EPIC Technology Meeting on
Disruptive Optics at Thales

Powering Innovation That Drives Human Advancement

Engineering Structural Color from Nanoscale to Macroscale

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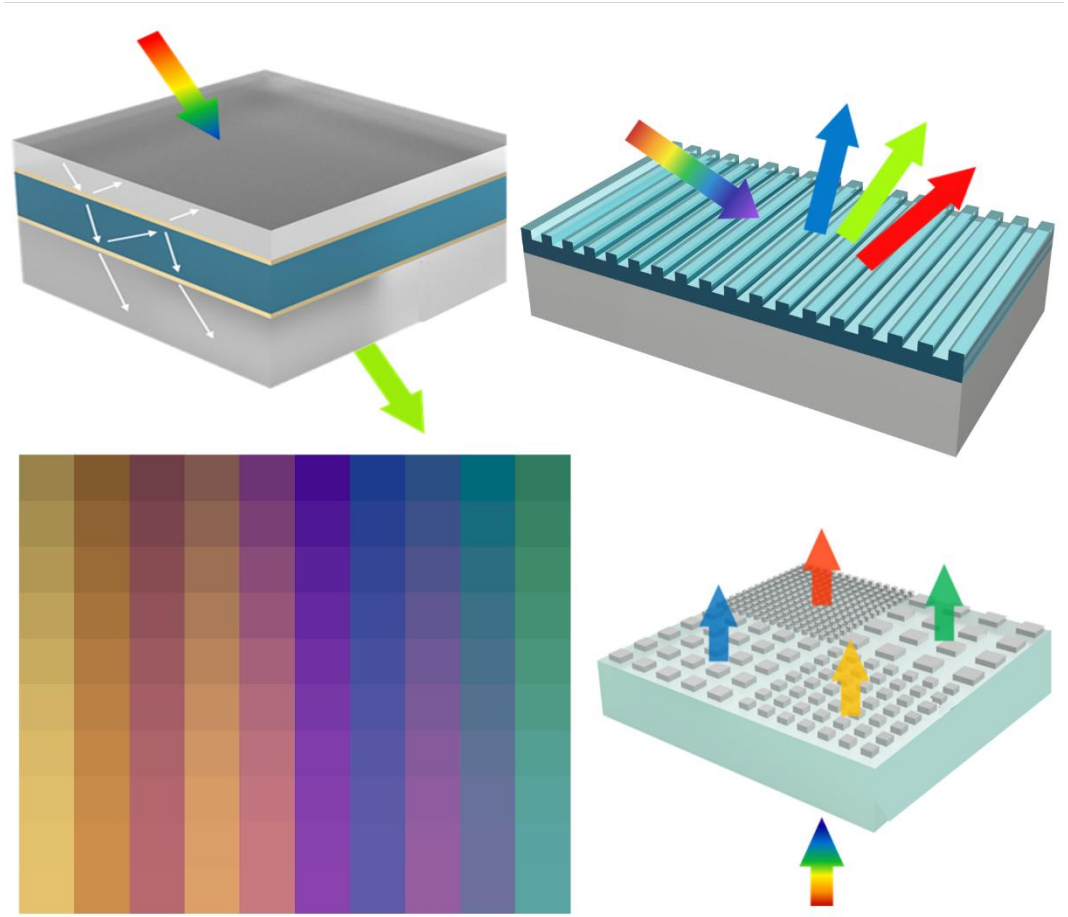
EMEA Photonics Application Engineering

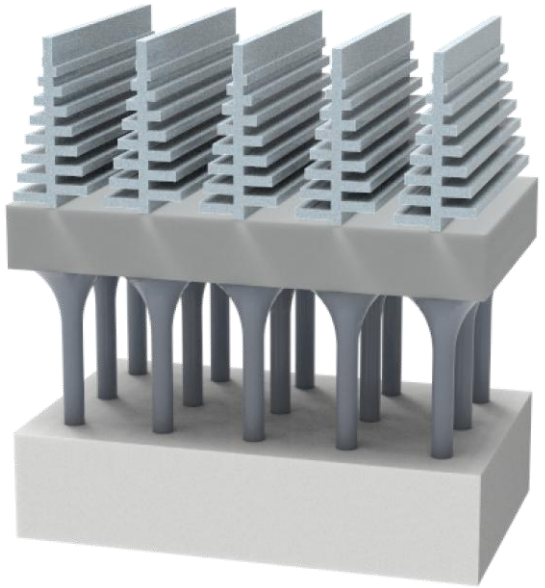
Outline

- Motivation
- Structural Color Design
  - Nanoscale simulations with Lumerical
  - Visualization with Speos
- Summary



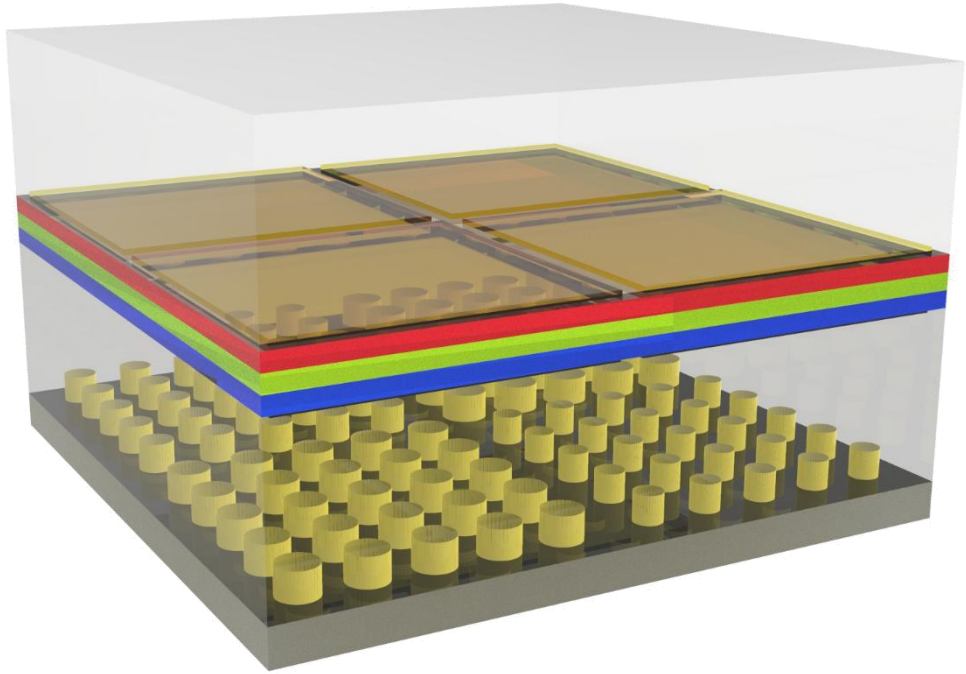
Types of Color Generation

- Color is the visual perception based on the electromagnetic spectrum.
- The spectral response of an object is affected by its material and structural properties.
  - Dyes and pigments: Absorption by material
  - Geometric patterns: Interaction of light with nanostructures



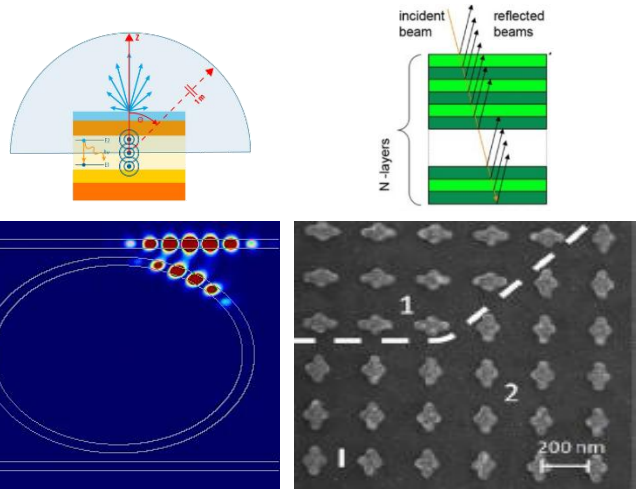
Structural Color – Motivations and Applications

- Advantage of structural coloration over dyes and pigments:
  - Eco-friendly
  - Less prone to chemical degradation
  - Higher resolution
  - Higher purity
- Emerging areas of applications include:
  - Advanced color displays
  - Filters for sensors
  - Spectral imaging
  - Authentication and aesthetics for high-value items



Ansys Optics: Multi-Scale, Multiphysics Simulation Platform

Ansys LUMERICAL

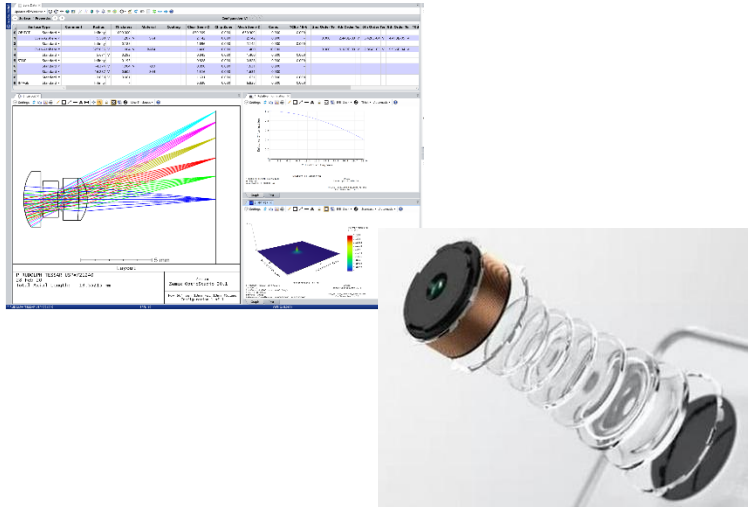


Photonic Component Modeling

Nano-Chip-Level

- Waveguide development
- Sensor & Emitter development
- Nanostructure design
- HR-AR coating layer design

Ansys ZEMAX

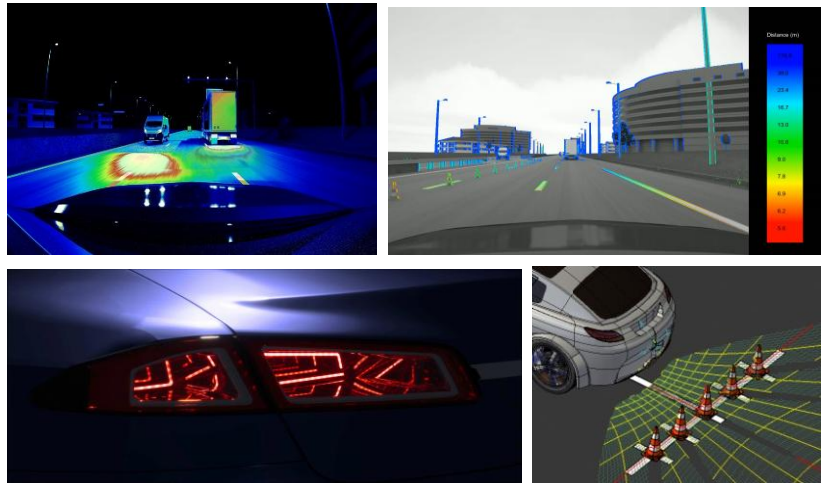


Optical Design & Modeling

Optical-Design-Level

- Optical design
- Optical validation
- Optical tolerance analysis
- Mechanical tolerance analysis

Ansys SPEOS



Optical System Modeling & Validation

System-Design-Level

- Individual 3D environment integration
- Lighting evaluation
- Human Vision rendering
- Customer's perception for decision making

From Nano → **To Macro** → **To System**

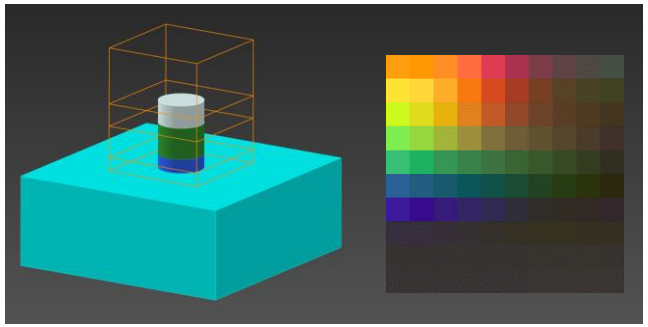
Tools for Nanoscale Simulations

Solver	Geometry	Sources	Material	Notes
STACK	Planar	Planewave, dipole	Anisotropic, dispersive	• Analytical
FDTD	Arbitrary	Planewave, dipole, Gaussian, mode, import	Anisotropic, dispersive, nonlinear	• Numerical • most general and versatile • Rich structure and analysis groups • Structures with finite periodicity
RCWA	Periodic	Planewave	Isotropic, dispersive	• Semi-numerical • Highly efficient for structures with uniform cross-sections
DGTD	Arbitrary	Planewave, Gaussian	Isotropic, dispersive	• Numerical • Good for curved surfaces and plasmonics • Visualization on non-planar surfaces • Structures with finite periodicity

Simulation Workflow

Step 1

STACK | FDTD | RCWA



Sweep source injection angle
Sweep geometric parameters

T/R spectrum
Color map
Diffraction characterization

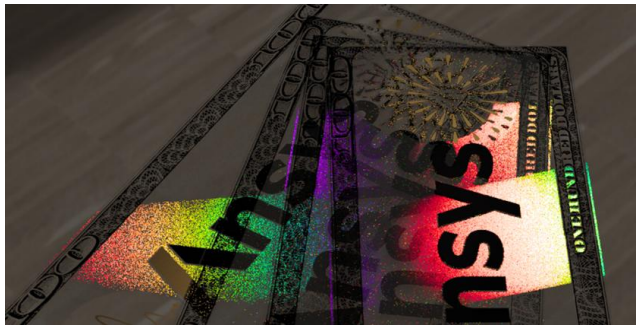
Lumerical Sub-Wavelength Model

JSON

- T/R for planar stack (STACK, FDTD)
- Grating characterization (FDTD, RCWA)
- In terms of f, θ, φ and polarization
- Idealized surface without simulation
  - User-defined T/R
  - Surface based on Jones matrices
  - User-defined grating orders

Step 2

Speos



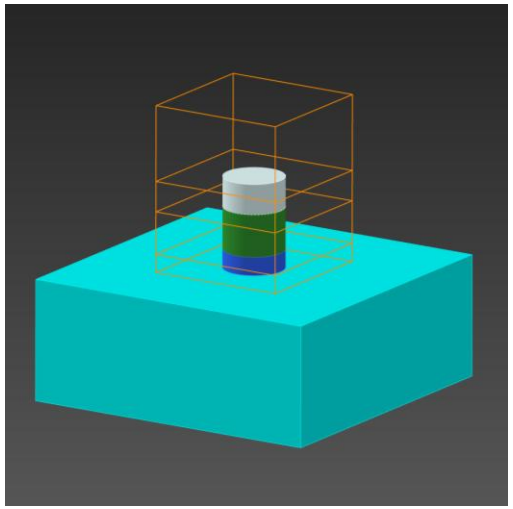
Apply LSWM to a surface
Illuminate the target with beam
Change the viewing position

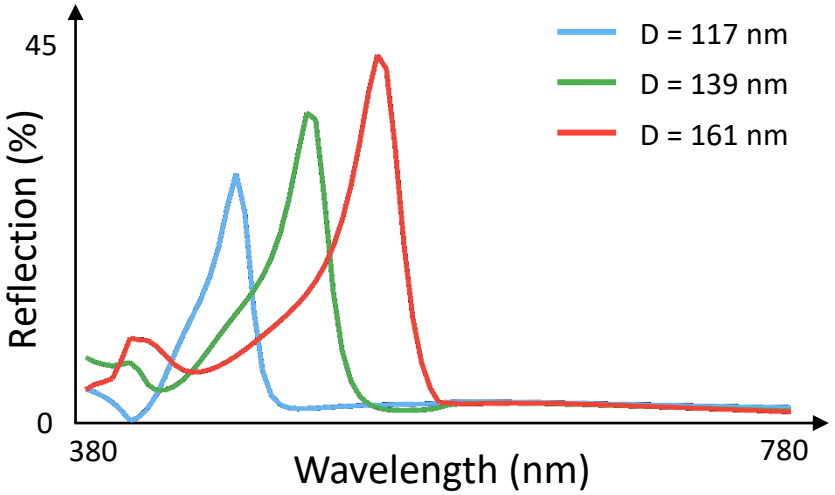
Human perception

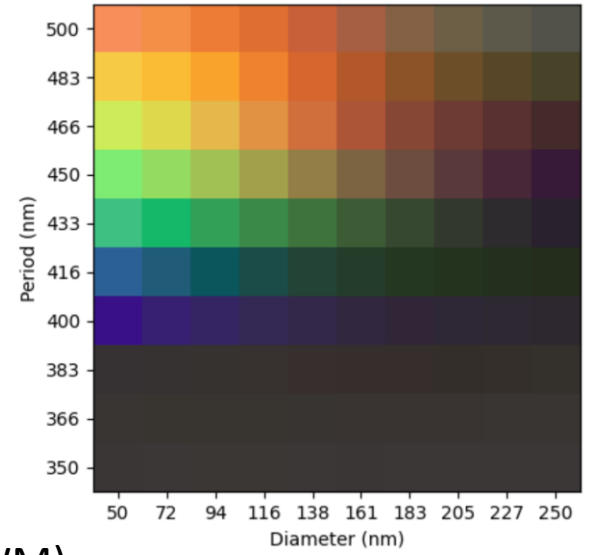
Dielectric Metasurface – RGB Color Map

RCWA solver

- $SiO_2/TiO_2/Si_3N_4/\ Sub\ (1.5)$
- Broadband source and specular reflection
- Color control by changing period & diameter
  - XYZ coordinates from R spectrum
    - converted to RGB value



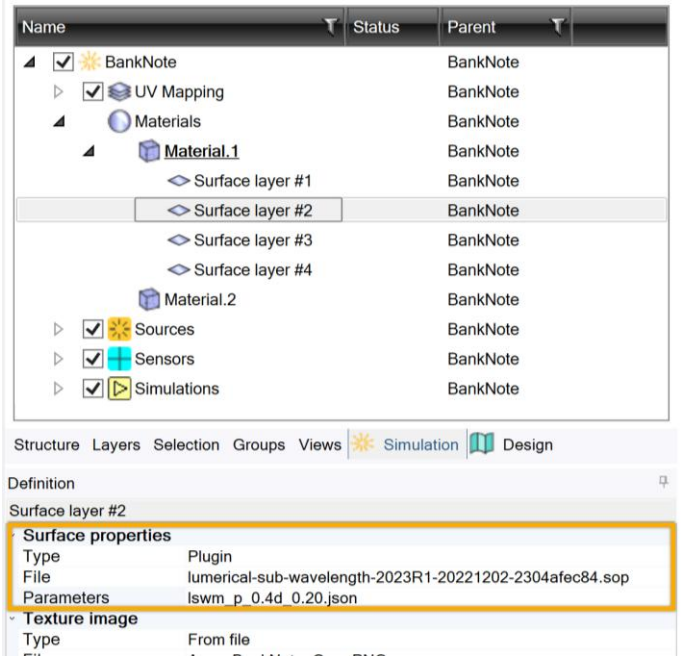


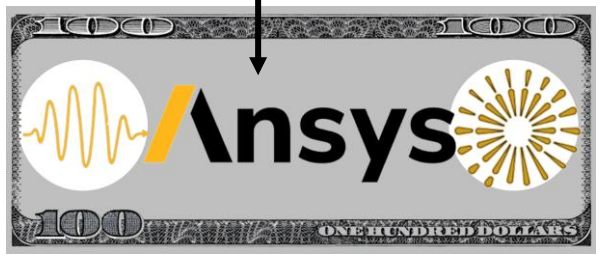


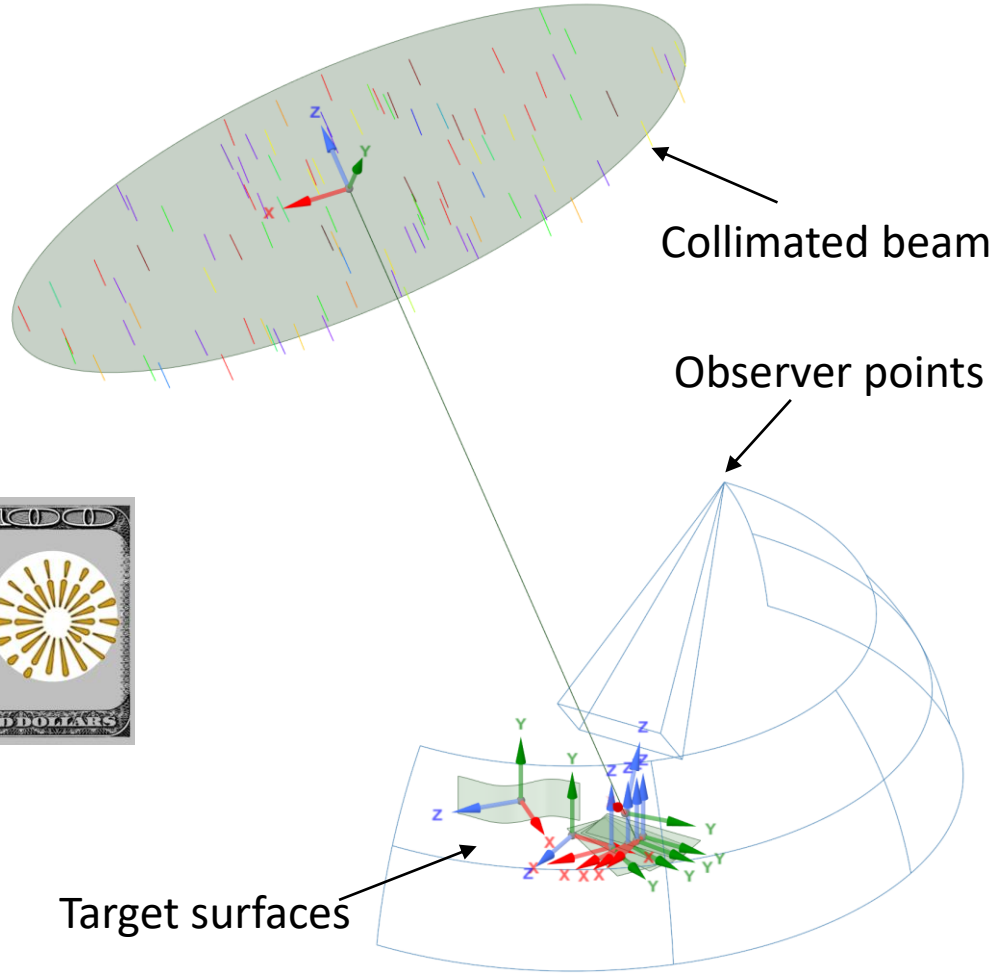
Data exported for Lumerical Sub-Wavelength Model (LSWM)

Speos Model and LSWM Import

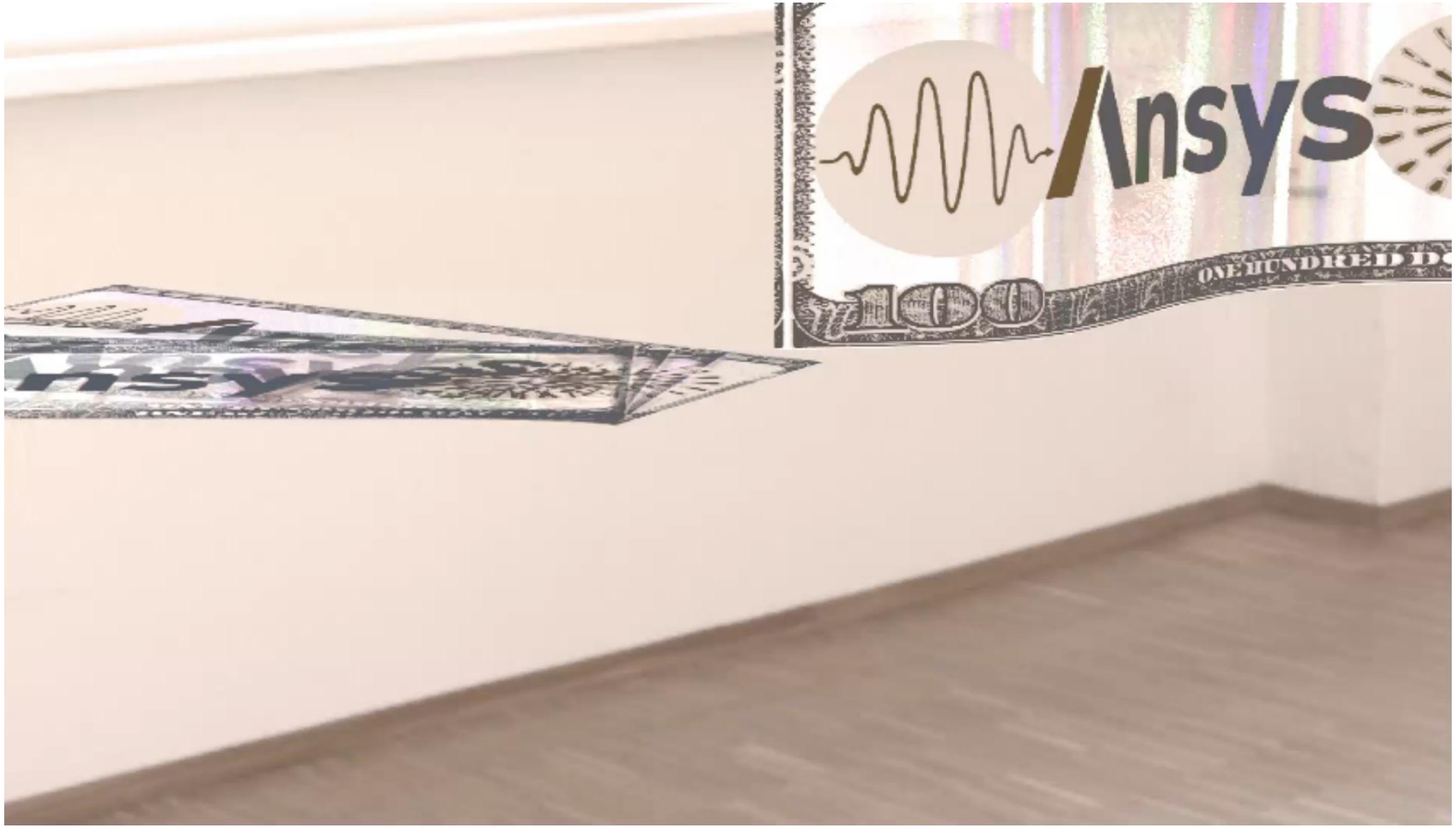
- LSWM imported as Plugin Surface
- Collimated beam with 15 observation points







Human Vision



Summary

- Design of structural colors and their visualization in realistic environment requires multi-scale simulation capabilities.

- Ansys Optics offers all the tools required for such simulations:
  - Nano-scale simulations with Lumerical STACK, FDTD and RCWA
  - Interoperability between Lumerical and Speos through LSWM
  - Color perception with Speos considering environment and human vision.

- For optimization, consider Ansys optiSLang, which provides state-of-the-art algorithms for design exploration, optimization, robustness and reliability analysis


Ansys