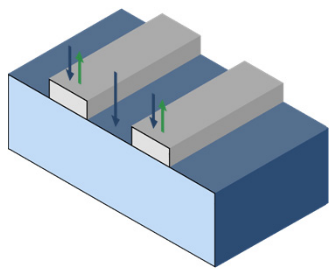
Interdigitated electrode with 50 percent metal coverage and 100 percent optical transmission

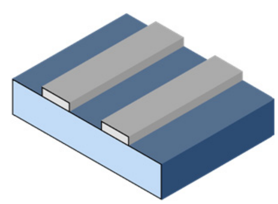
Pieter G. Kik

CREOL, The College of Optics and Photonics, UCF, Orlando, FL



Introduction

General challenge: electrical access to optically signal



Photovoltaics:

- need low-resistivity contacts: metallic top electrodes

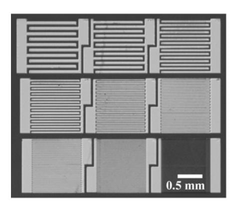
High speed photodetectors:

- need high conductivity for low RC times

Short wavelength detectors / exotic materials

- need rapid carrier collection to avoid recombination

Substantial fraction of light lost due to shadowing



MSM solar blind detectors on ZnMgO (Prof. Schoenfeld, CREOL, UCF)

Existing approaches:

- nanowire electrodes / transparent conductive oxides / graphene / plasmons

Proposed new design

Optical performance:

- 100% transmission at 50% metal areal coverage
- Not reliant on optical resonances, virtually unlimited bandwidth
- Not intrinsically polarization dependent

Structural characteristics

- Simple, compact metal electrode design
- Applicable on wide variety of substrates
- High conductivity
- Manufacturable feature sizes

Too good to be true?

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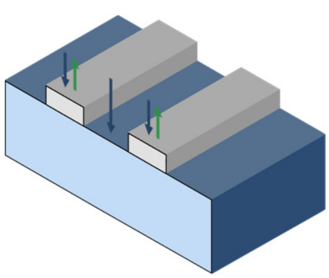
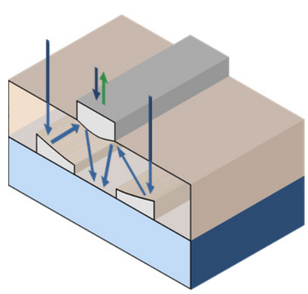
Designing a monolithic reflecting telescope

Standard interdigitated electrode with 50% metal coverage: 50% reflection loss

Goal: design integrated structure that works like catoptric (reflective) telescope





Challenge: central reflector blocks direct transmission through electrode gap

Solution: use transparent reflector?

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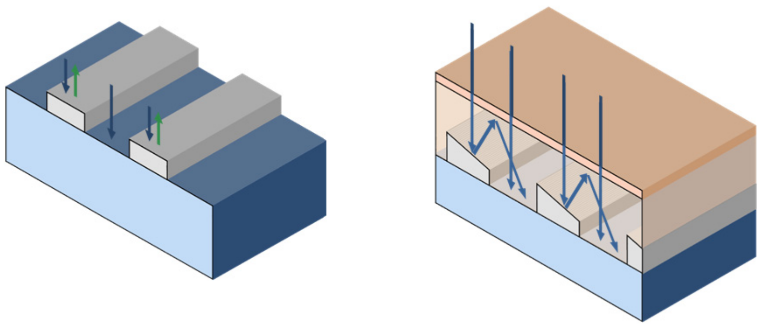
Replacing the secondary mirror with TIR

Proposed design: embedded shaped (tilted) electrode

Reflected light is directed to angles beyond TIR ⇒ surface = transparent reflector



Index match of cover layer with substrate ⇒ no reflection loss in electrode gap

AR coating on cover layer ⇒ no reflection loss at top surface

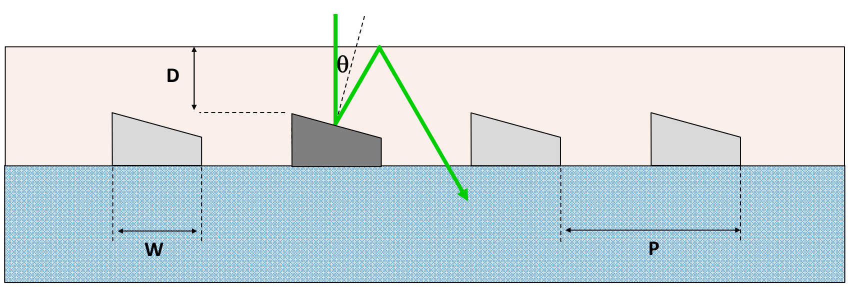
High transmission possible, polarization independent, non-resonant

Design constraints

Elementary structure: unidirectional constant tilt

Only requirement on electrode surface tilt angle: $\theta > \theta_{TIR}/2$

In this design: n_{cover} must match $n_{substrate}$ (not an intrinsic limitation)

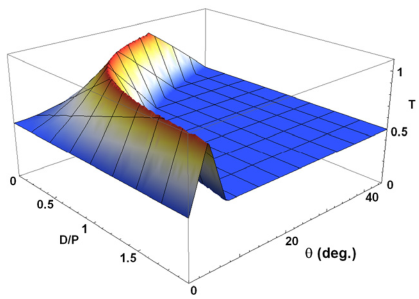


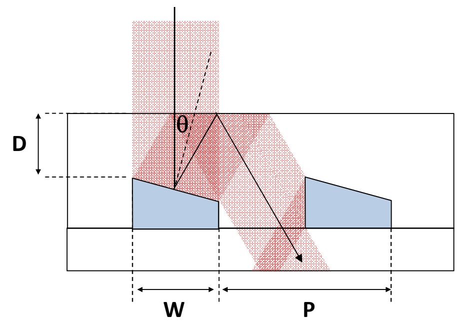
Reflected light can be directed to electrode gap at given cover layer thickness

First: evaluate transmission using ray optics analysis

Calculated transmission – ray picture

Simplification: light considered 'lost' if not in electrode gap after three reflections



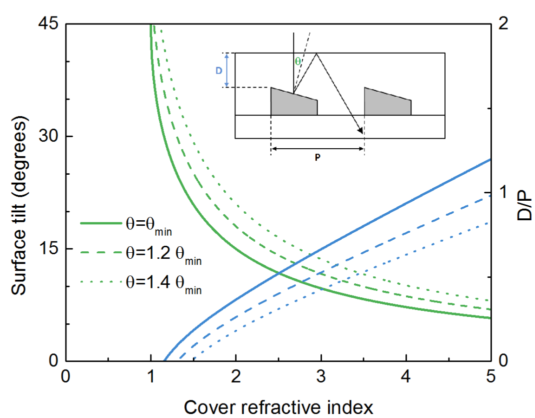


At 50% coverage 100% transmission possible at specific D/P ratio

Concept not dependent on polarization, on wavelength, and on absolute scale

Note: ray optics picture with lossless metal → total electrode thickness irrelevant

Cover layer thickness range vs. index



Optimum cover thickness

$$\frac{D}{P} = \frac{1}{4}[Cot(2\theta) - Tan(\theta)]$$

Angle requirement: $\theta > \theta_{TIR}/2$

Small cover refractive index ⇒ steep tilt angle needed to achieve TIR

Reasonable index values ⇒ surface tilt angle and cover thickness reasonable

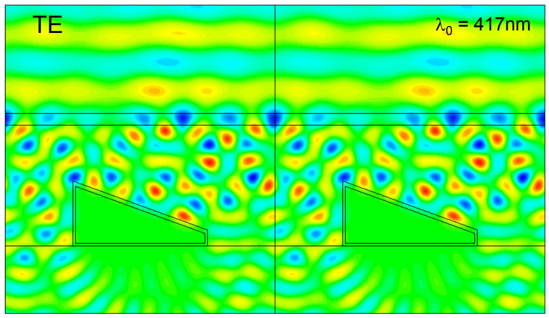
Next: test this concept using realistic (lossy) metal electrodes

Numerical simulation of catoptric electrode design

Numerical simulation (FIT, CST) at single electrode tilt angle

Silver electrode (good reflector), 1 μm wide lines, n=2 cover layer, θ = 20°

AR coating at top surface (n = 1.41, thickness 88 nm, optimized for λ=500nm)



← no standing wave above surface

Average line thickness **500nm**

Wavelength reduced in cover + interference between incident and reflected light

Note: multiple angles transmitted through gap

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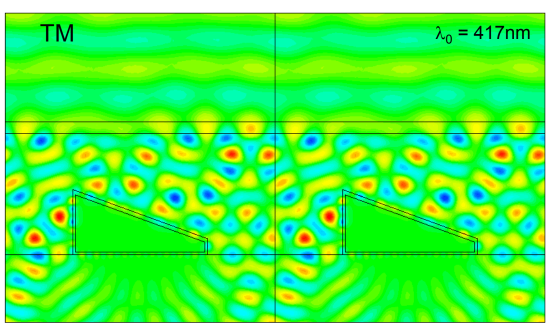
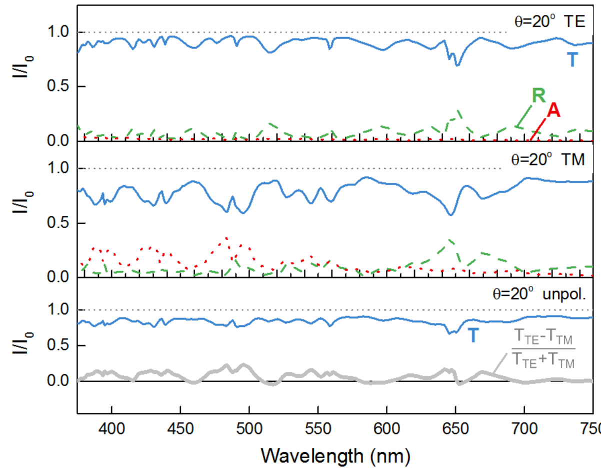


← *some* standing wave above surface

Evidence of surface plasmons on silver electrode

Next: calculated transmission, absorption, reflection spectra

Frequency dependent transmission and degree of polarization



Resistance

< 0.1 Ω / □

TE : T_{ave} = 90% across entire VIS range; **TM** : T_{ave} = 77%

Unpolarized light: 84% transmission, degree of polarization < 0.24

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Conclusions

Optical performance:

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- Polarization independent

Structural characteristics

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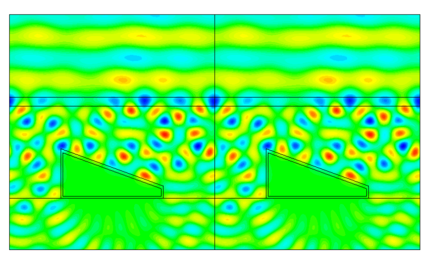

Real-world example:

- 84% frequency averaged transmission of unpolarized light over full octave
- Degree of polarization of transmitted light less than 25%

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