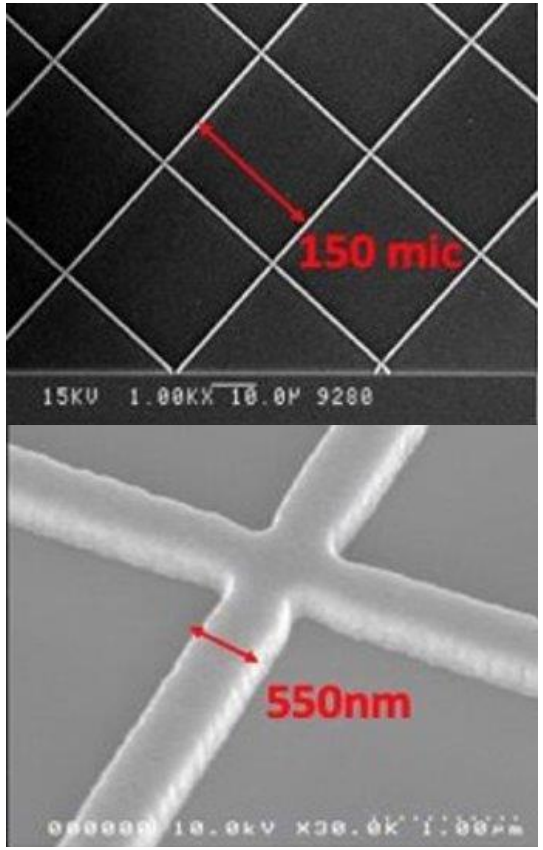
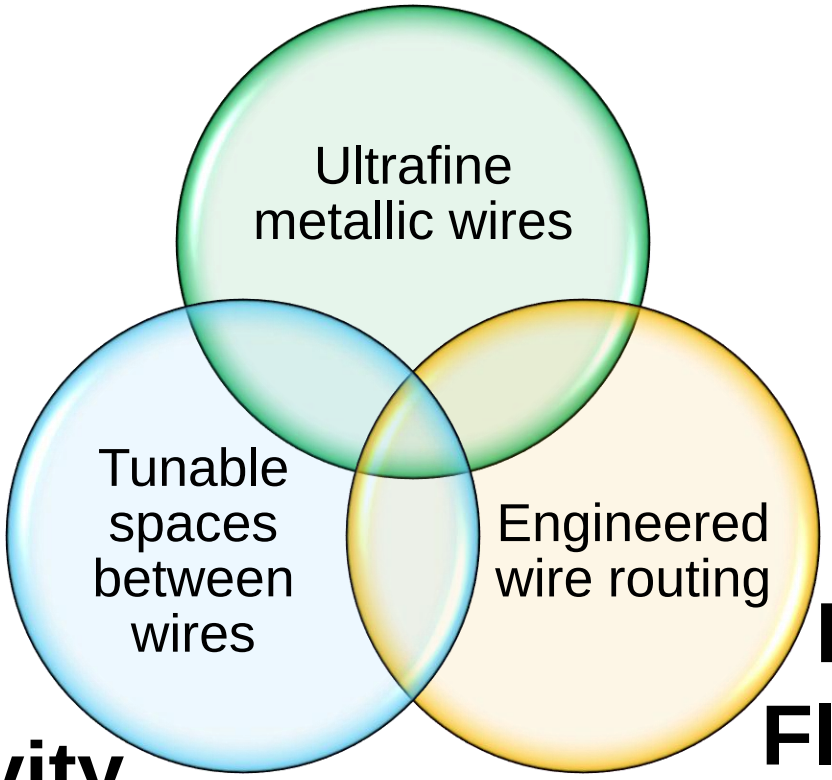
# NANOWEB – The Engineered Transparent Conductor




**High Transparency**




**High Conductivity**

**Design Flexibility**



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# NANOWEB - Characteristics and Performance

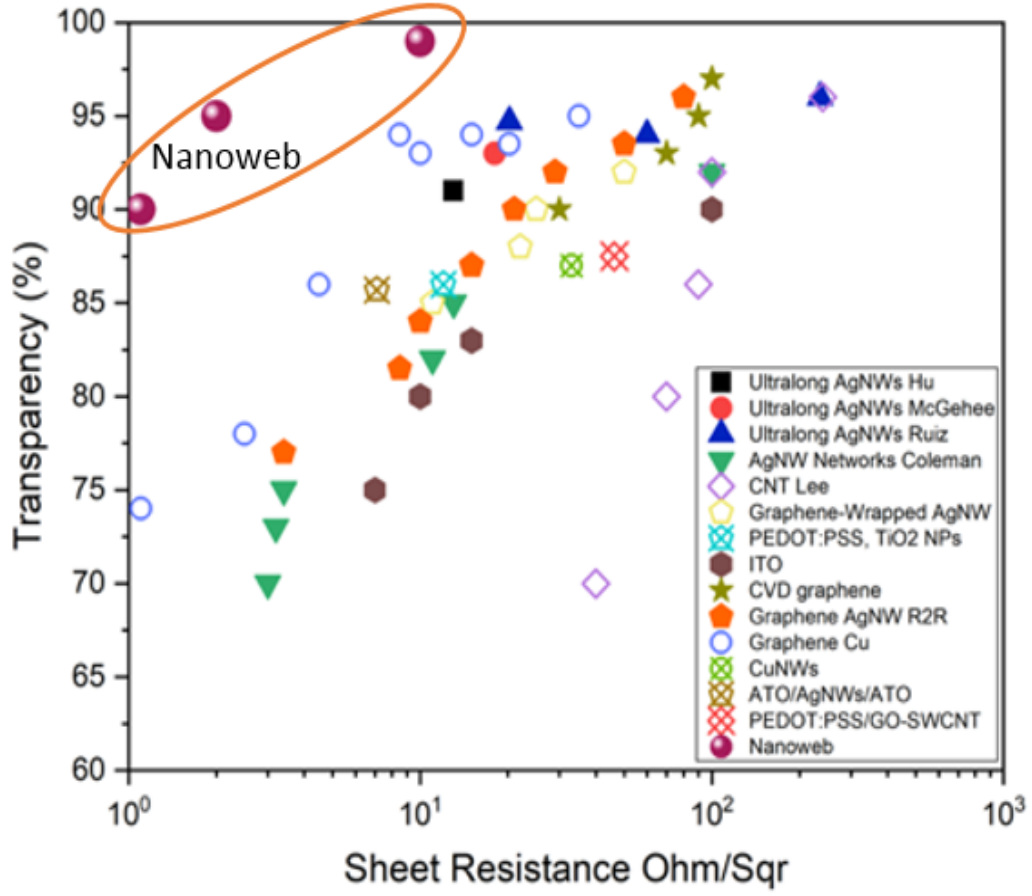
## DESIGN

- **Wire width:** 0.20 to 1 micron
- **Wire spacing:** 10 microns and above
- **Wire thickness:** 50 nm to 1 micron
- **Wire material:** Ag, Cu, Al, alloys,
- **Substrate material:** Glass, PET, sapphire, etc.

(PC coming soon)

## PERFORMANCE

- **Sheet resistance:** <1 to 20 Ω/sq
- **Optical transparency:** 90-98% (Fresnel corrected)



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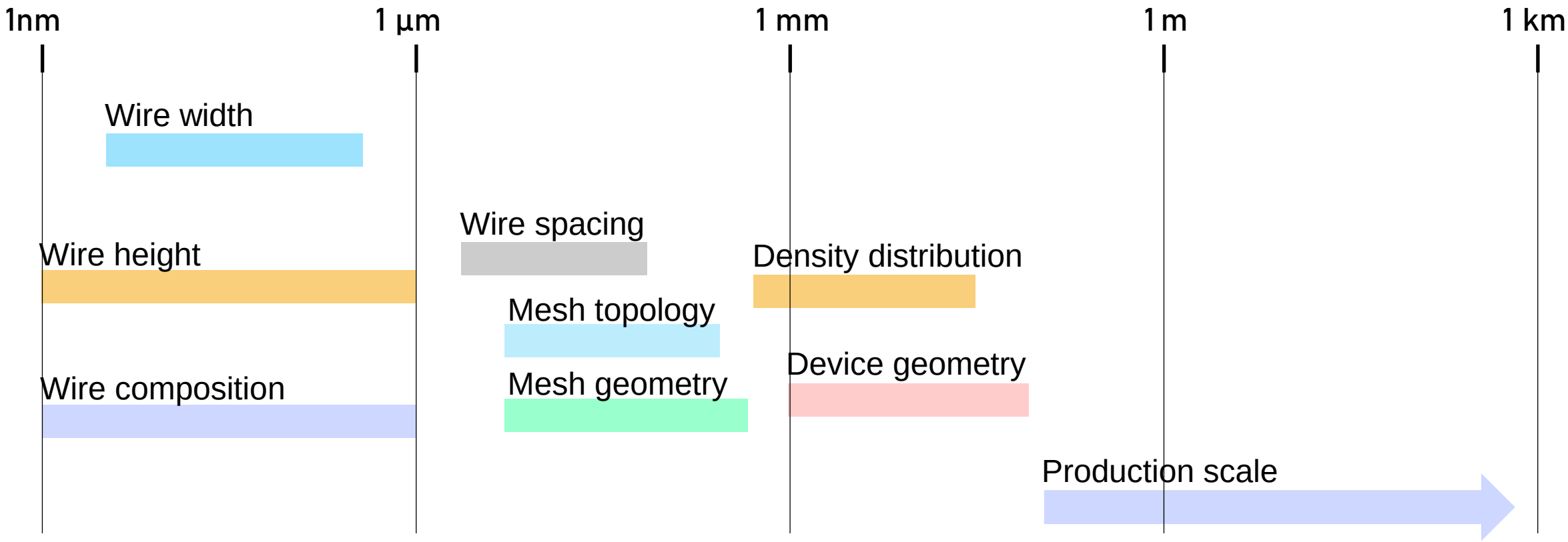
# Engineered Across Multiple Length Scales




NANOWEB





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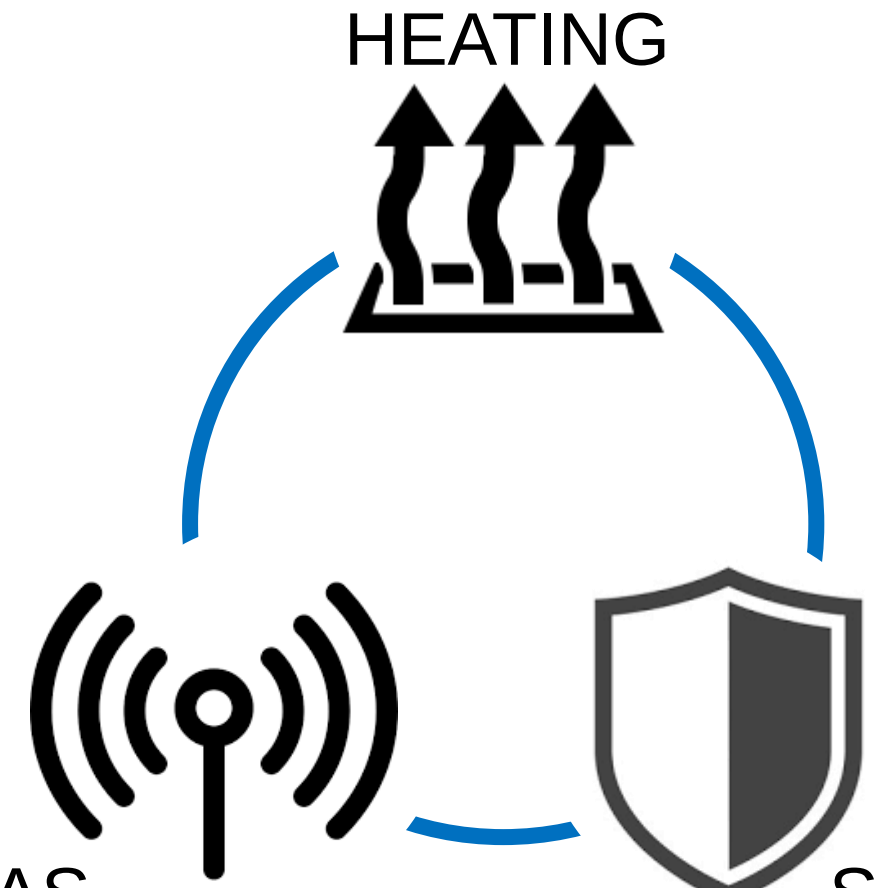
# NANOWEB Application Areas



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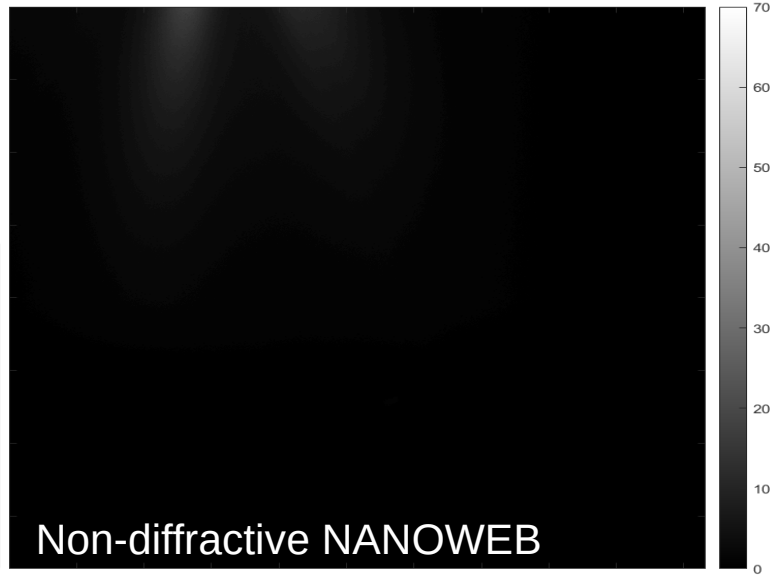
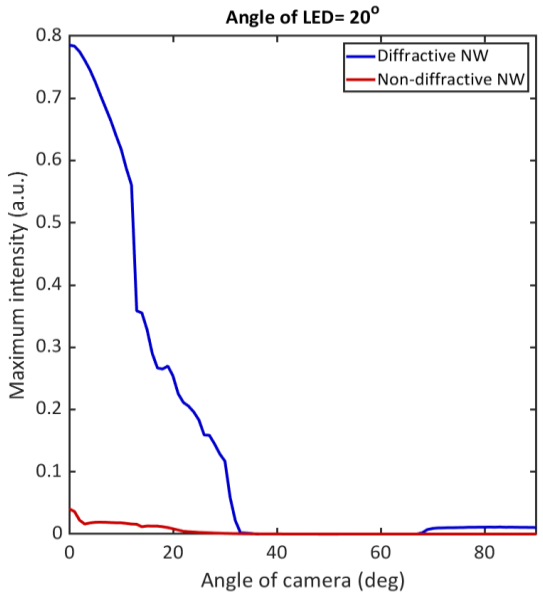
# Engineered Diffraction Management

- Transmitted diffraction in visible regime tuned by mesh geometry
- Reduced artifacts for imaging sensors operating in the visible & NIR (LIDAR and cameras)


| | Standard mesh | New mesh geometry – I | New mesh geometry – II |
|---|---|---|---|
| **Optical transmittance** | 99% | 99% | 99% |
| **Haze** | 1 % | 1 % | < 0.7 % |
| **Sheet Resistance** | 10 Ω/sq | 6 Ω/sq | 6 Ω/sq |
| **Availability** | Available | June 2023 | August 2023 |

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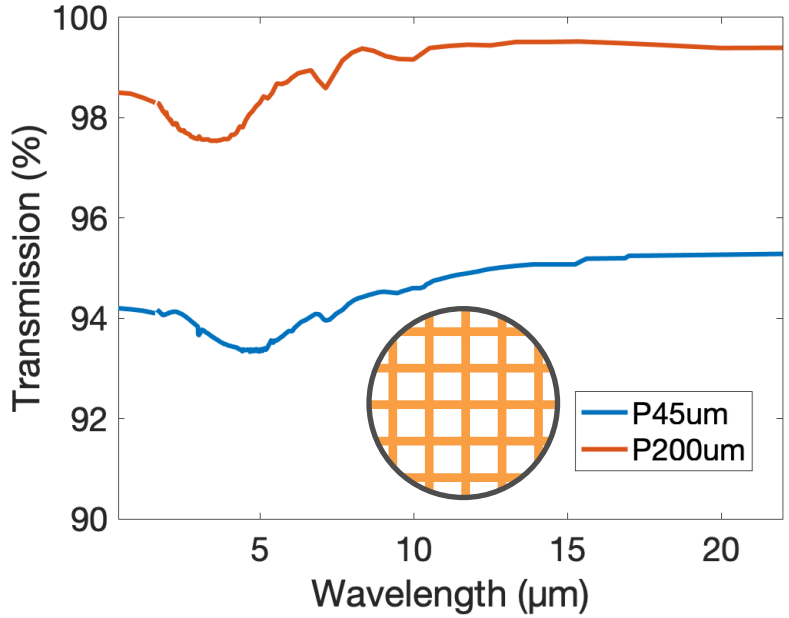
# Long Wavelength Transparency

***Multimodal sensor compatible***

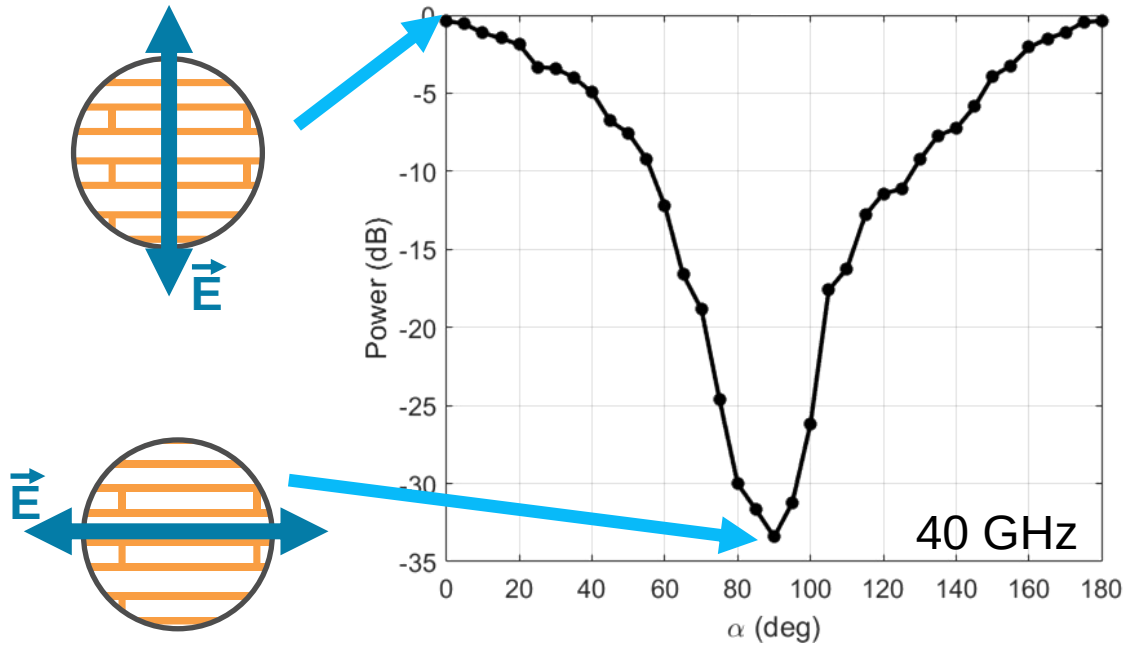
**THERMAL**

- Grid designs maintain high transparency from visible through LWIR region (unlike ITO)




**RADAR**

- Transparency into the RF achieved through adapted mesh design





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# Transparent Antennas

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# Transparent Antenna Benefits

Integrate high-performing antenna functionality while maintaining visibility

Benefits:

- Invisible & aesthetic
- Compatible with lidar, camera systems
- Integrated de-ice, de-fog options
- Lightweight for easy installation
- Directional, Omni-directional antenna
- Highly customizable for multiple bands
- High conductivity
- Multi-band, ultra-wide band
- Excellent radiation performance



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# Library Antenna Application Designs

**Antenna for Augmented Reality WiFi/BT, 2.4/5.0 GHz**

- Transparent antenna on the glass lens enables hi-band I/O reducing BULK and POWER – Eyeglass Formfactor

**Automotive communication**

- Transparent antenna (arrays) on the roof or windshield for LEO satellite communication (Ka/Ku bands)
- Vehicle to vehicle communications for autonomous driving

**Automotive radar/lidar for collision avoidance (77 GHz)**

**TV reception: Transparent antennas on window for TV signal (400-800 MHz)**

**mm-wave 5G (26-28 GHz)**

Transparent 5G Antenna invisible to naked eye

**AR glasses with Transparent 5G antenna**

**Vehicle with ADAS and/or LEO satellite comms**

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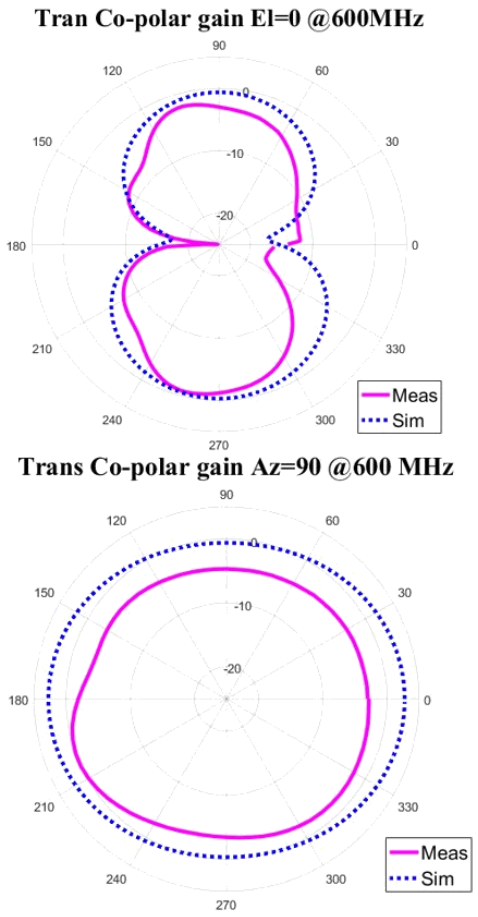
# Antennas

***Transparent antennas enable new design flexibility for antenna placement***

- Radar TX/RX antennas embedded in windshield or headlamps
- 5G antennas in glazing
- Satellite antennas in rear windows or sunroof

- Conventional antenna modelling approaches work (no need to model nano-properties)





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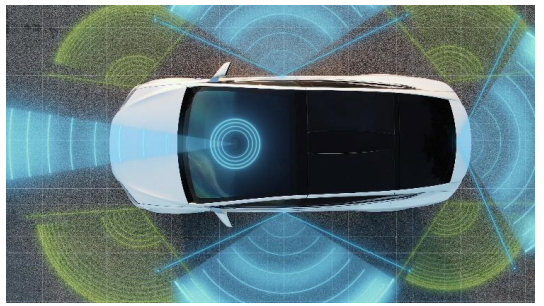
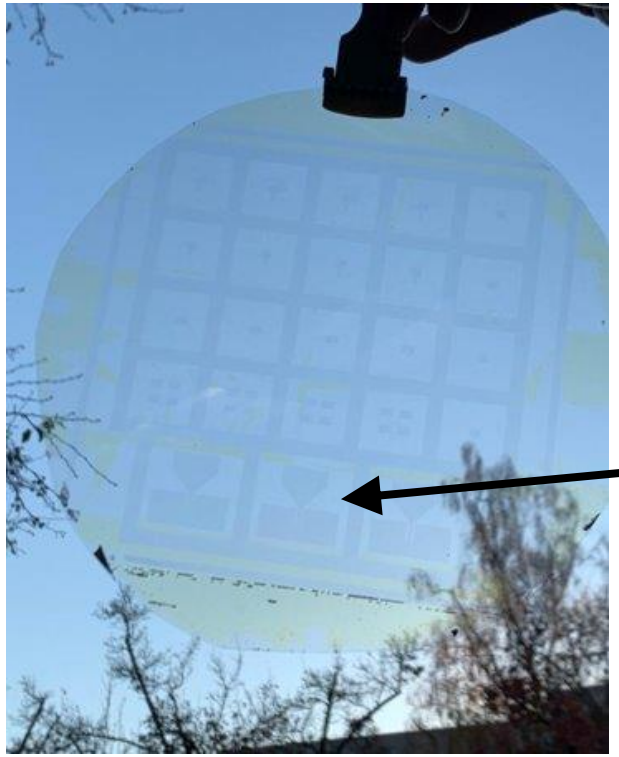
# Antennas

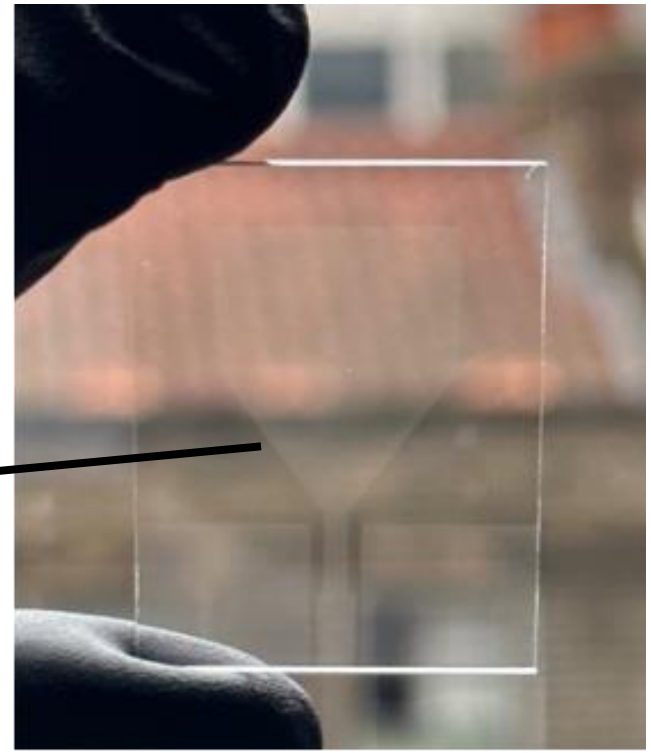
- Lithographically defined antenna structure(s)



Multiple antenna designs on one wafer:

| Frequency | Application |
|---|---|
| 2.4 GHz | WiFi / BT |
| 5.0 GHz | WiFi |
| 10 GHz | 5G (proposed) |
| 26-28 GHz | 5G-FR2 |







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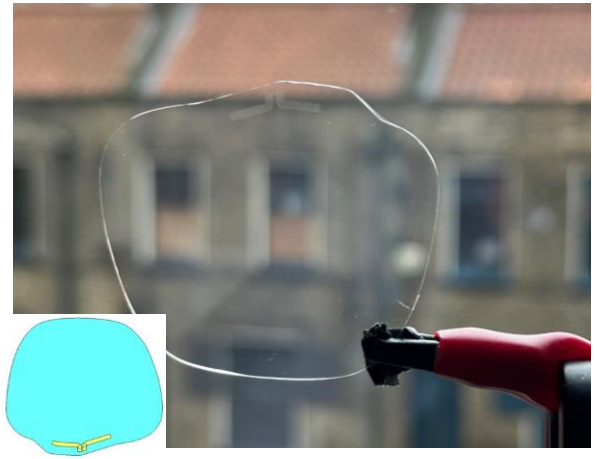
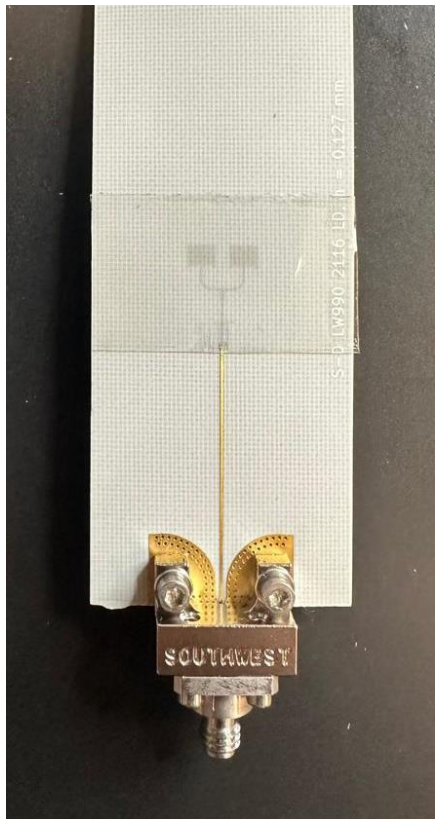
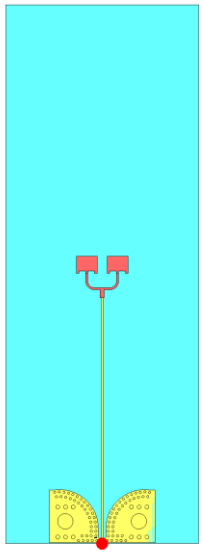
# Selected Antenna Samples Produced in 2022



Dipole @5GHz on lens

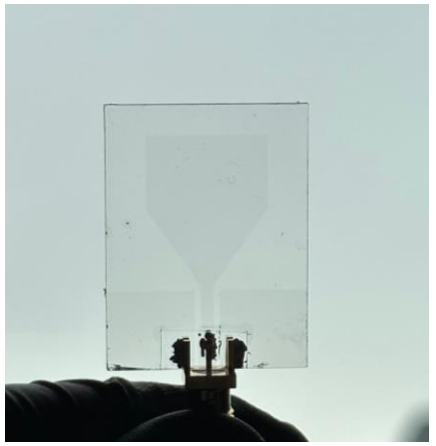
Dipole @2.4 GHz on lens

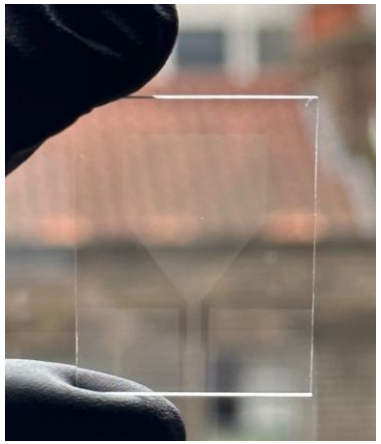


Automotive Radar 40 GHz

TV antenna patterned on Glass @400-800 MHz





Monopole @5.5 GHz on glass



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# 5.0 GHz WiFi Gen1 on glass lens on frame; AWE 2022 demo




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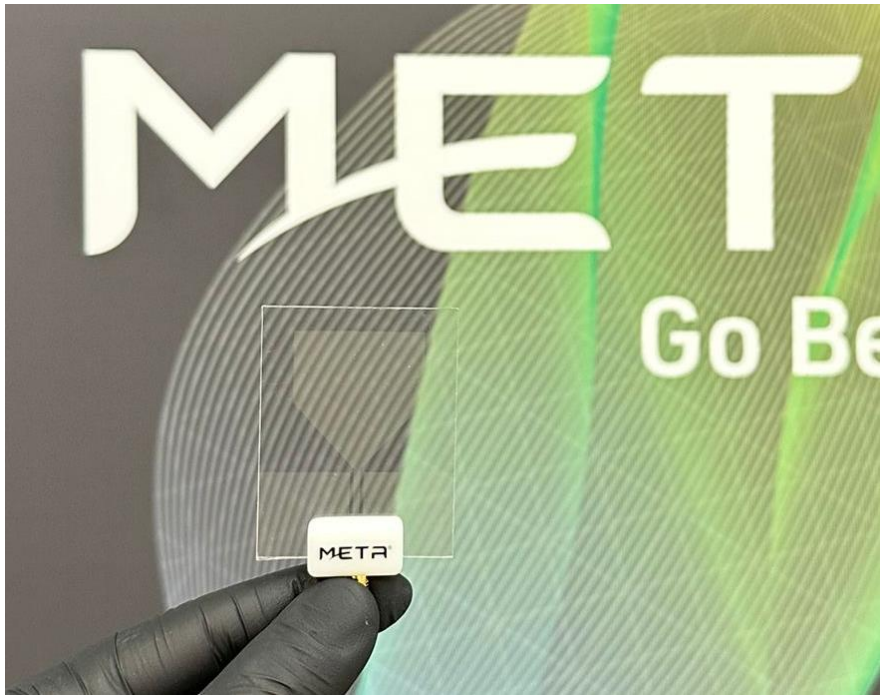
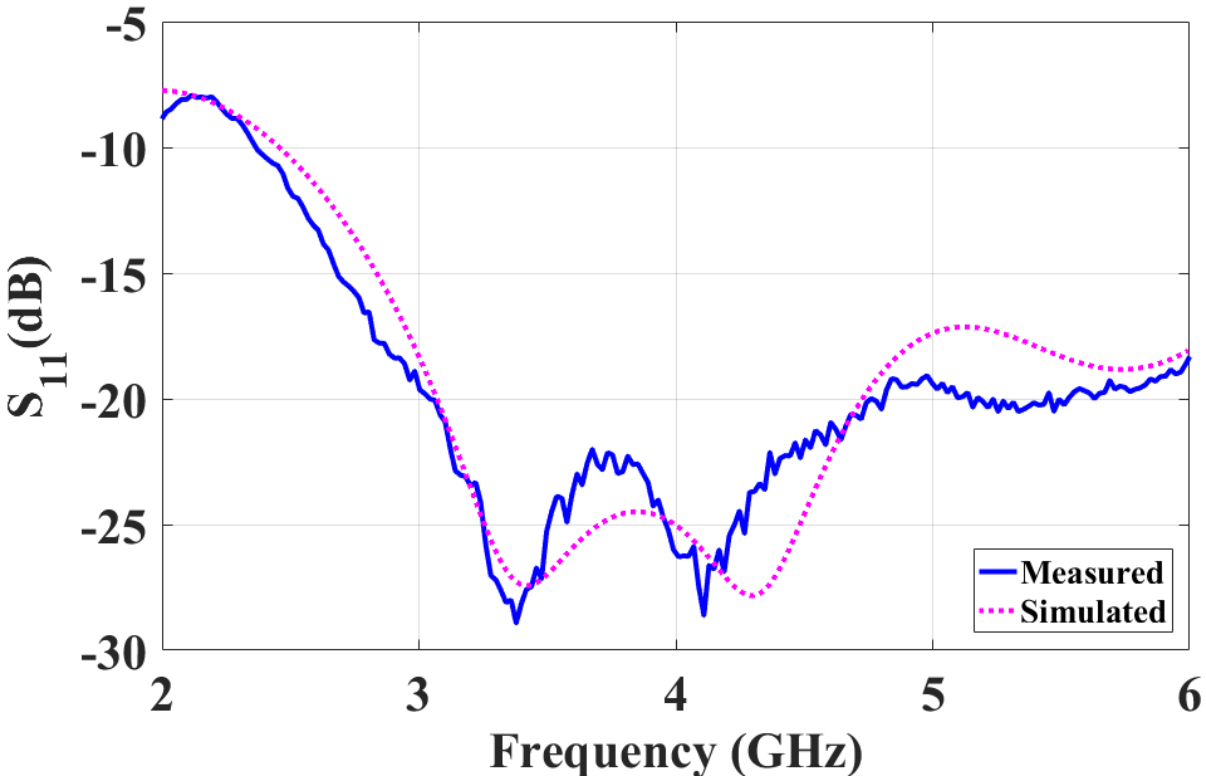
# ANT-NGS-P25-GEN-004 Measured Data




Nanoweb P25 Monopole
ANT-NGS-P25-GEN-004



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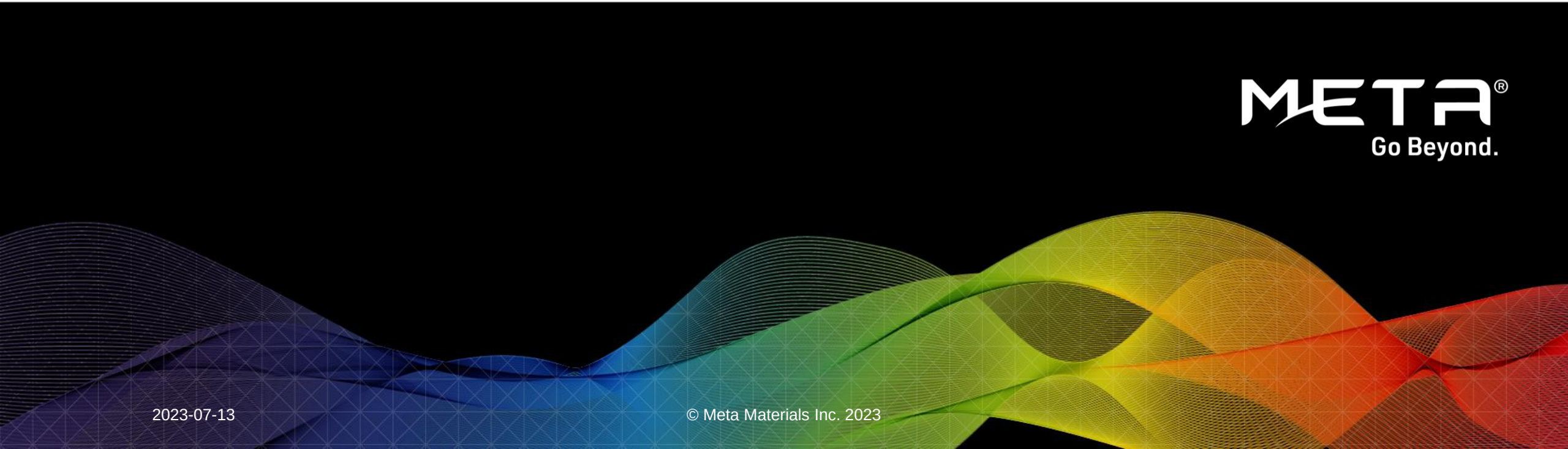
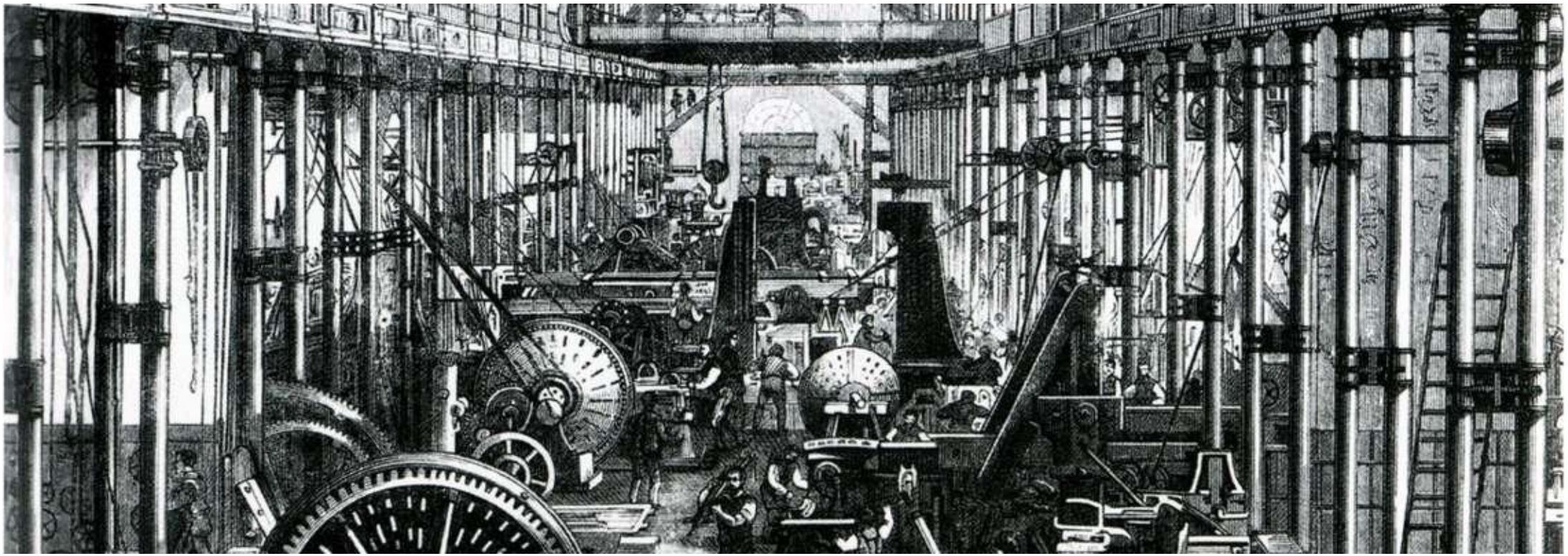
# Manufacturing







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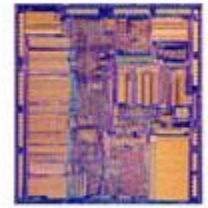
| 1950s | 1960s | 1970s | 1980s | 1990s | 2000s | 2010s |
|---|---|---|---|---|---|---|
| Silicon Transistor | TTL Quad Gate | 8-bit Microprocessor | 32-bit Microprocessor | 32-bit Microprocessor | 64-bit Microprocessor | 3072-Core GPU |
|  |  |  |  |  |  |  |
| **1 Transistor** | **16 Transistors** | **4500 Transistors** | **275,000 Transistors** | **3,100,000 Transistors** | **592,000,000 Transistors** | **8,000,000,000 Transistors** |



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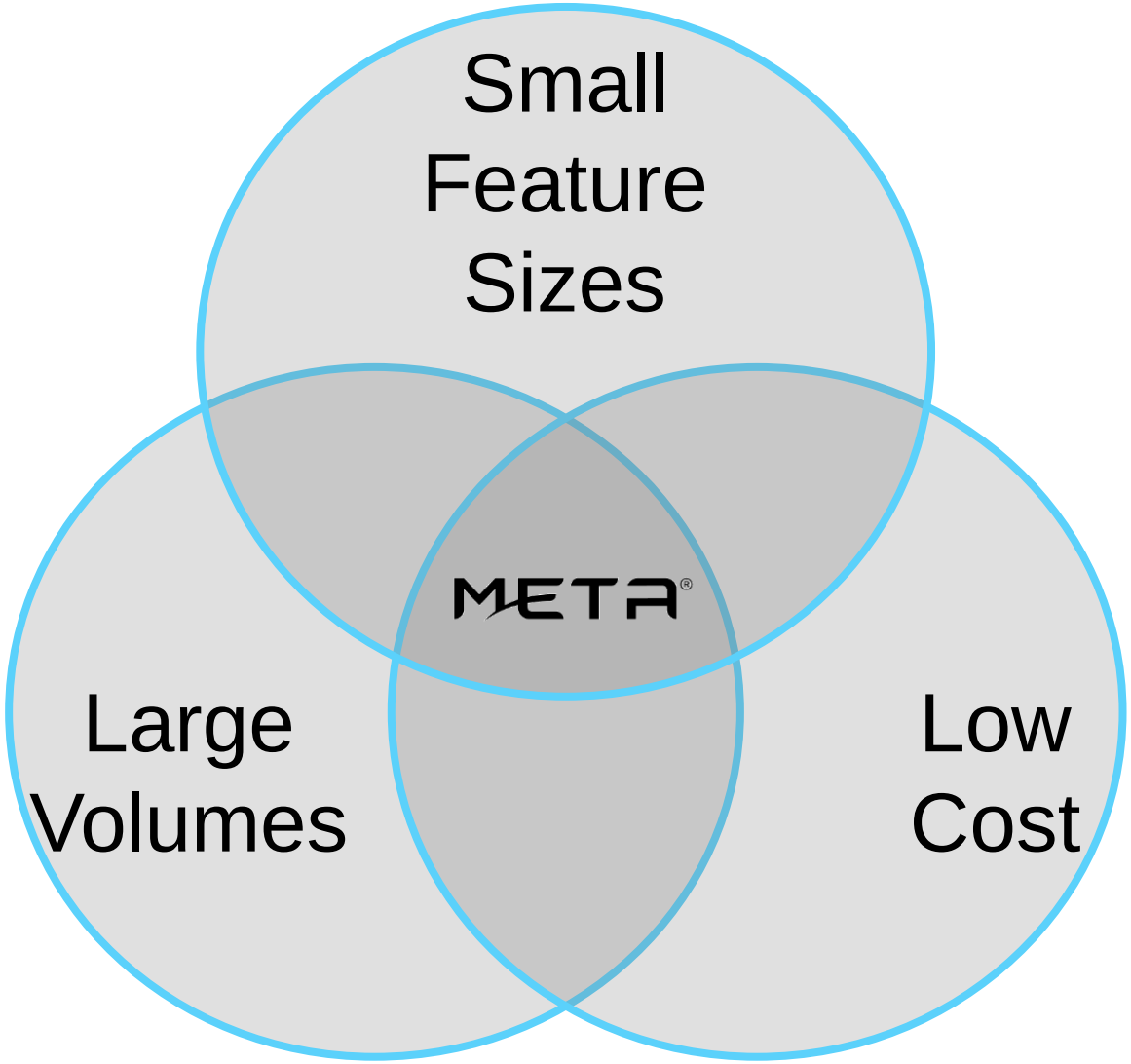




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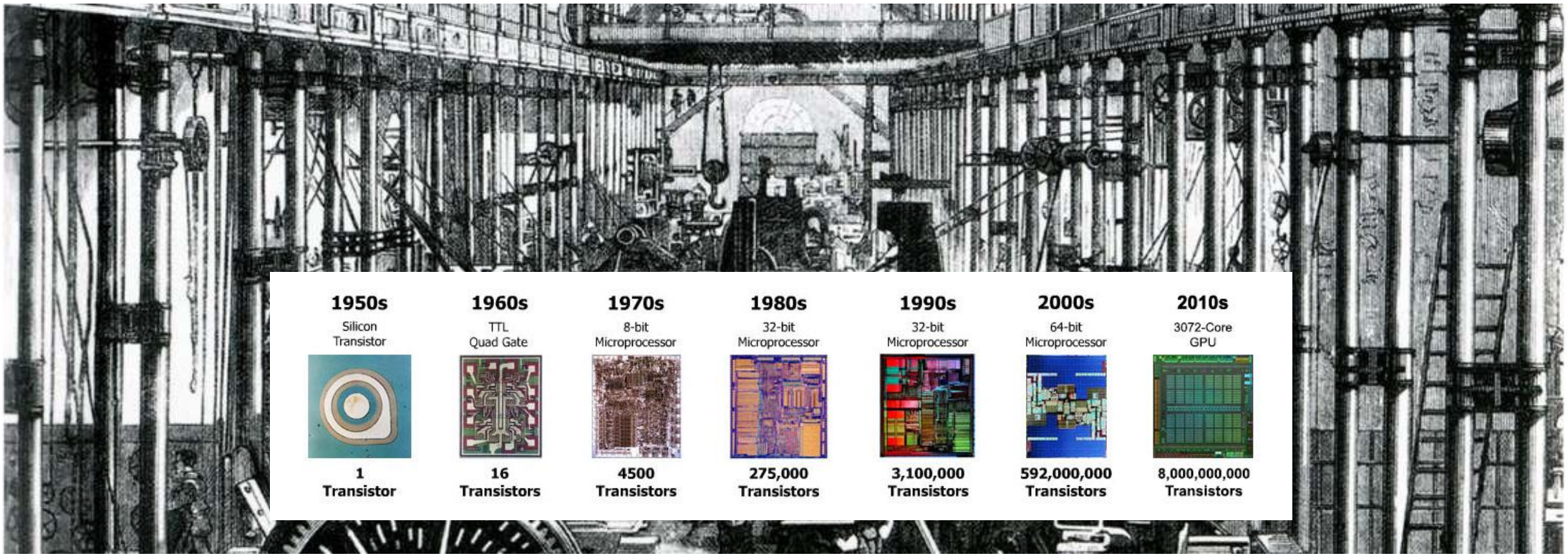




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# R2R Lithography Capabilities at META

## R2R UV-NIL

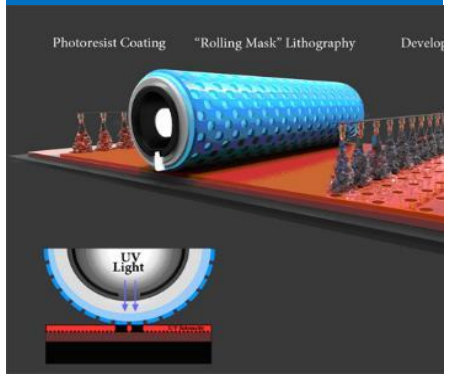
**Merging of Micro and Nanostructures:**
**KolourOptik®** secure brand protection

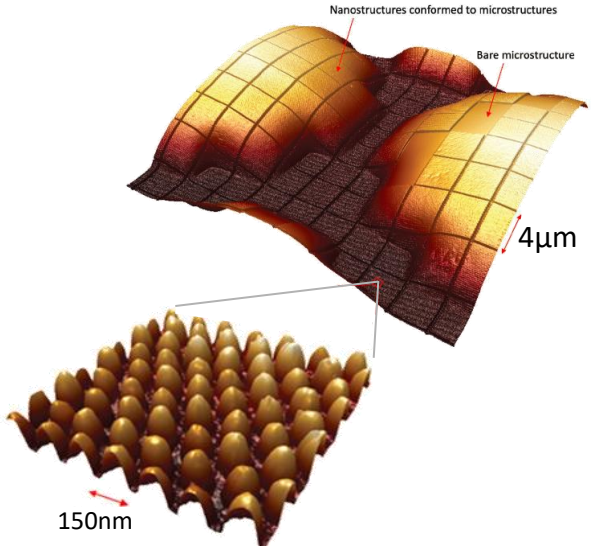
## RML Lithography

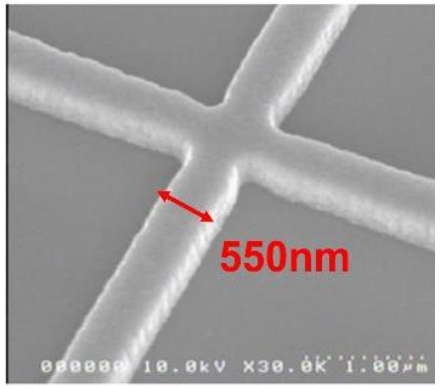
**RML® produces sub-micron metal mesh:**
**NANOWEB®** antennas, 5G communication, EMI shielding, de-ice/de-fog

## NIL Lithography

## Rolling Mask Lithography



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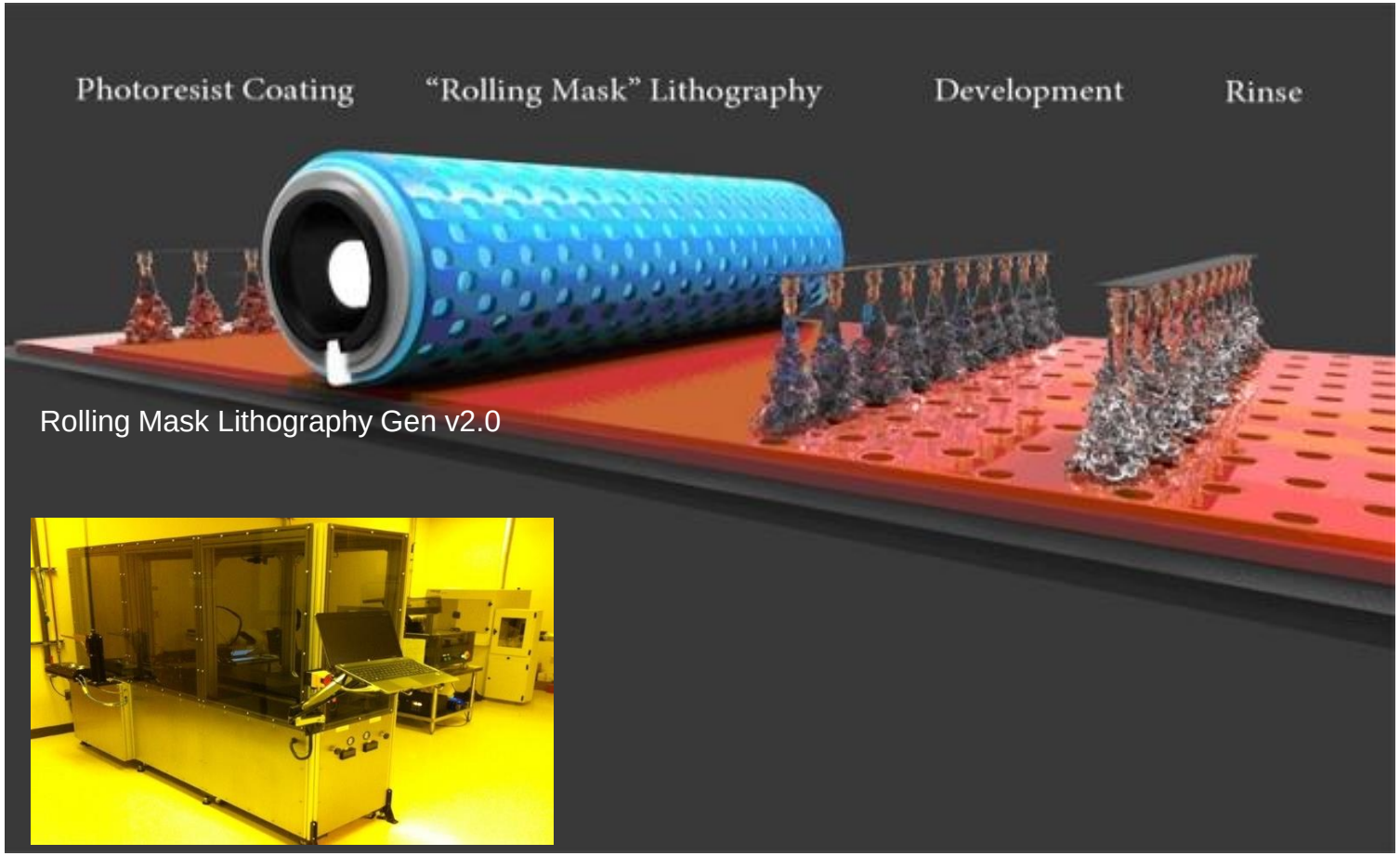
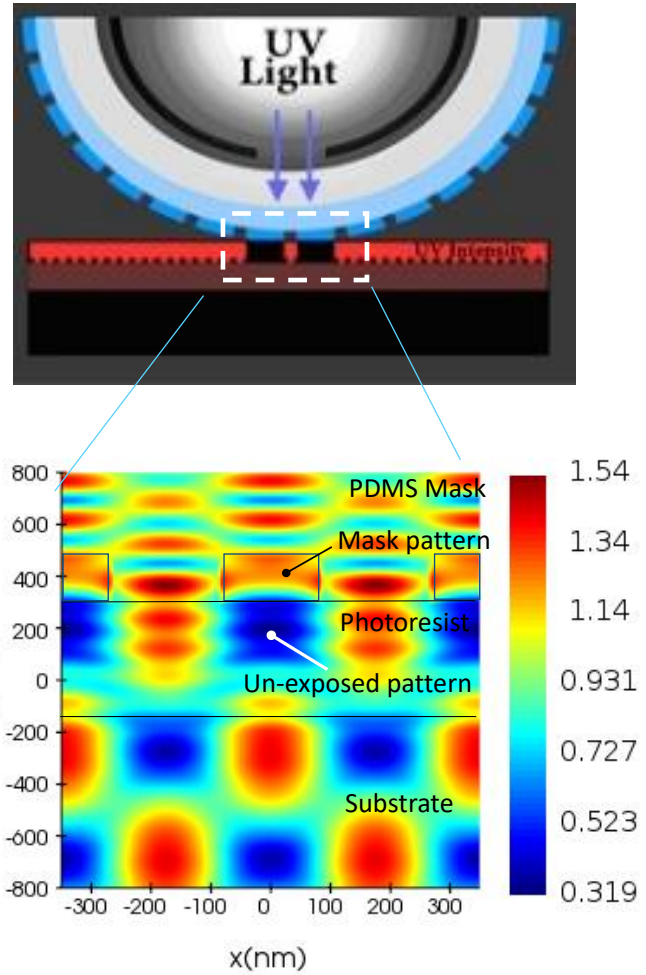
# Rolling Mask Lithography

Proprietary **RML®** technology can fabricate nano-structures directly onto rigid or flexible surface

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# Roll-to-roll Nanoimprint Lithography

## Industrialized Nanofabrication

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

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

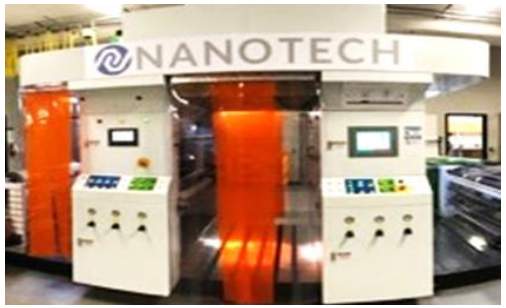
**Recombination**
- Expertise in recombination of nanostructures to preserve quality and fidelity over large areas

**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**



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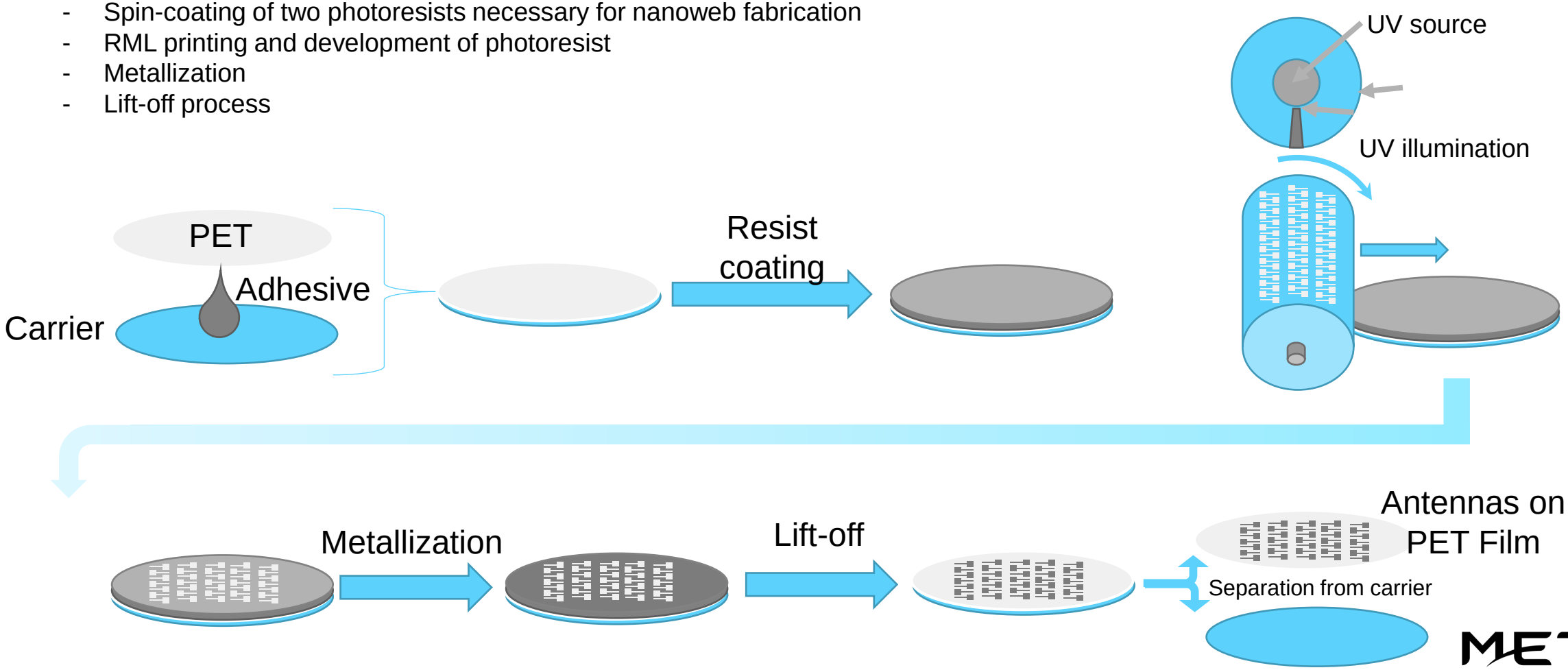
# Fabrication – Nanoscale R2R Patterning “for Free”

Fabrication of Antennas:

- Laminate PET on wafers carriers using UV curable as adhesive
- Spin-coating of two photoresists necessary for nanoweb fabrication
- RML printing and development of photoresist
- Metallization
- Lift-off process

Rolling Mask lithography (RML) process



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# In Closing

“Themos,
I made marble look like
TRANSPARENT VEIL

You got this”

- Strazza



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