

Rui-yuan WU, Tie-jun CUI, 2020. Microwave metamaterials: from exotic physics to novel information systems. *Frontiers of Information Technology & Electronic Engineering*, 21(1):4-26. <https://doi.org/10.1631/FITEE.1900465>

Microwave metamaterials: from exotic physics to novel information systems

Key words: Metamaterial; Effective medium theory; Metasurface; Surface plasmon polaritons; Digital coding; Programmable; Information

Corresponding author: Tie-jun CUI

E-mail: tjcui@seu.edu.cn

 ORCID: <https://orcid.org/0000-0002-5862-1497>

Introduction

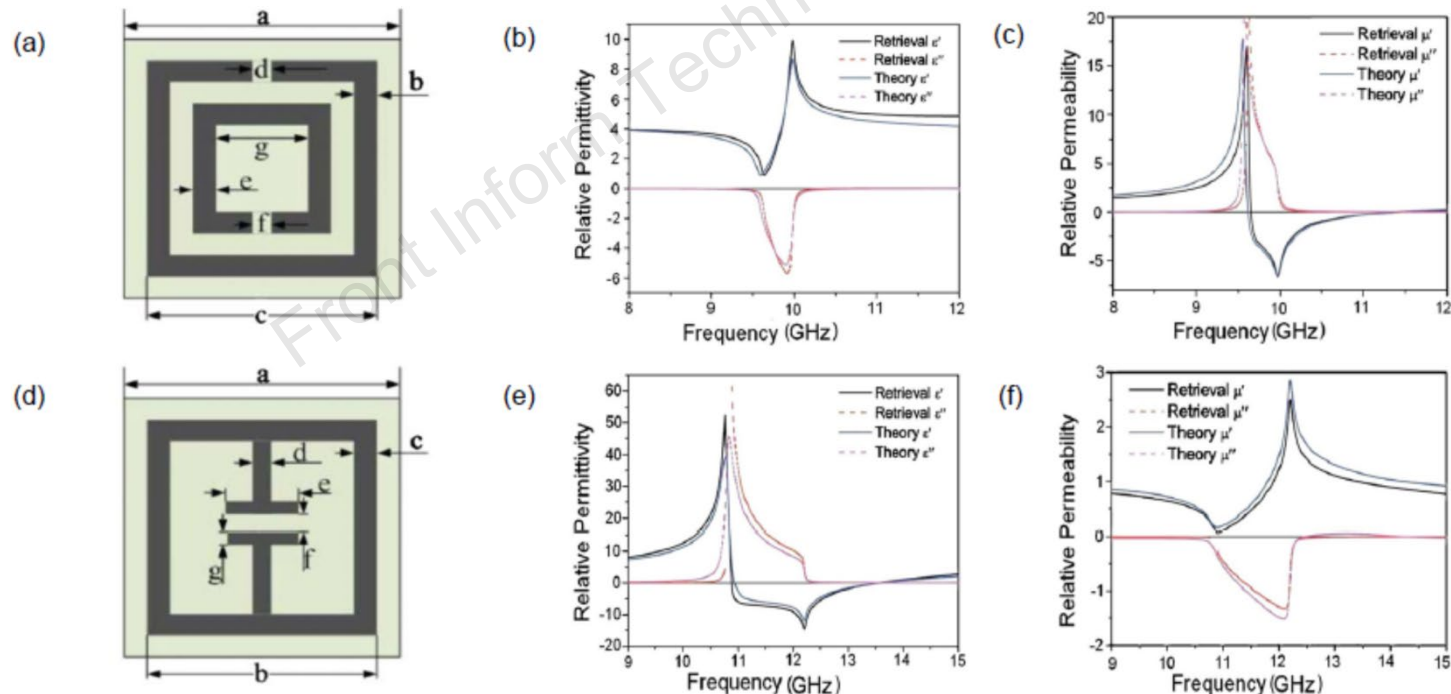
Metamaterials and metasurfaces have attracted much attention due to their powerful ability to control electromagnetic (EM) waves. In this paper, we review the recent developments in the field of EM metamaterials, starting from their exotic physics to their applications in novel information systems.

Content

1. We show the fundamental understanding of traditional metamaterials based on the effective medium theory and related applications, such as invisibility cloaks and meta-lenses.
2. We review the two-dimensional versions of metamaterials, i.e., metasurfaces, for controlling spatial waves and surface waves, and thereafter present their typical designs.
3. We briefly introduce spoof surface plasmon polaritons and their applications in microwave frequencies.
4. We emphatically present the concepts of digital coding metamaterials, programmable metamaterials, and information metamaterials. By extending the principles of information science to metamaterial designs, several functional devices and information systems are presented, which enable digital and EM-wave manipulations simultaneously.

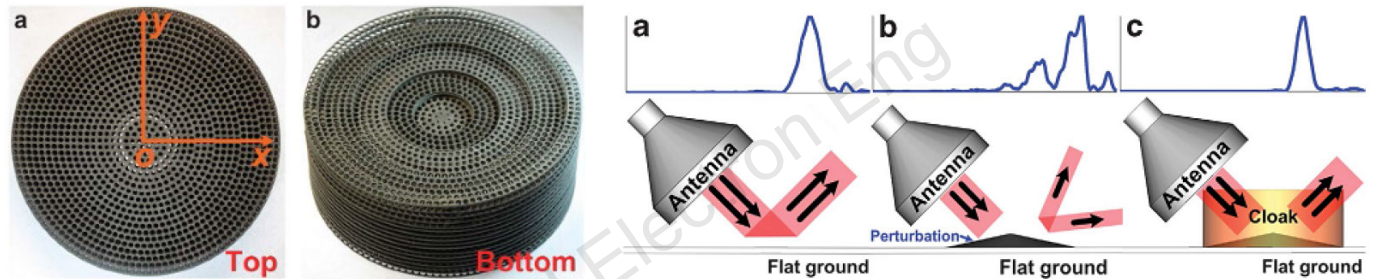
Analog metamaterials effective medium metamaterials

Metamaterials are actually composed of subwavelength-scale meta-particles arranged periodically or quasi-periodically, which can be described by continuous effective medium parameters (effective permittivity ϵ and effective permeability μ).

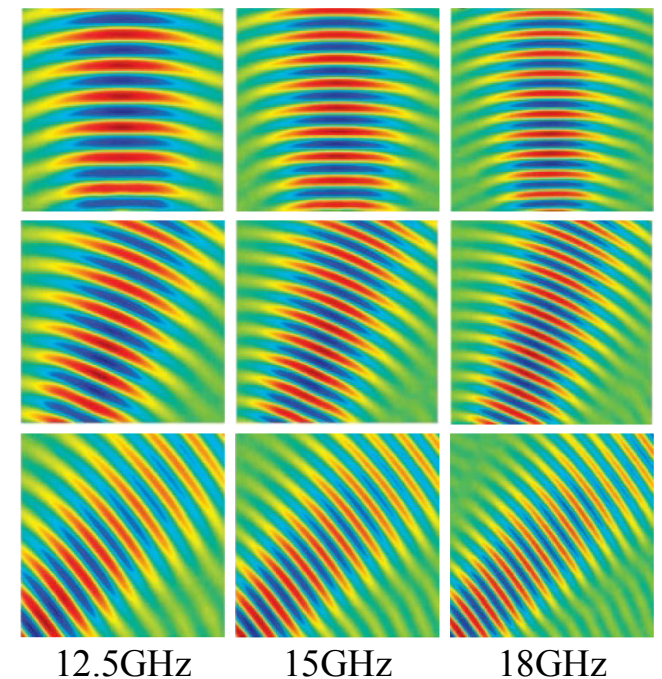
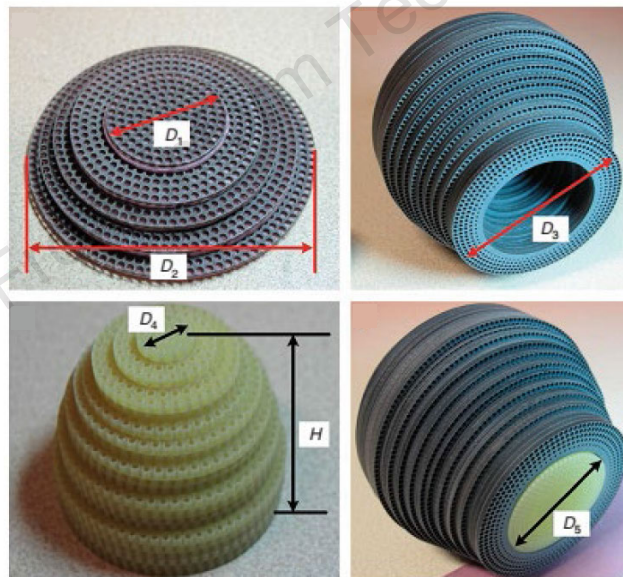


Analog metamaterials effective medium metamaterials (Cont'd)

Invisibility
cloak



Meta-lens

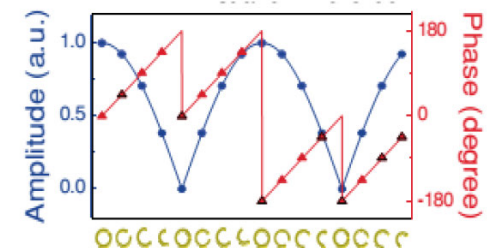
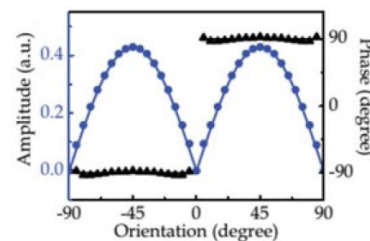
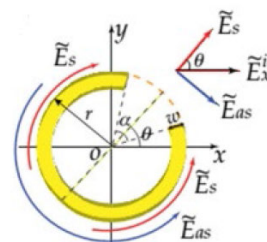
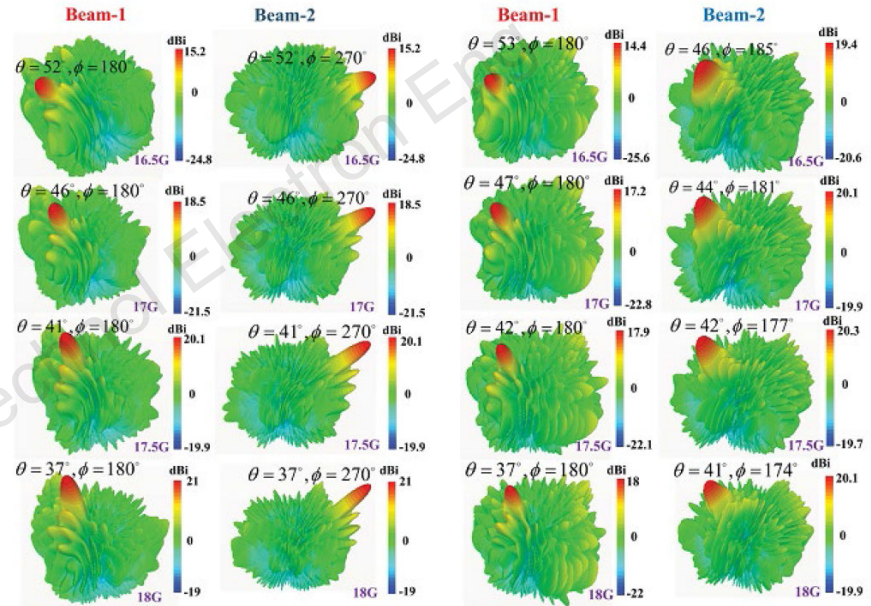
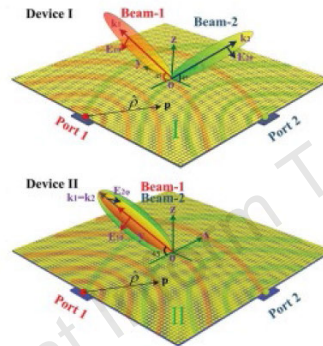
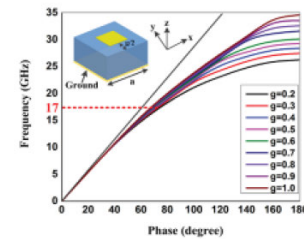


Analog metamaterials metasurfaces

2D case of
metamaterial

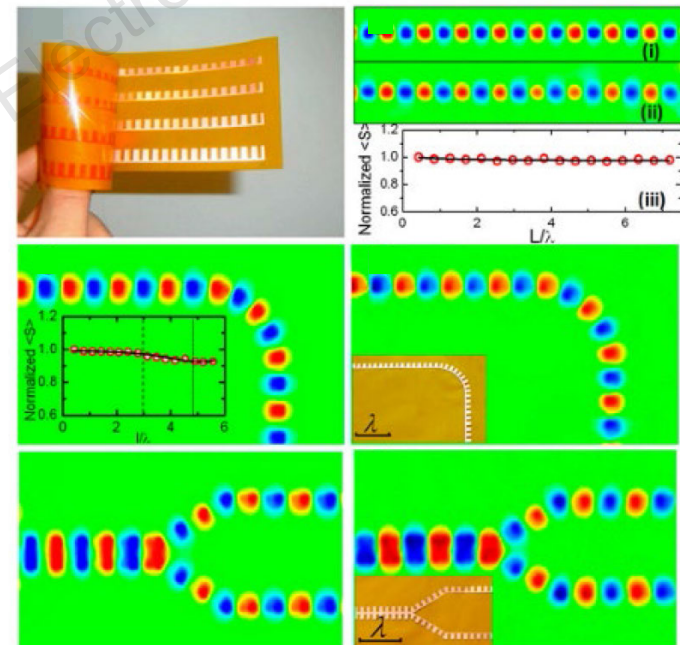
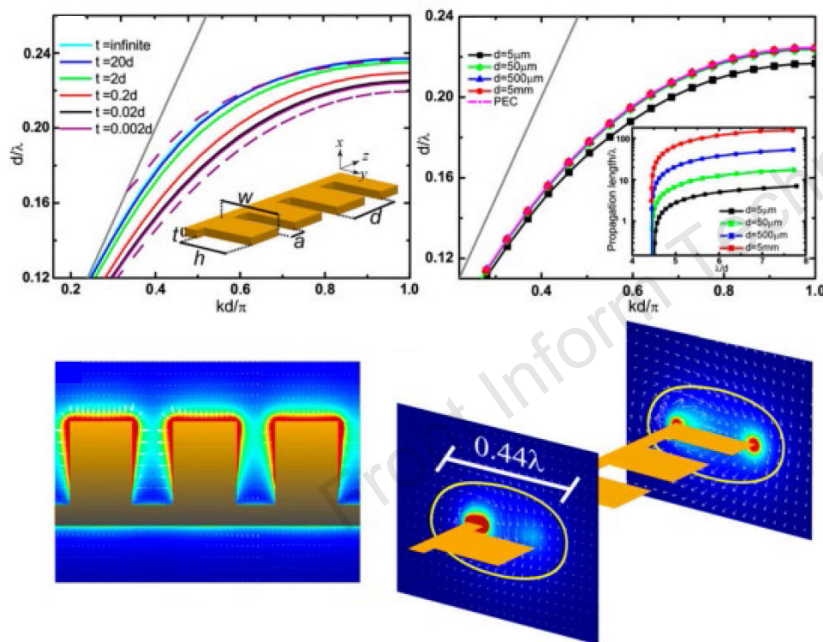
Surface-wave
control

Spatial-wave
control



Analog metamaterials metasurfaces (Cont'd)

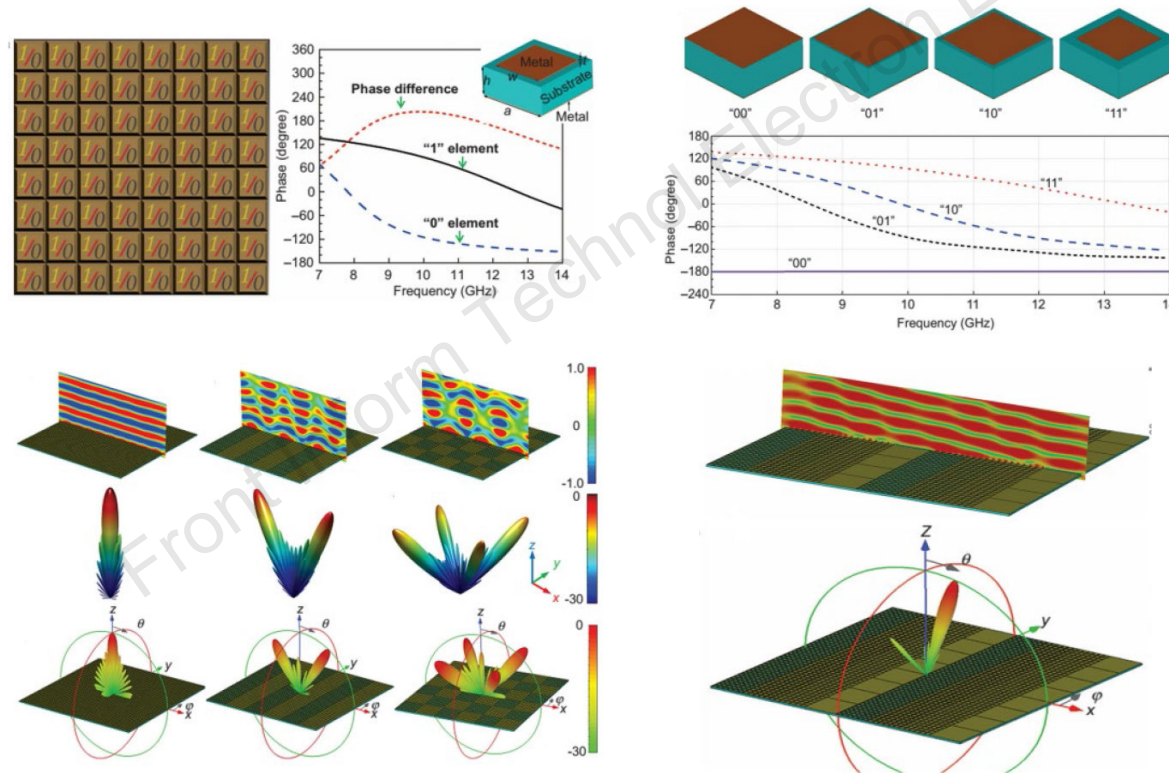
Highly localized EM waves



EM waves can propagate along the structure

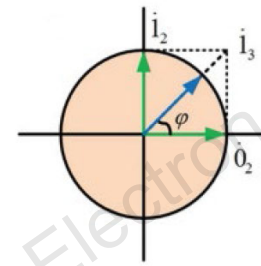
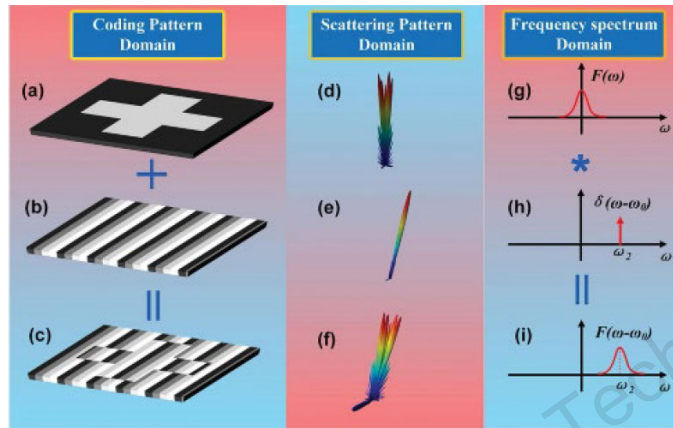
Information metamaterials coding and digital metamaterials

EM properties are described by digital states

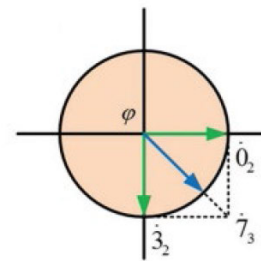


Far-field and near-field performances rely on the coding patterns

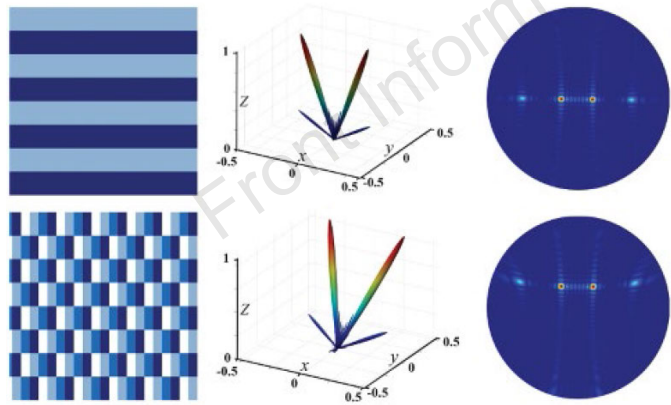
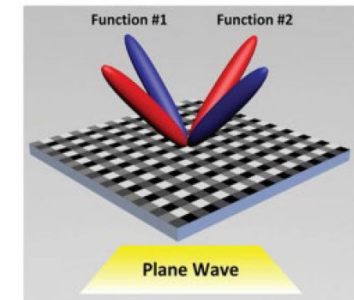
Information metamaterials coding and digital metamaterials (Cont'd)



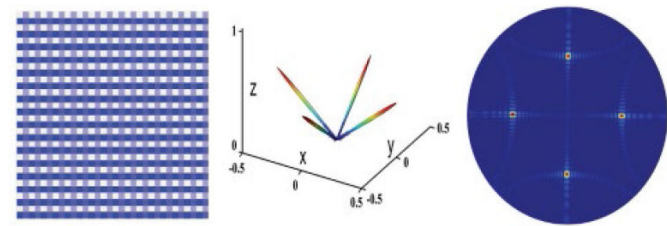
Unit-cell Level



Metasurface-system Level



Convolution operations

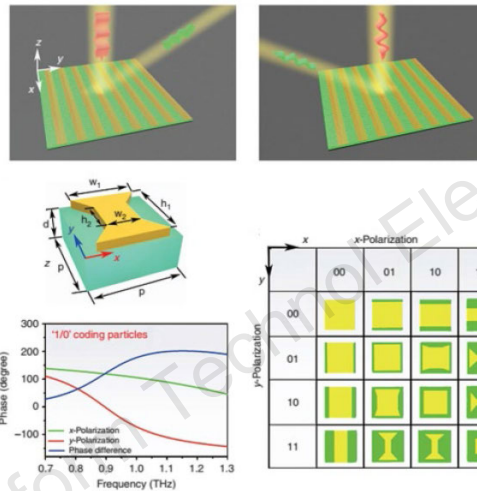


Addition theorem

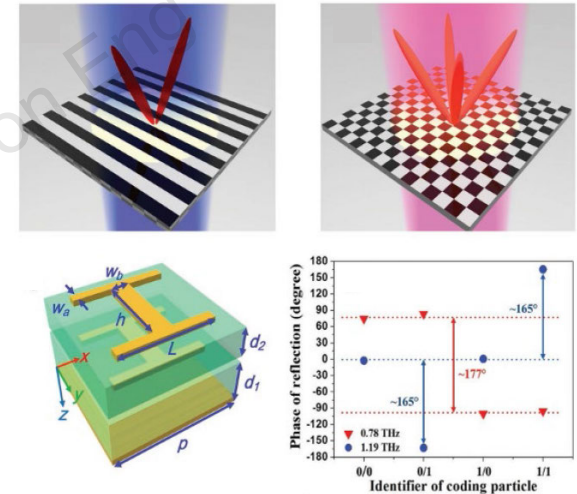
Information metamaterials coding and digital metamaterials (Cont'd)

Applications

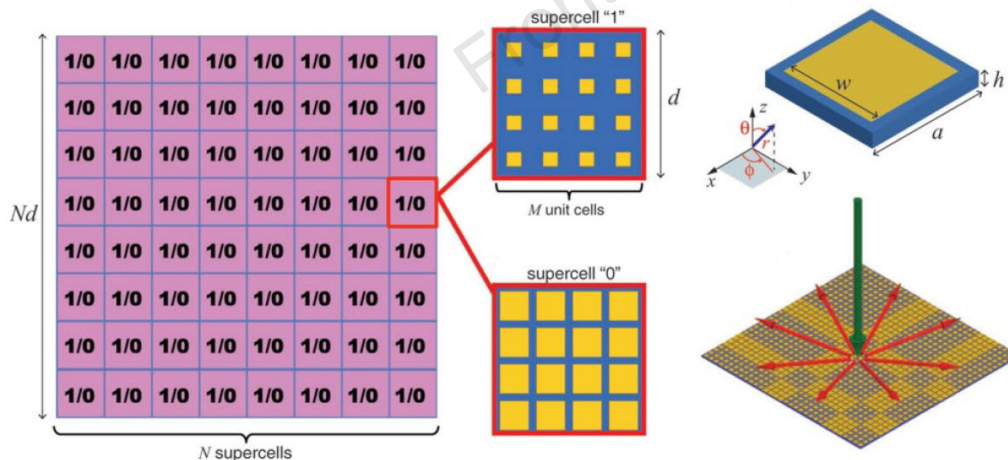
Anisotropic design



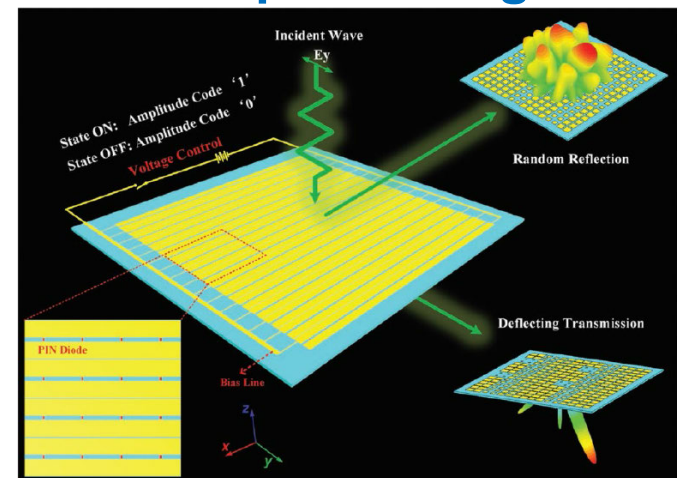
Dual-band design



Random scattering

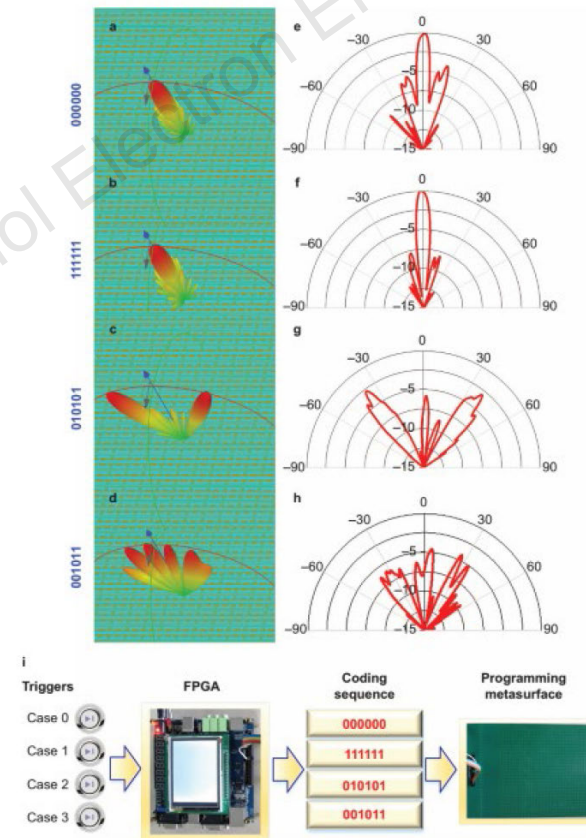
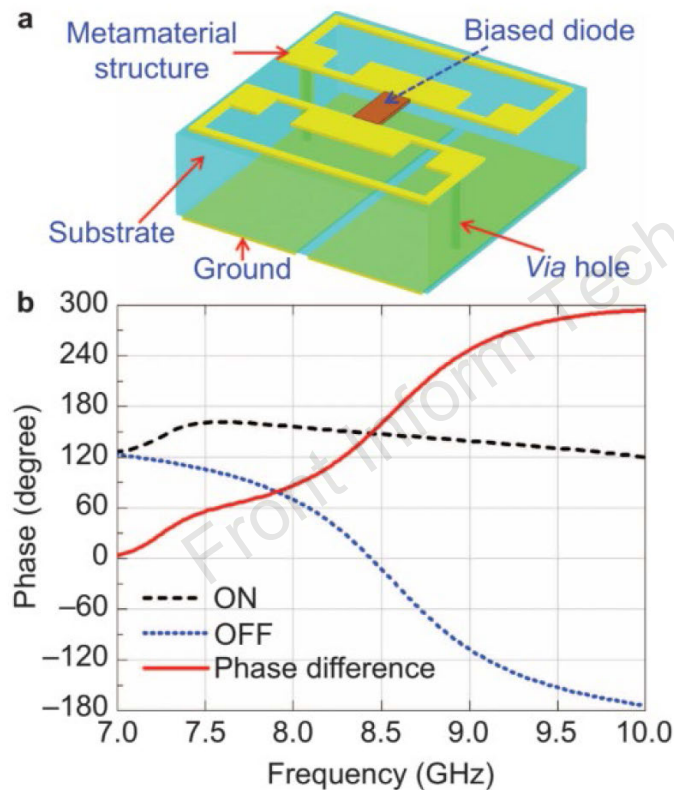


Full-space design



Information metamaterials programmable metamaterials

Real-time EM manipulations



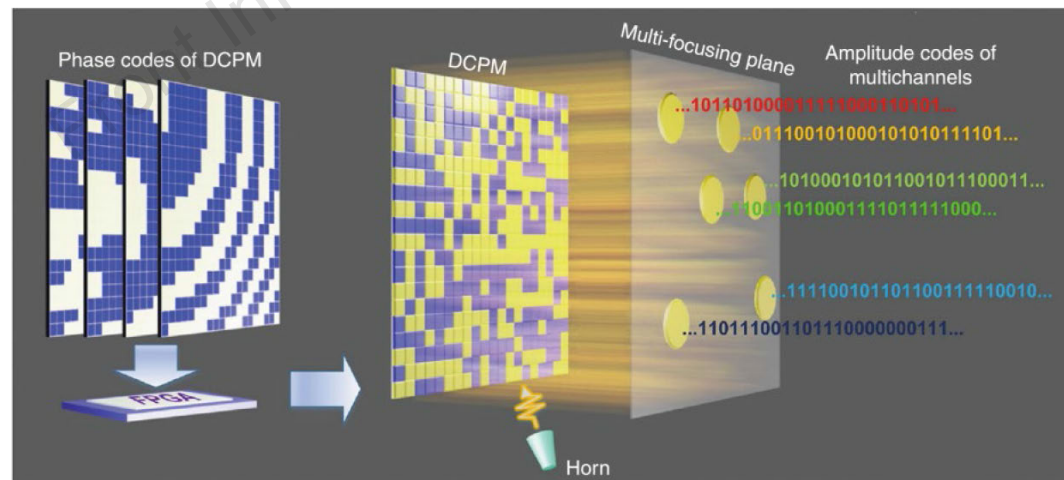
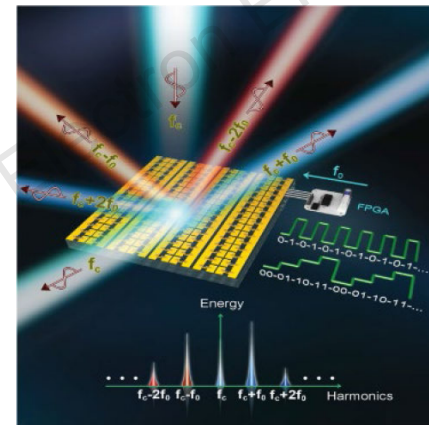
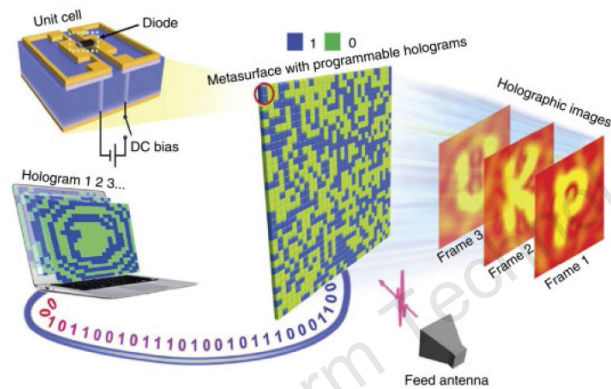
Radiating patterns can be controlled by FPGA

Information metamaterials information system

Imaging system

Communication system

Radar system



Conclusions

1. For effective medium metamaterials: integrated, miniaturized, and low-cost applications in engineering.
2. For metasurfaces: multi-coefficient and multi-functional designs.
3. For spoof SPPs: on-chip SPP devices and SPP-based information systems.
4. For information metamaterials: improving combination with information science, more advanced intelligent metamaterials, and software-driven metamaterials.