A meta-prism for high-efficiency coupling between free space and optical waveguides

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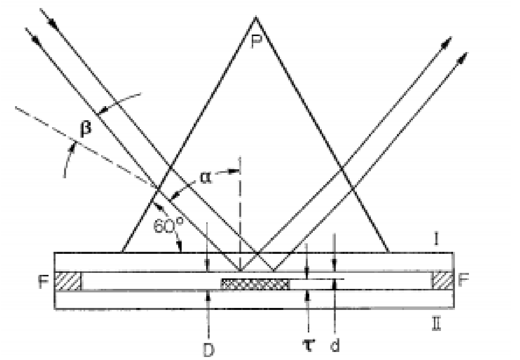
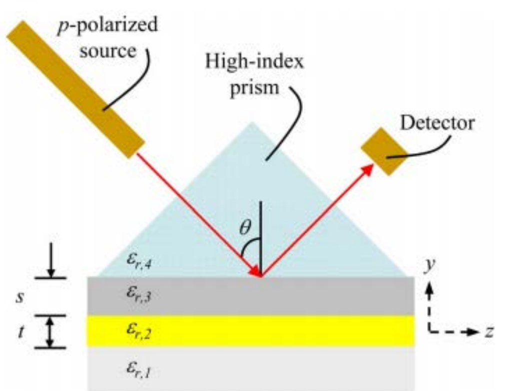
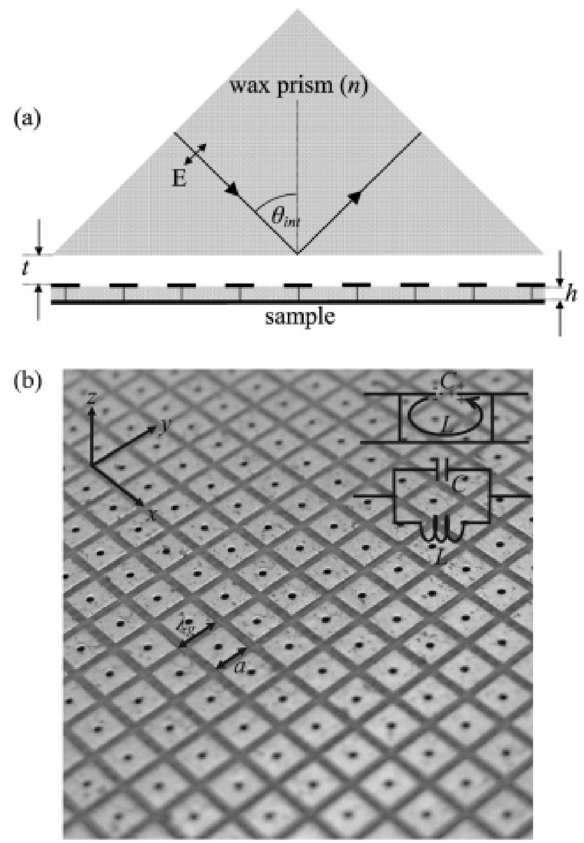
Traditional prisms for coupling between free space and optical device



A. Otto, Zeitschrift Phys. 216, 398 (1968).



P. Berini, Adv. Opt. Photonics 1, 484 (2009).



M. J. Lockyear, A. P. Hibbins, J. R. Sambles, Phys. Rev. Lett. 102, 073901 (2009).

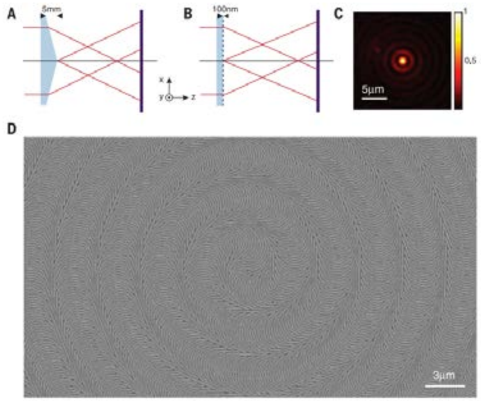
Planar waveguide

Total reflection

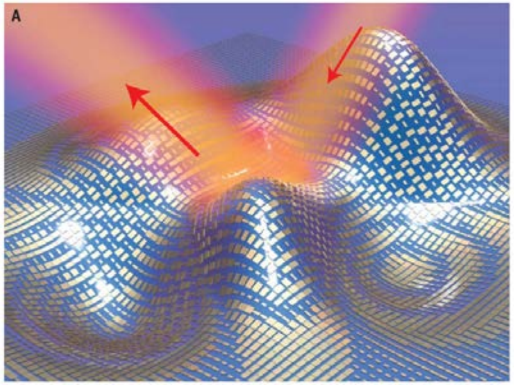
Bulky in size

Low efficiency

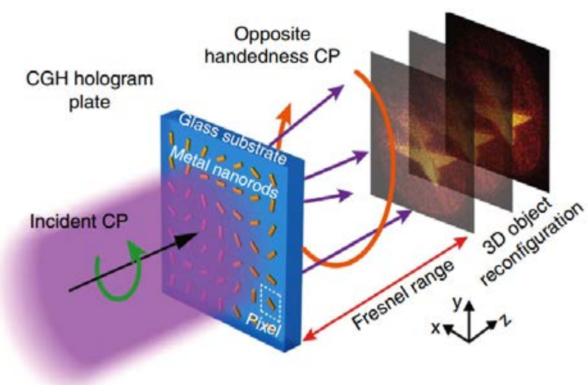
Gradient metasurfaces



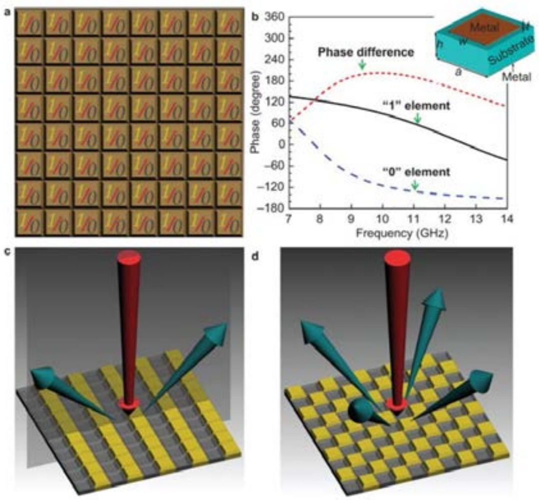
Metalenses



Cloaking



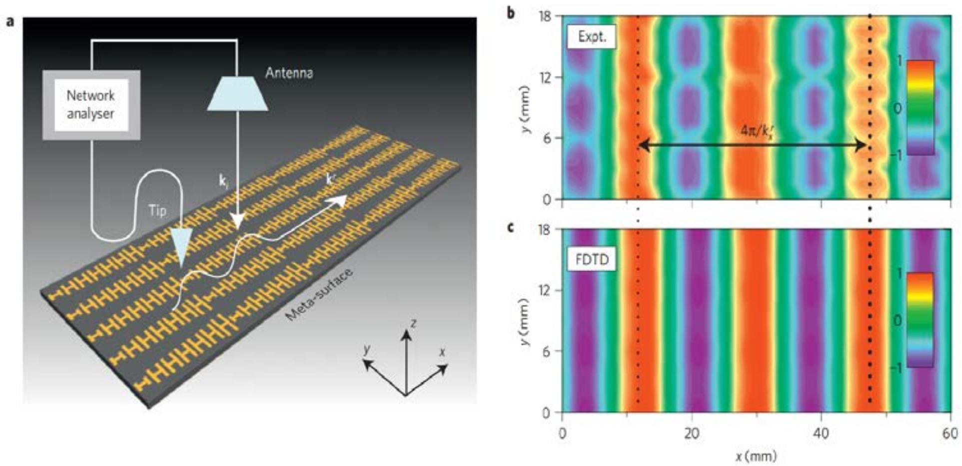
Holography



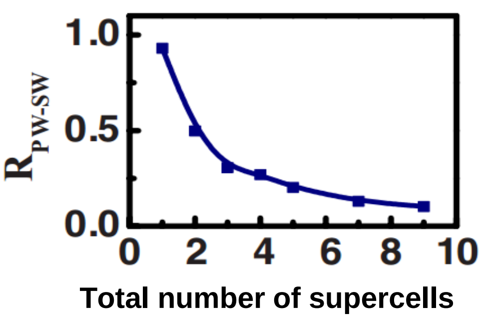
Coding

Gradient metasurfaces for converting propagating waves into surface waves

Manipulation of reflected waves



S. Sun, Q. He, S. Xiao, Q. Xu, X. Li, and L. Zhou, Nat. Mater. ***11****, 426 (2012)*

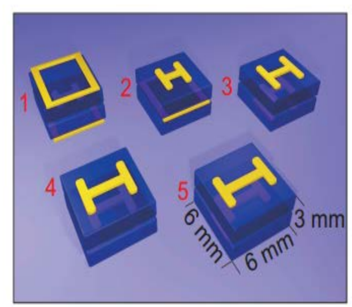


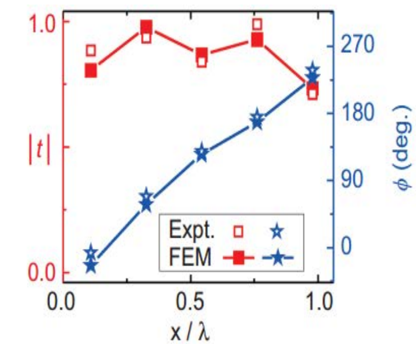
Abrupt inhomogeneity caused by supercell boundaries scatters SWs.

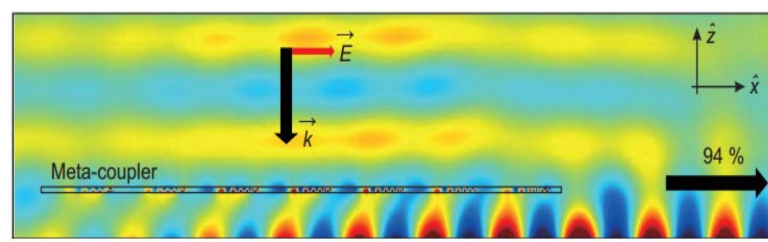
C. Qu, etc. , EPL,101 (2013)

Manipulation of transmitted waves

Bragg scattering by the periodic supercells is significantly reduced.



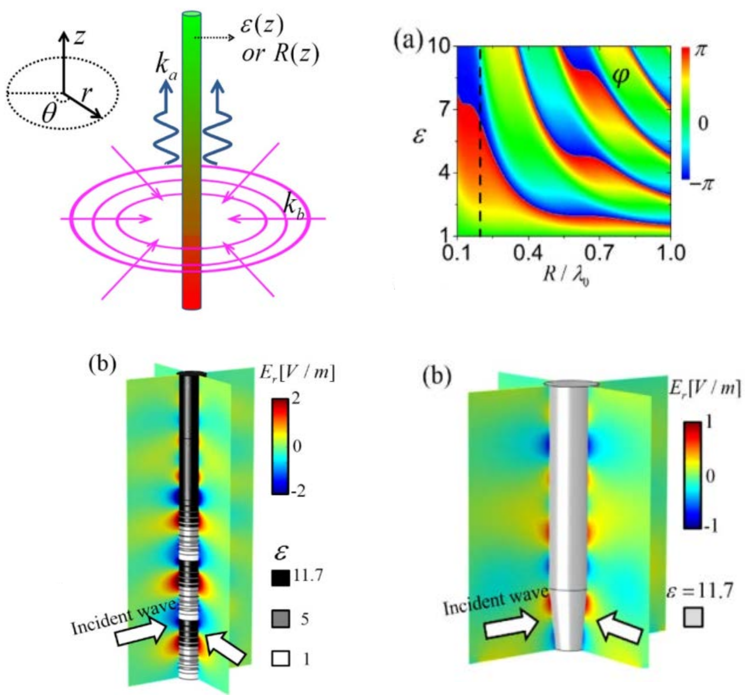




W. Sun, Q. He, S. Sun, and L. Zhou, Light Sci. Appl. ***5****, e16003 (2016).*

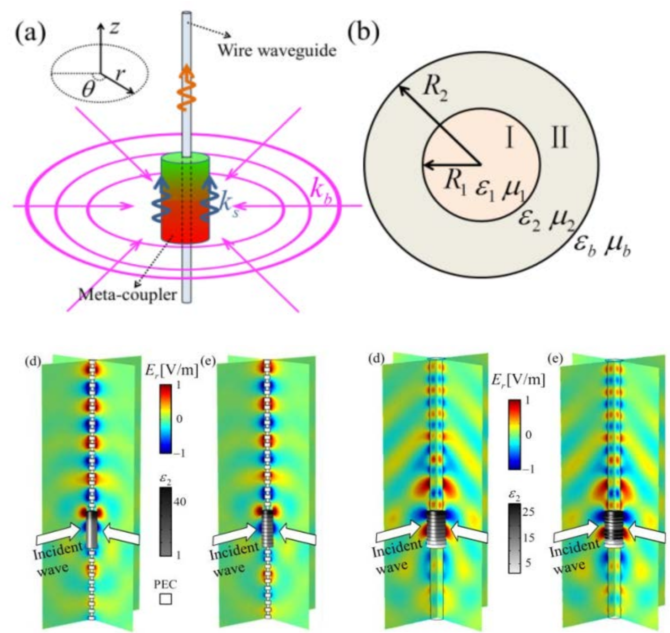
Gradient structures for converting cylindrical propagating waves into guided waves

Gradient tip strctures



H. Chu, J. Luo and Y. Lai, *Opt. Lett.* **41** 3551 (2016)

Non-invasive meta-couplers



H. Chu, J. Luo and Y. Lai, *IEEE Photonics J.* **9**, 1 (2017)

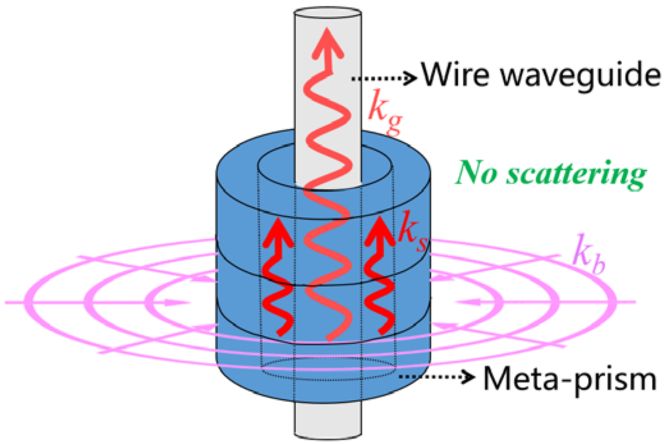
Manipulation of reflected waves → Relatively low efficiency

Difficulty in material realization → Microwave frequency

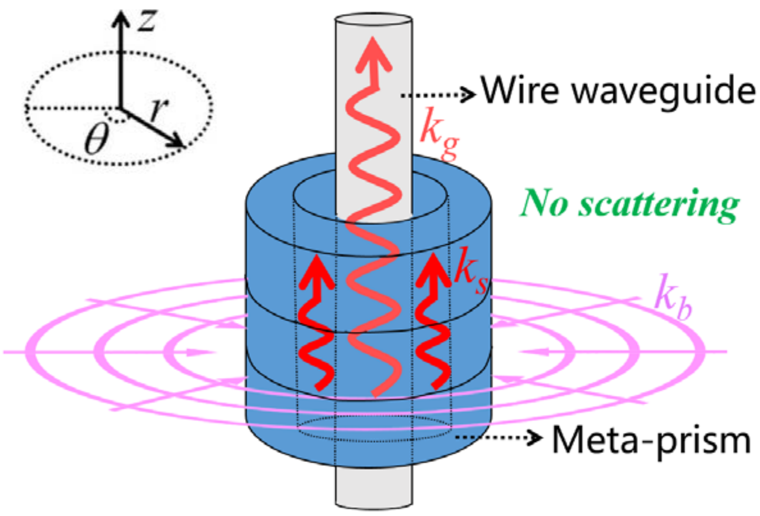
In this work

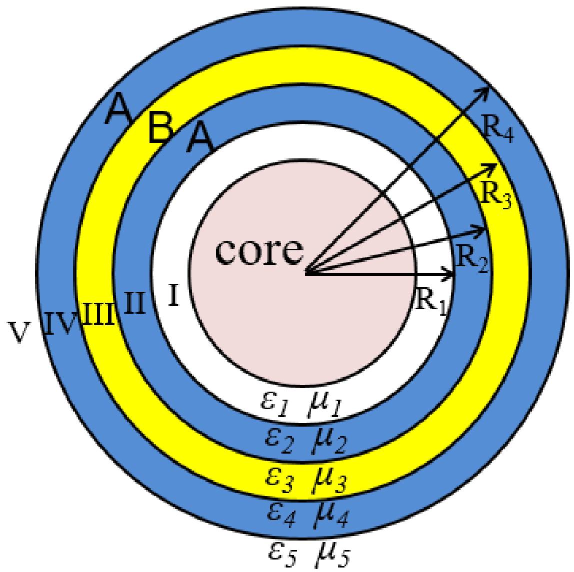
We design a type of meta-prism for CPW-GW conversion by using ABA multilayer structure in a noninvasive way.

- ✓ Manipulation of transmitted waves
- ✓ High conversion efficiency
- ✓ Fixed total thickness
- ✓ Infrared frequency
- ✓ Different angular momentums



Descriptions of model





Electric field in the p-th layer: $$E_p = \sum_{m=-\infty}^{\infty} [A_{m,p} H_m^{(2)}(k_p r) + B_{m,p} H_m^{(1)}(k_p r)] e^{im\theta} \hat{z}$$

By matching the boundary conditions: $$\begin{pmatrix} A_{m,I} \\ B_{m,I} \end{pmatrix} = M_m \begin{pmatrix} A_{m,V} \\ B_{m,V} \end{pmatrix}$$

Transmission coefficient: $$S_m = A_{m,I} / A_{m,V}$$

Meta-prism design

Incident waves with zero angular momentum quantum number (i.e.,m=0)

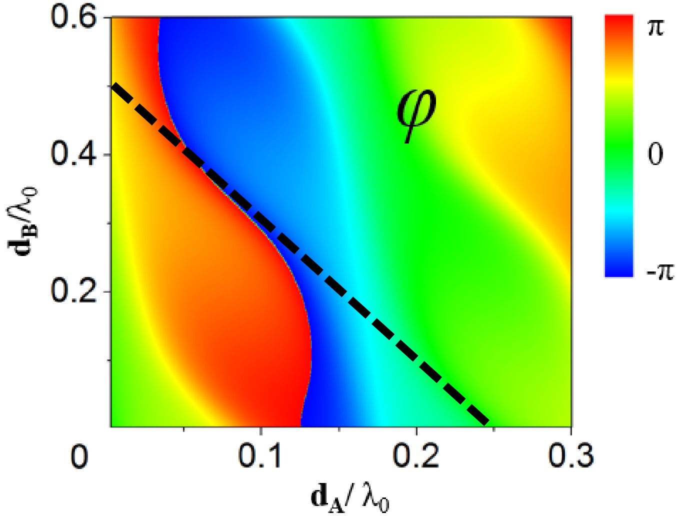
$\varepsilon_A = 9.3$ (GaP)

$\varepsilon_B = 2.3$ (SiO_2)

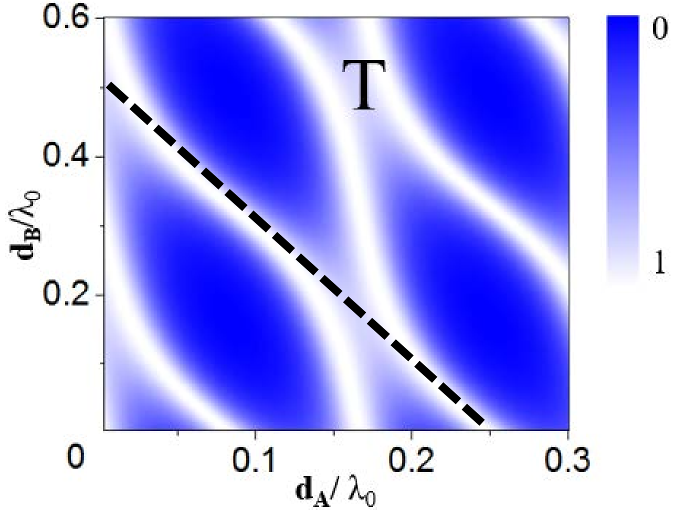
Vary the filling ratio of the components

i.e.,thickness of layer A and layer B (d_A and d_B)

Transmission phase $\varphi = Arg(S_m)$



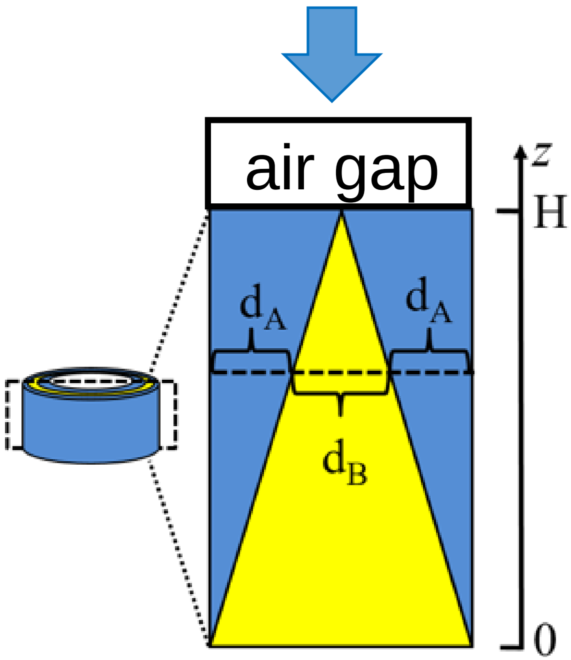
Transmittance $T = |S_m|^2$



$$2d_A + d_B = \lambda_0 / 2$$

Meta-prism design

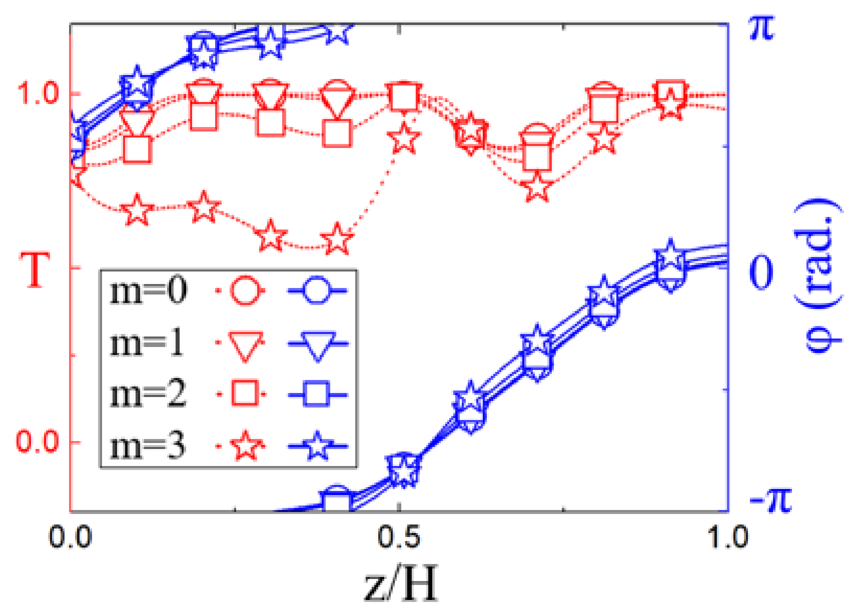
$$2d_A + d_B = \lambda_0 / 2$$



d_A :   0 $\rightarrow$ $\lambda_0/4$

d_B : $\lambda_0/2$ $\rightarrow$ 0

The total thickness is a constant of $\lambda_0/2$

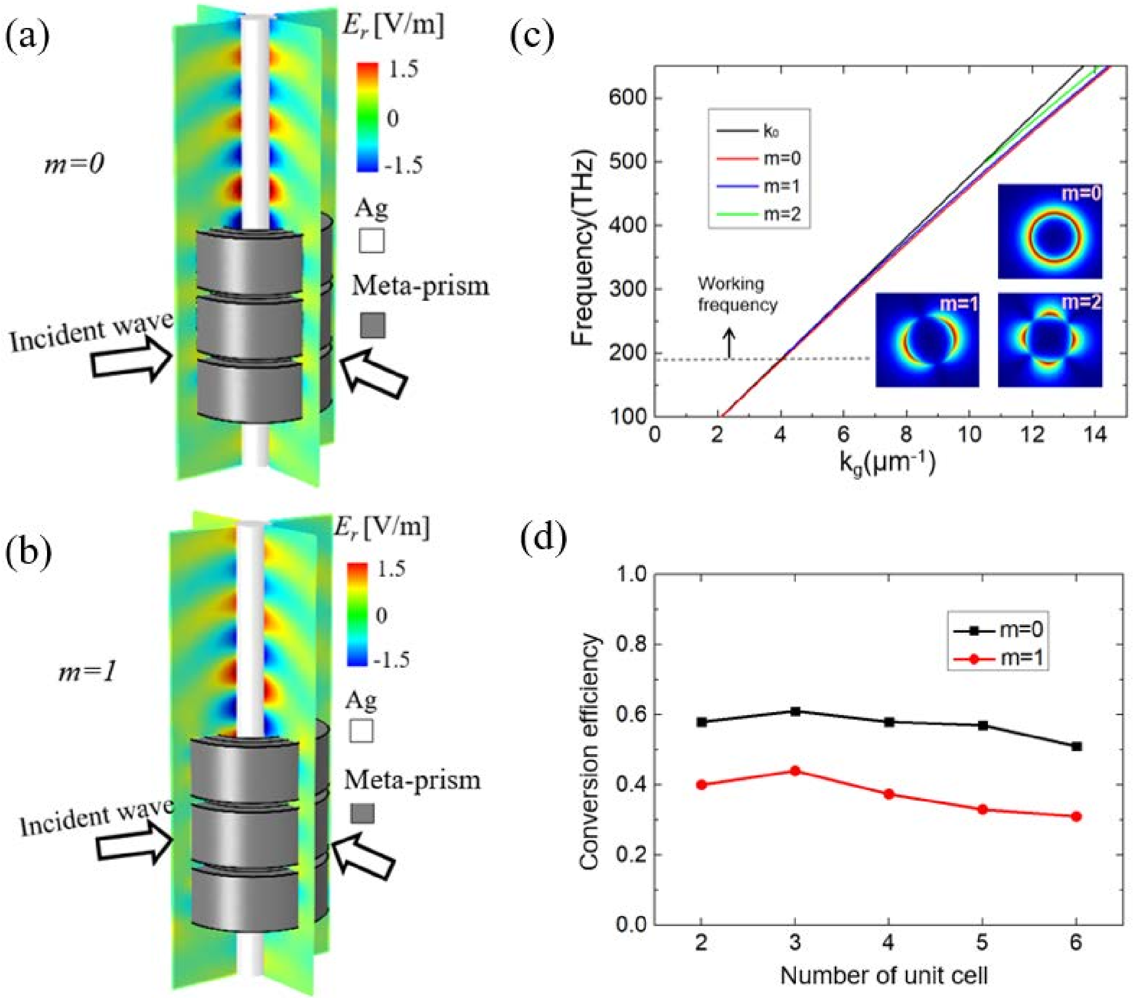


The calculated T and φ of the meta−prism for different angular momentum quantum numbers when R=0.63λ_0

Numerical simulation

$$E_b = \sum_{m=-\infty}^{\infty} H_m^{(2)}(k_0 r) e^{im\theta} \hat{z}$$

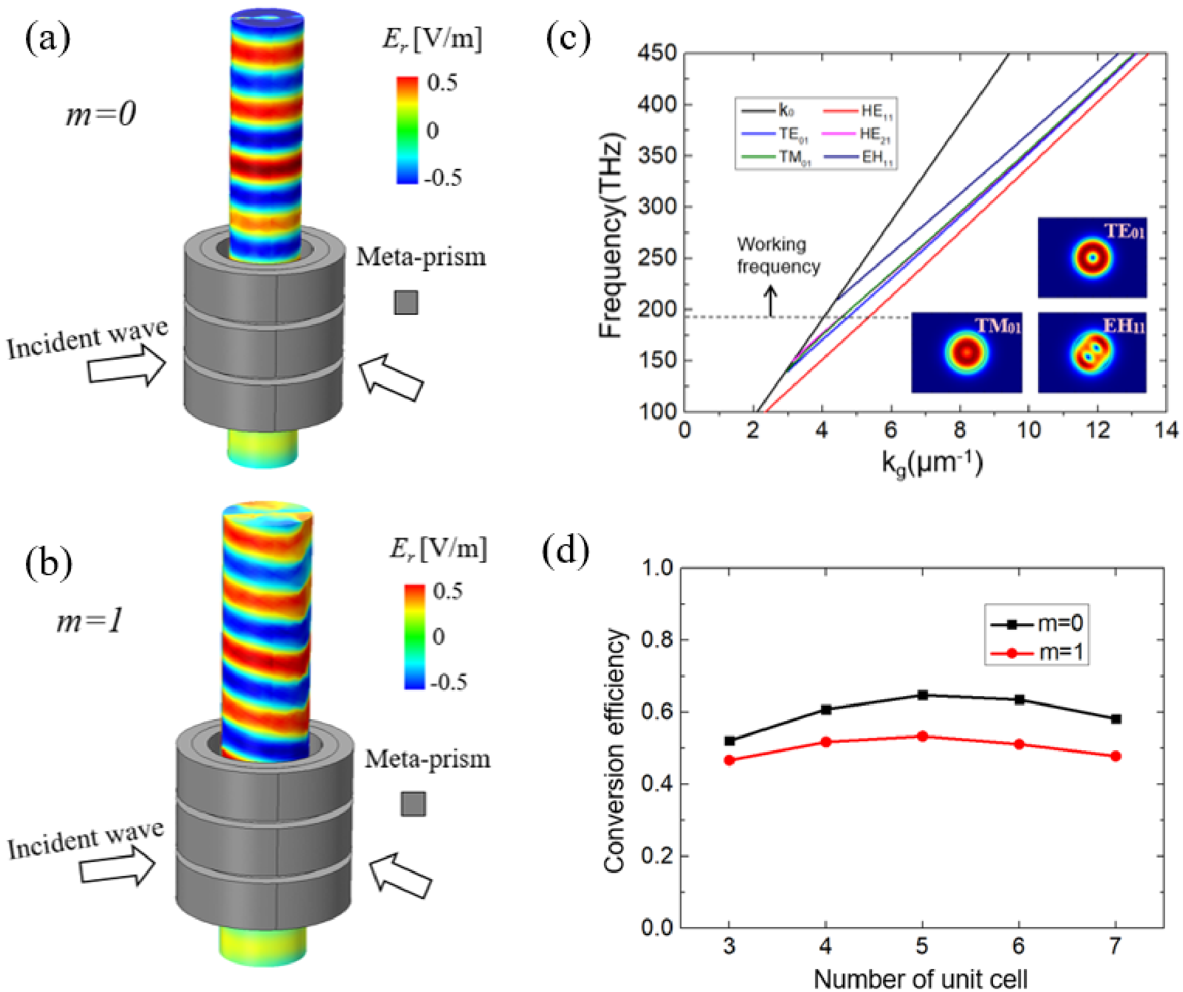
Metal wires



Numerical simulation

$$E_b = \sum_{m=-\infty}^{\infty} H_m^{(2)}(k_0 r)e^{im\theta}\hat{z}$$

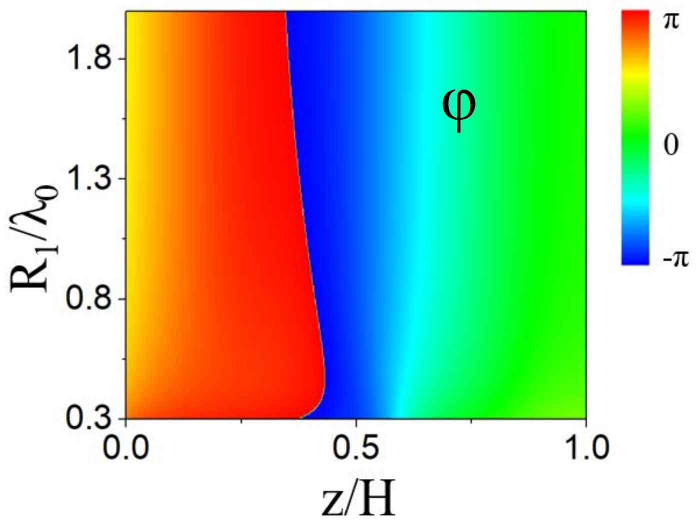
Optical fibers

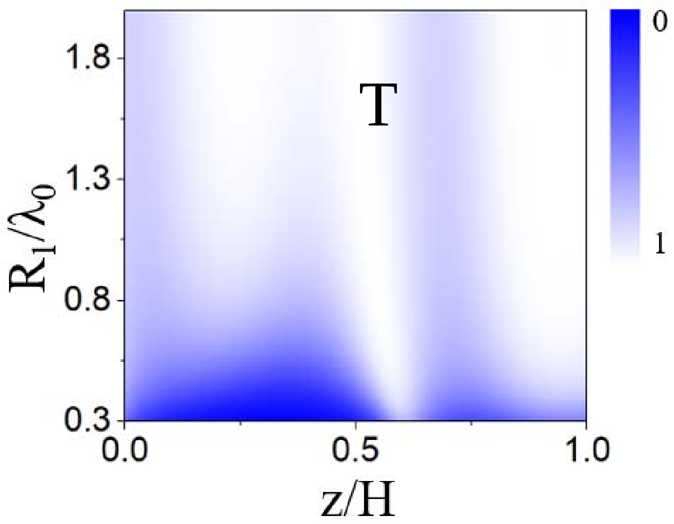


Influence of the radius

m=3

(R_1: inner radius of the meta-prism)





Transmission phase:

Cover a wide range

Vary linearly with z

Transmittance:

Relatively Low when R is small

Increase to over 80% when $R>\lambda_0$

The designed meta-prism could also apply to incident waves with even larger angular momentums when the radius of the meta-prism is large enough.

Conclusions

We have proposed a meta-prism which can convert CPWs in free space to GWs along waveguides.

The meta-prism is constructed with ABA multi-layer structure, which can generate transmitted waves with high transmittance and linearly varying phase.

We have designed the meta-prism for metal wires and optical fibers. Relatively high conversion efficiency has been achieved.

The meta-prism applies for different angular momentums, which provides a method to generate GWs with different angular momentums.


Thanks for your attention!