Metasurface-assisted optical transparency of a continuous metal film

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15s-Summary

Question: Transparent conductors are useful, but conventional ITO film is expensive and not sustainable.

Task: Find a new design strategy of transparent conductors based on continuous metal film.

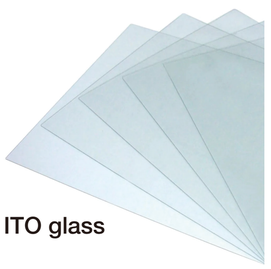
Results: A transparent metasurface/metal film/metasurface configuration is proposed based on Coupled Mode Theory (CMT).

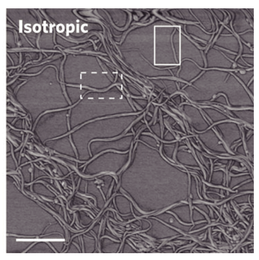
Free-standing samples were fabricated by the transmitted e-beam lithography technique.
$T_{max} \approx 55\%$ is obtained for a 28nm thick Ag film.

Introduction

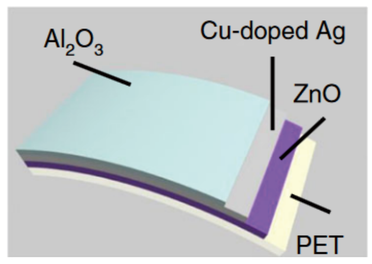
Former realizations of transparent conductors

- Indium Tin Oxide (ITO): widely used, but expensive due to the scarcity of *indium*.
- Nanosturctures (cabon nanotube, Ag nanowire/mesh etc.) : low conductivity and high optical haze.
- Continuous metal film: good conductance, but hard to be made transparent.





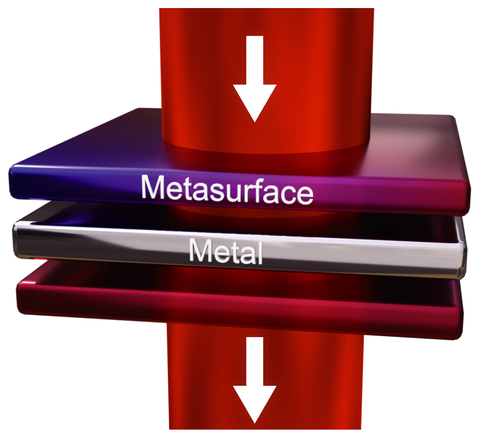
Nat Nanotech (2011)



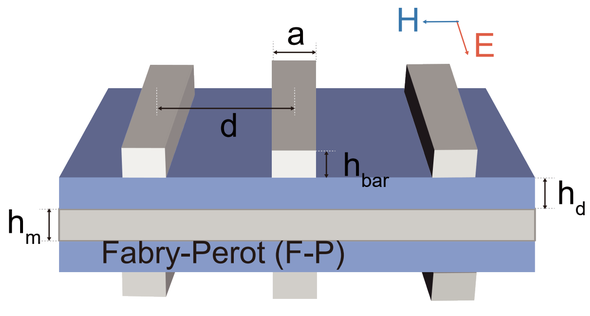
Nat Commun (2020)

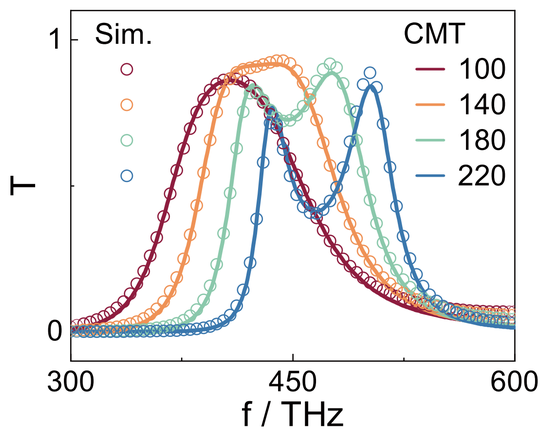
Our results

- Metasurface-assisted transparency of a continuous metal film with numerical and experimental verifications.
- Transparency is interpreted by CMT.
- Optoelectronic performance comparable to ITO.



Design

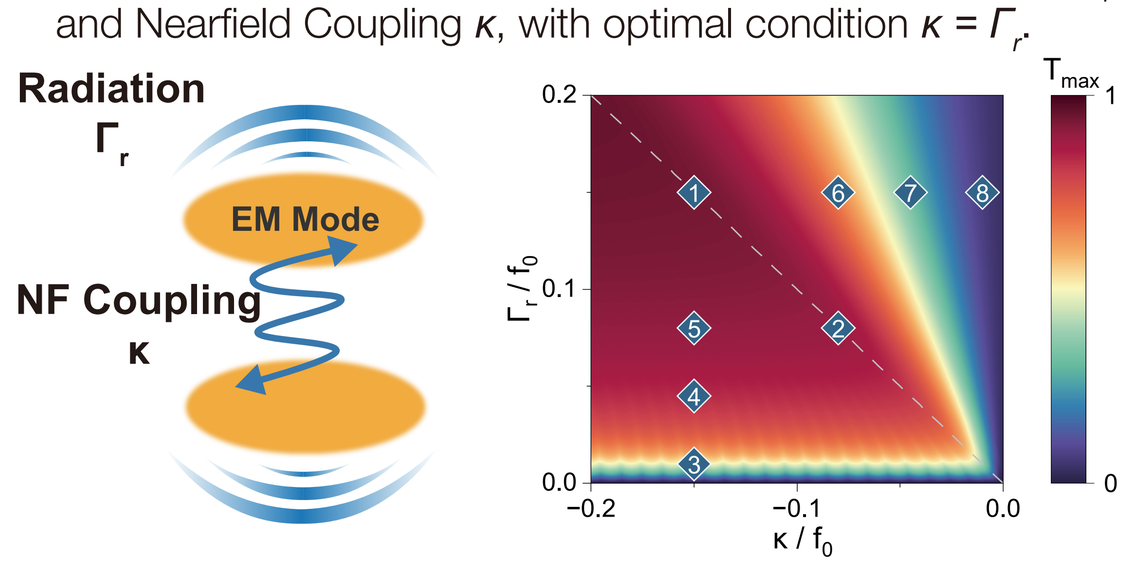




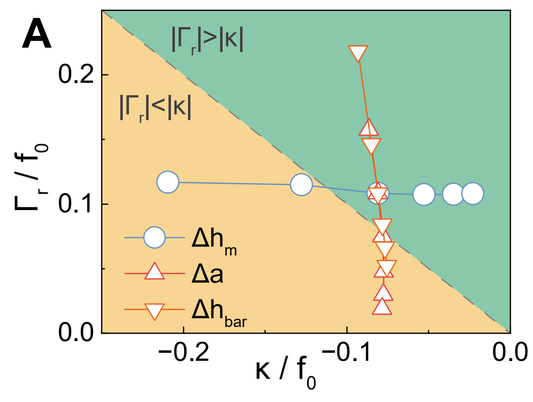
- 5-layer demo: Ag grating/SiN_x/Ag film/SiN_x/Ag grating.
- Transmittance simulated and fitted by two-port two-mode CMT with different *a* (nm)

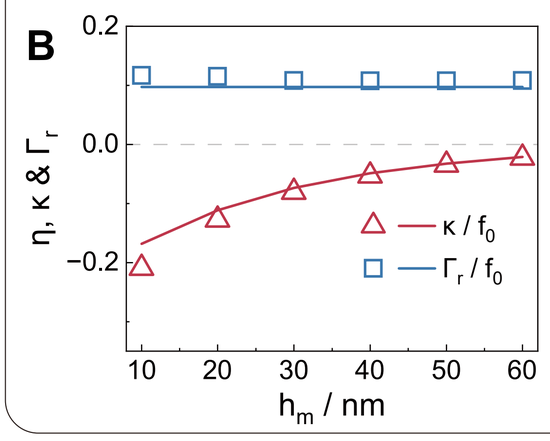
Theory

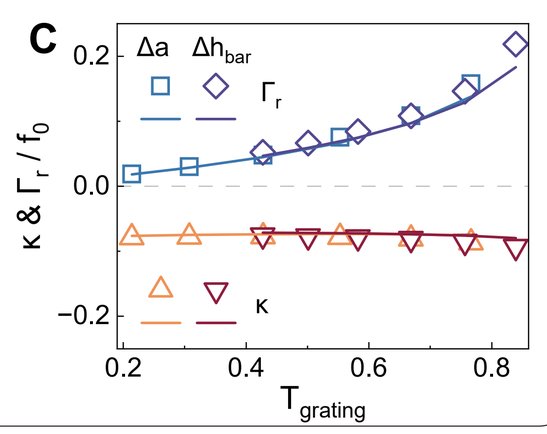
- Two SiN_x cavities support two F-P electromagnetic modes.
- Max transmittance is mainly controlled by Radiation Loss Γ_r and Nearfield Coupling κ, with optimal condition $\kappa = \Gamma_r$.



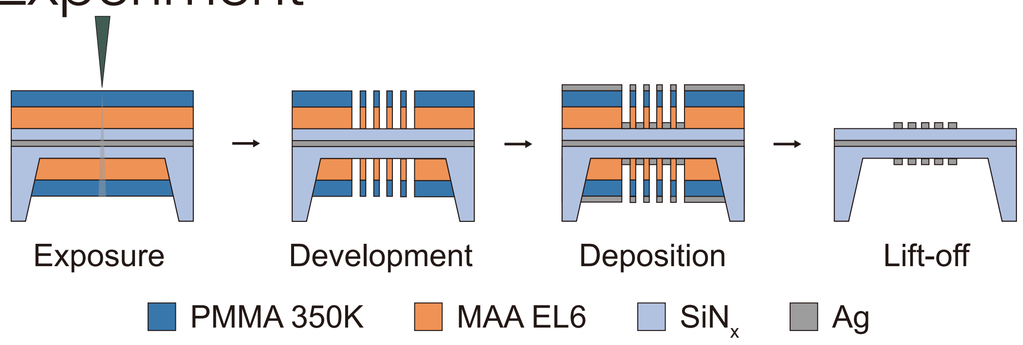
- **A:** κ and Γ_r are controlled by the geometry.
- $h_m \rightarrow \kappa$; a, $h_{bar} \rightarrow T_{grating} \rightarrow \Gamma_r$.
- **B, C:** κ, Γ_r from theory (line, by Tight Binding Method and energy flow analysis) and simulation (scatter) agree well.



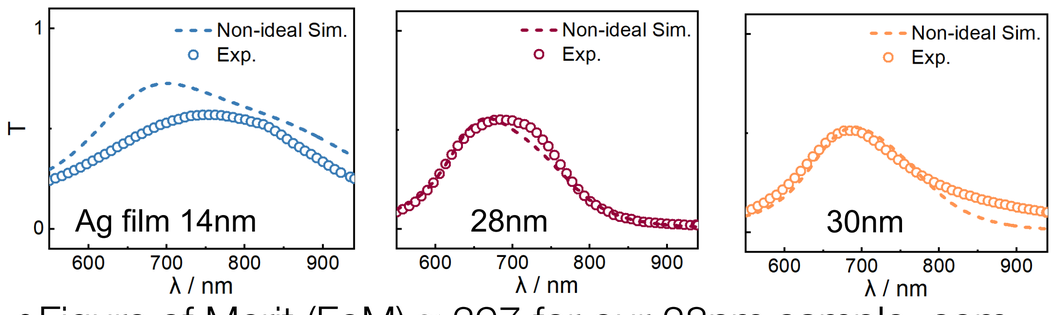




Experiment



- Transmitted e-beam lithography was applied to fabricate free-standing samples



- Figure of Merit (FoM) ≈ 397 for our 28nm sample, comparable to ITO (FoM ≈ 350)

References

[1] D. J. Lipomi et al., Nat. Nanotech. 6, 788 (2011).
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[3] J. Yun, Adv. Funct. Mater. 27, 1606641 (2017).
[3] X. Zheng et al., PhotoniX 4, 3 (2023).