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Microwave metamaterials: from exotic physics to novel information systems

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

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Introduction

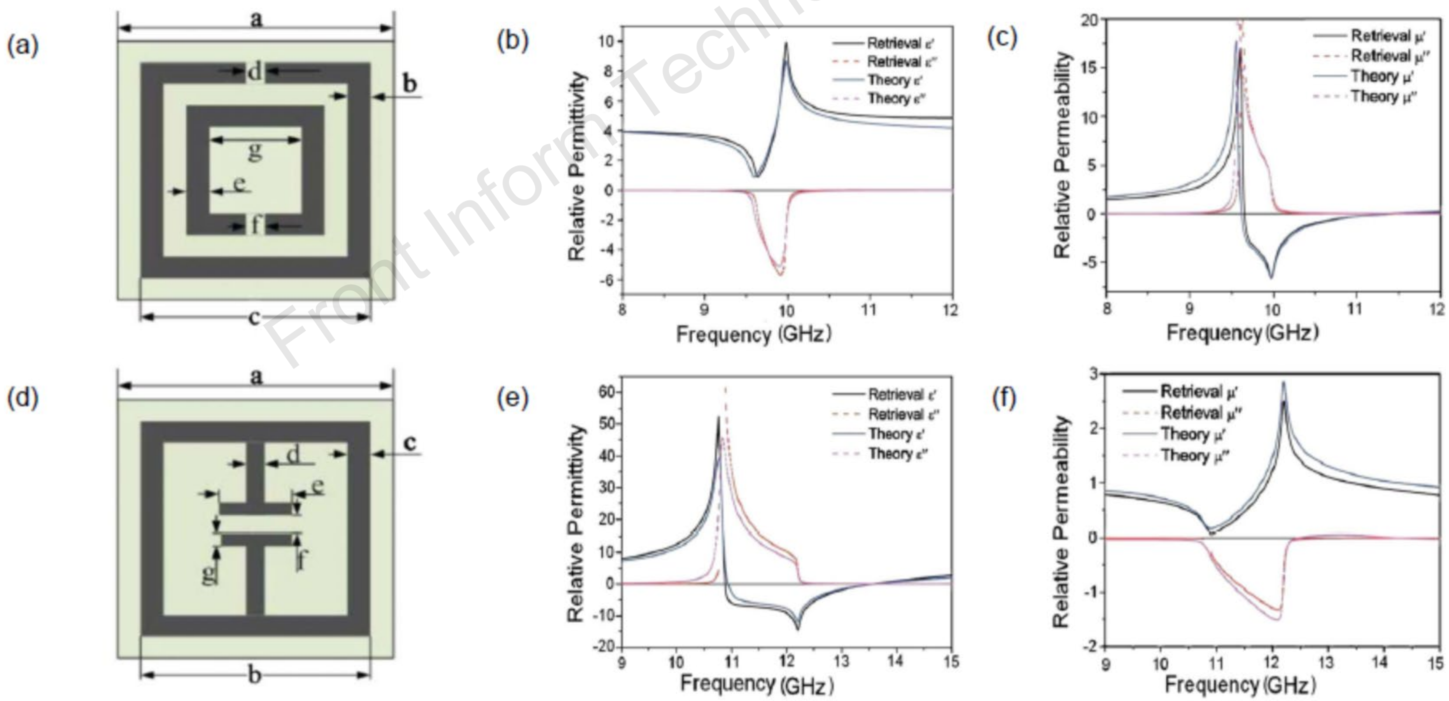
Metamaterials and metasurfaces have attracted much attention due to their powerful ability to control electromagnetic (EM) waves. In this paper, we review the recent developments in the field of EM metamaterials, starting from their exotic physics to their applications in novel information systems.

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.

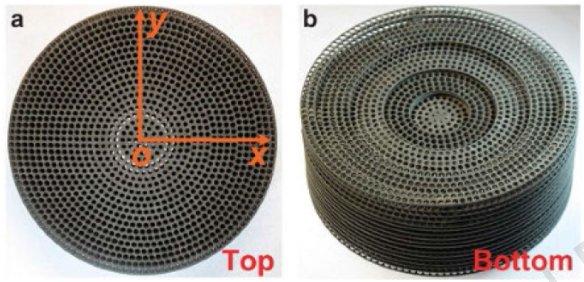
Analog metamaterials effective medium metamaterials

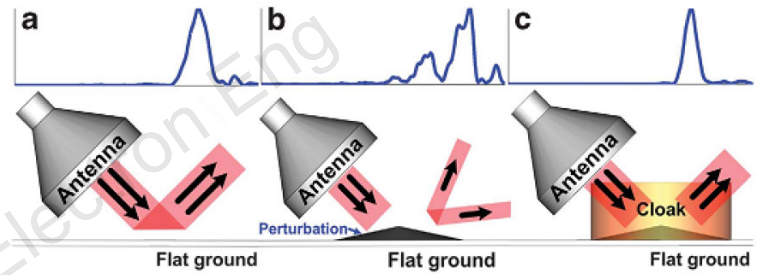
Metamaterials are actually composed of subwavelength-scale meta-particles arranged periodically or quasi-periodically, which can be described by continuous effective medium parameters (effective permittivity *ε* and effective permeability *μ*).



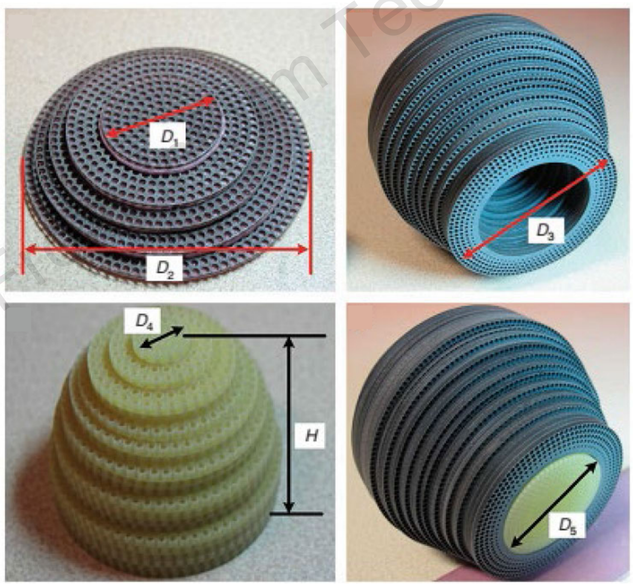
Analog metamaterials
effective medium metamaterials (Cont'd)

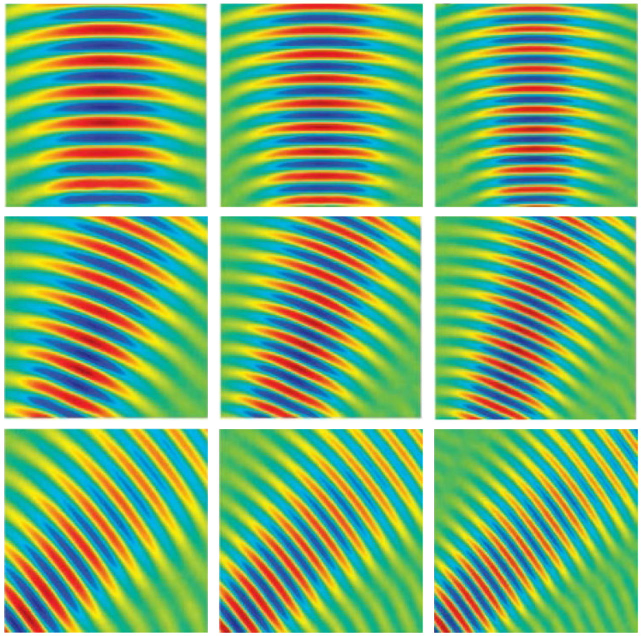
Invisibility cloak





Meta-lens



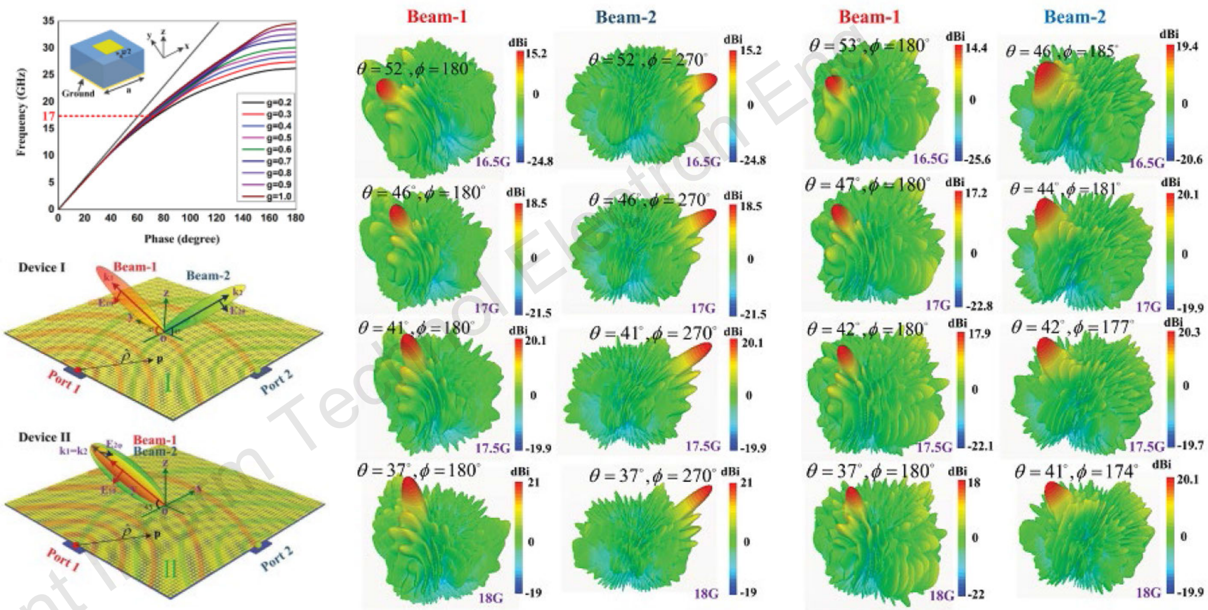


12.5GHz 15GHz 18GHz

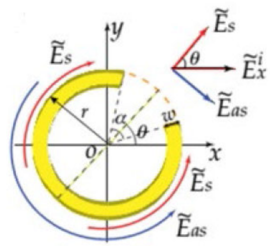
Analog metamaterials metasurfaces

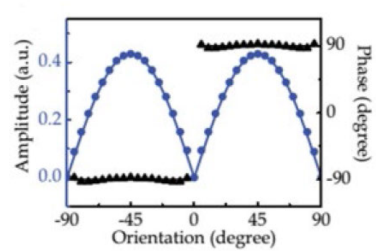
2D case of metamaterial

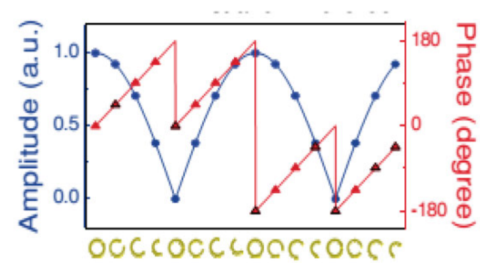
Surface-wave control



Spatial-wave control

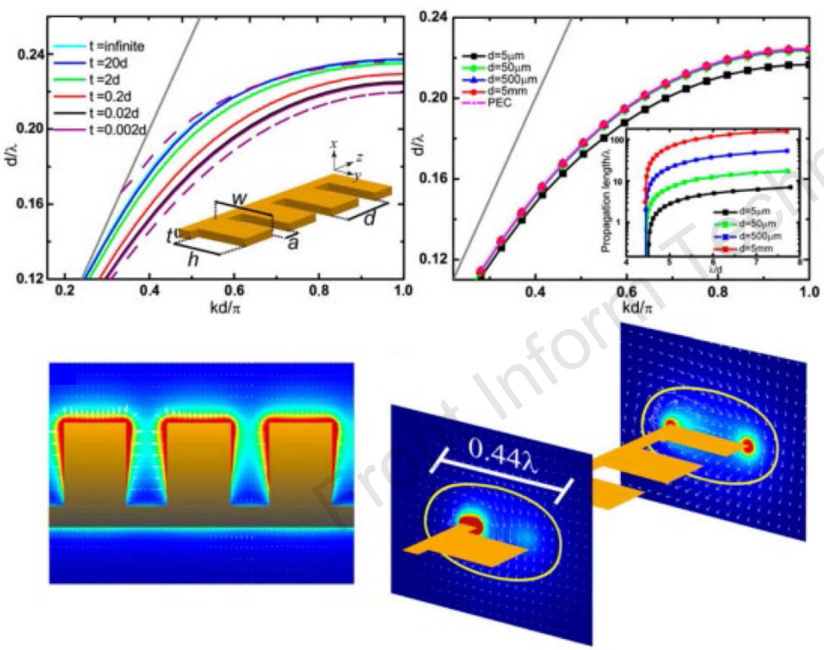


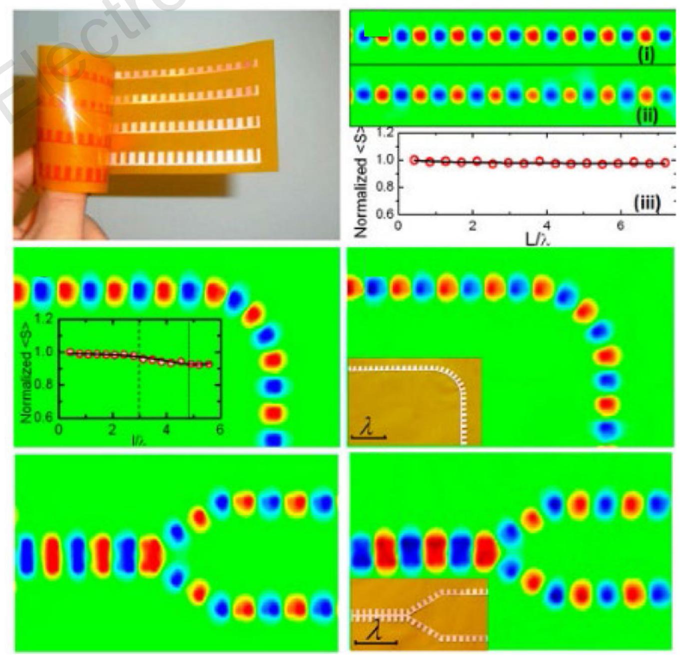




Analog metamaterials metasurfaces (Cont’d)

Highly localized EM waves

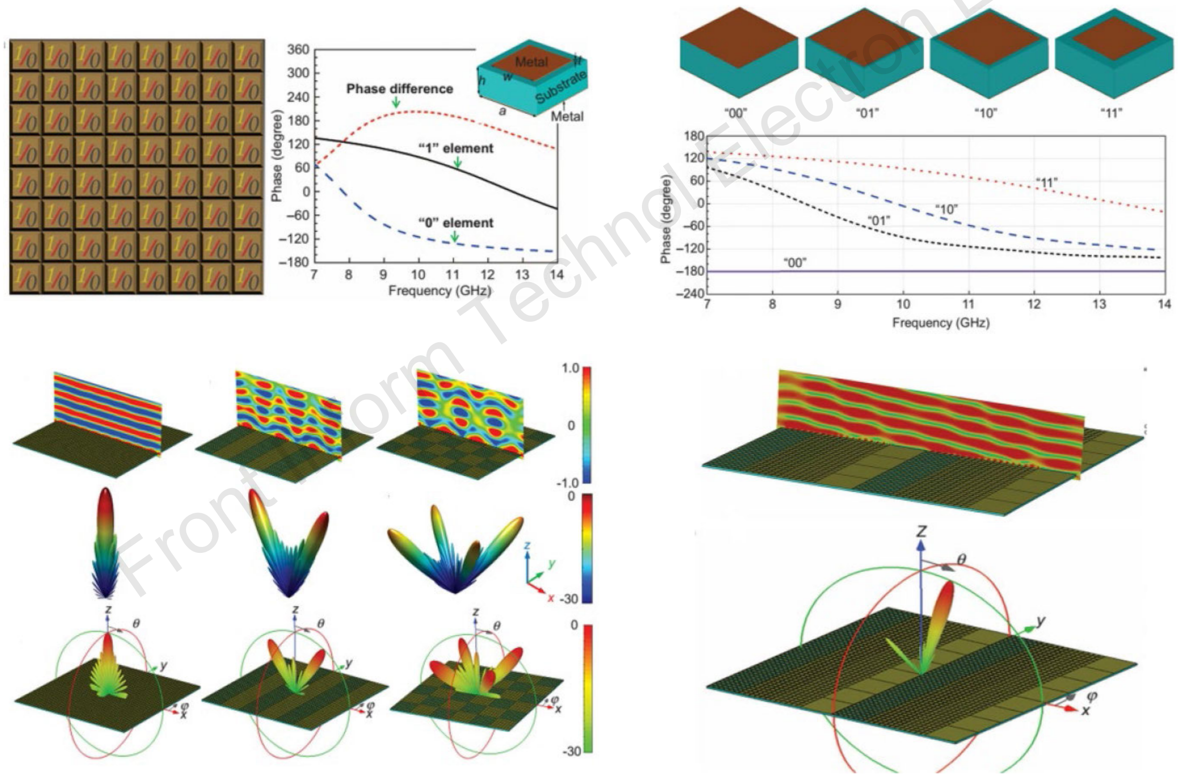




EM waves can propagate along the structure

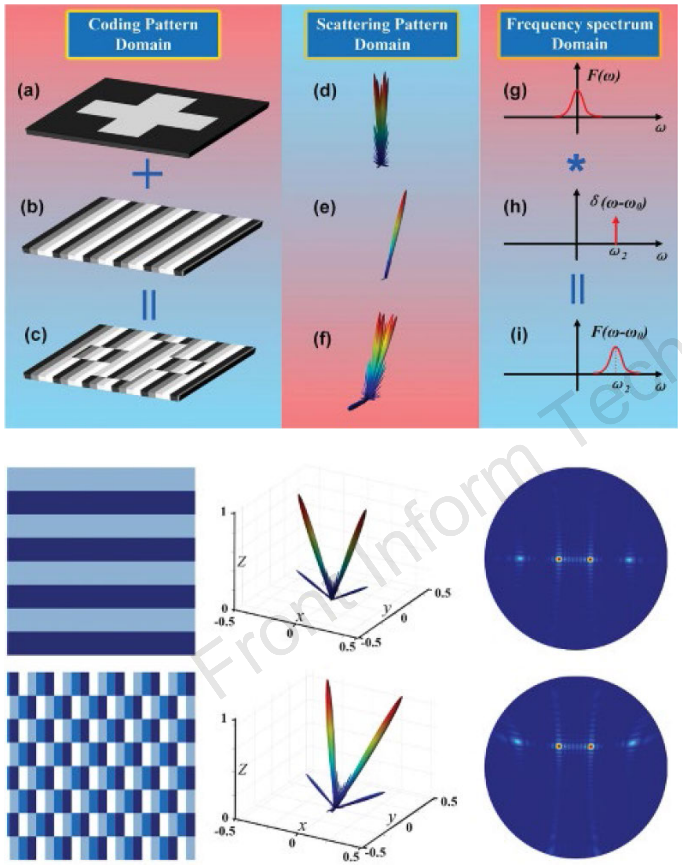
Information metamaterials
coding and digital metamaterials

EM properties are described by digital states

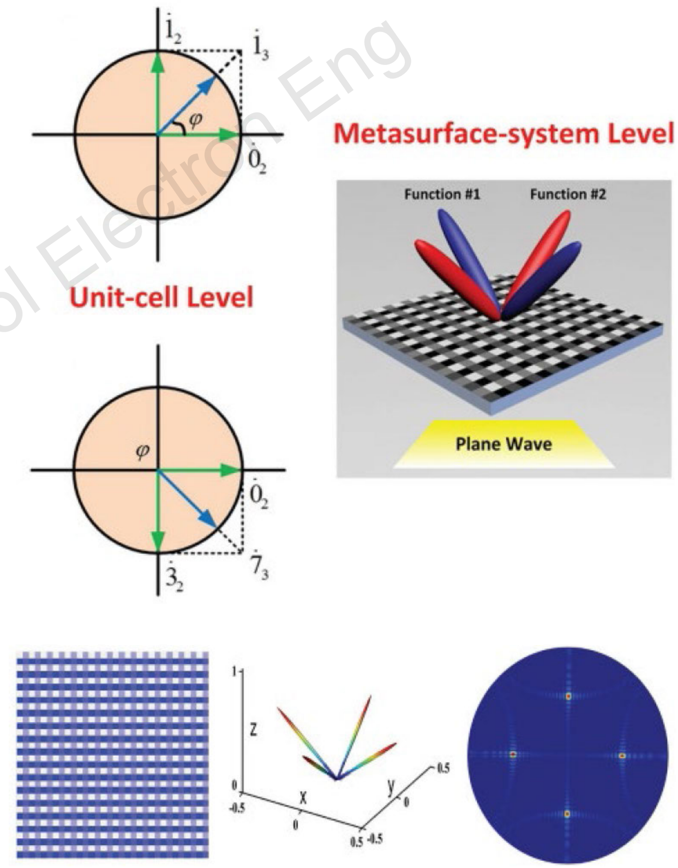


Far-field and near-field performances rely on the coding patterns

Information metamaterials
coding and digital metamaterials (Cont’d)



Convolution operations

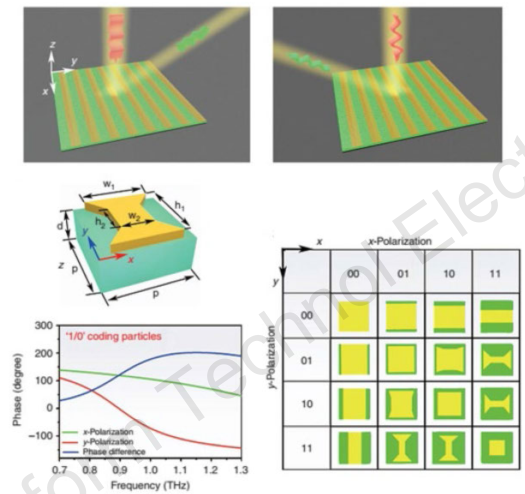


Addition theorem

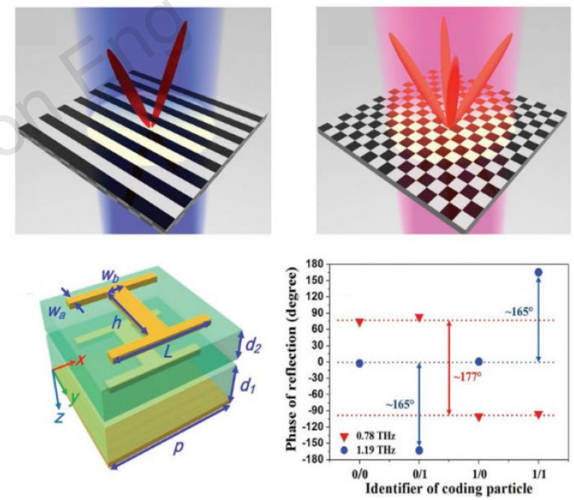
Information metamaterials
coding and digital metamaterials (Cont'd)

Applications

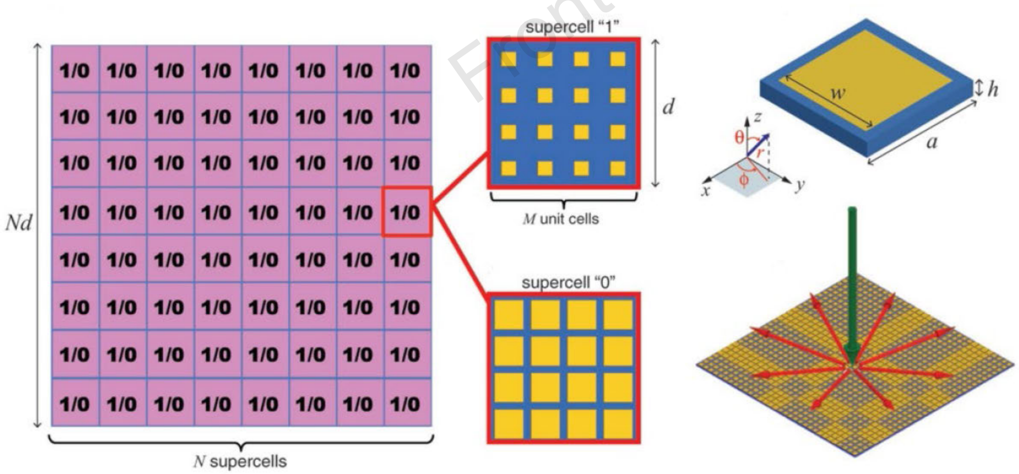
Anisotropic design



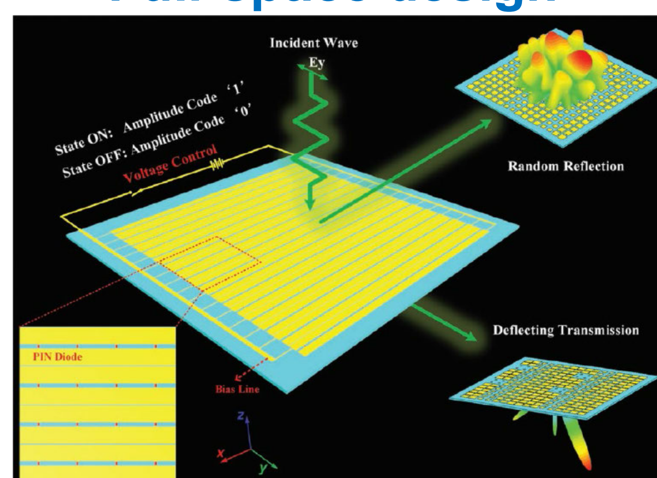
Dual-band design



Random scattering

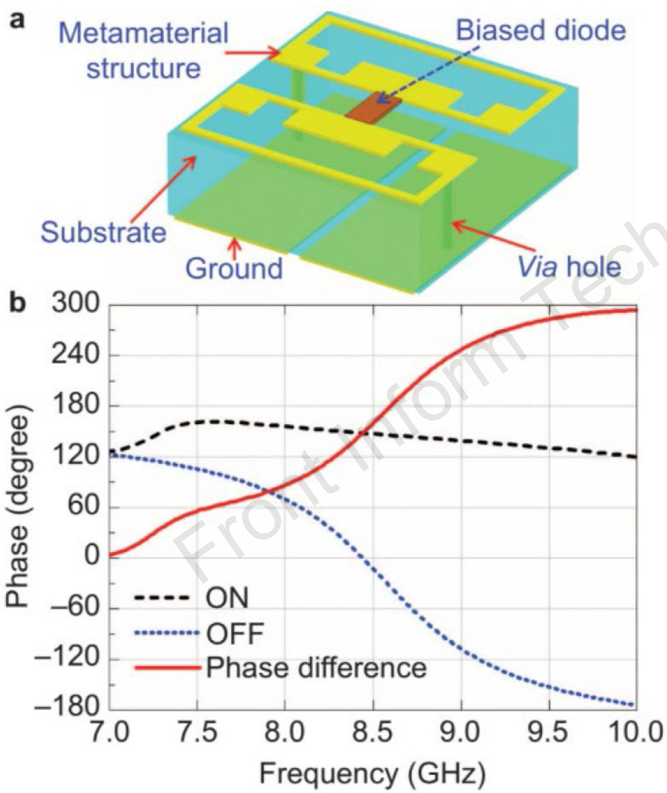


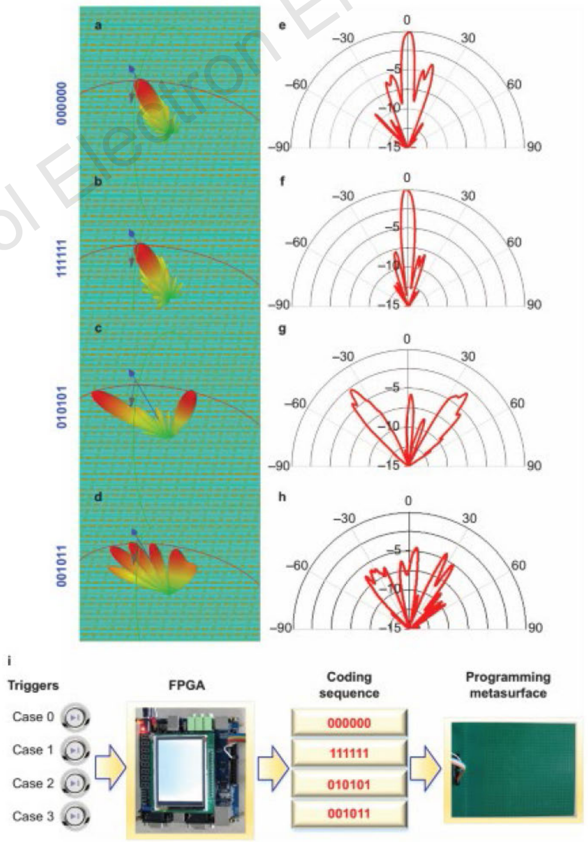
Full-space design



Information metamaterials programmable metamaterials

Real-time EM manipulations

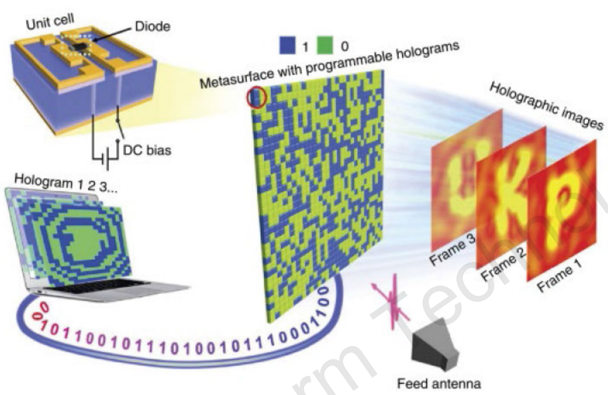


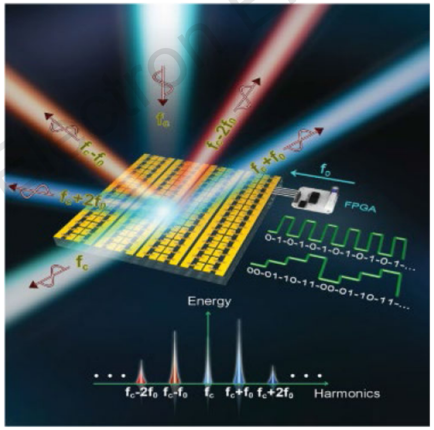


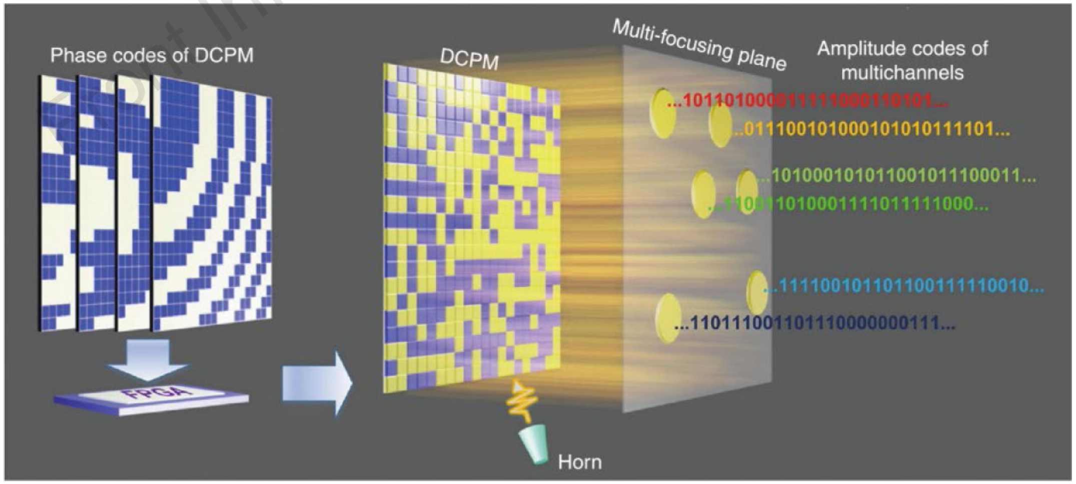
Radiating patterns can be controlled by FPGA

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.