# Digtial Metasurface with Simultaneous EM Absorption and Scattering

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***Abstract*— The absorption and scattering behaviors are two fundamental concerns for artificial metamaterials (MMs) toward a variety of applications like radar, antennas, stealth, wireless communication, etc. Here we propose a metasurface with dynamical control the absorption and scattering performance simultaneously in a broad bandwidth. By changing the bias voltage of the PIN diodes embedded in the meta-atoms, different absorption and scattering characteristics can be invoked as a result, giving rise to a pair of operation modes for the metasurface: One is the scattering mode, where the scattering features can be manipulated in a predefined manner, and the other is the absorption mode, where the incident waves can be efficiently dissipated at the surface. The simulation results demonstrate the validity of our design.**

***Keywords—tunnable metamaterial; PIN diode;***

## I. Introduction

The rapid progress of the metamaterials (MMs) [1,2] and metasurface provide new degrees of freedom in waves manipulation with sub-wavelength structures arranged in a periodic or aperiodic way. The equivalent permittivity and permeability can be designed arbitrarily by tailoring the element shapes and spatial arrangement, therefore leading to abnormal parameters like negative refractive index [3] or zero refractive index, and plenty of extraordinary physical phenomena such as cloaking [4], perfect imaging and optical transformation [5]. They have also been widely used in the design of electromagnetic devices including high directional lens antenna [6], absorbing materials [7,8], holographic systems, etc.

Recently, dynamic control of the electromagnetic waves via digital or programmable MMs has attracted increasing attention within the scientific and engineering communities [9,10,11], which demonstrates that the binary elements can be employed to alter the radiation of the scattering features by elaborately adjusting the coding sequences [12,13].

In this article, a 1-bit digital metasurface is proposed to implement electromagnetic absorption and beam generation in a wide frequency band. In general, such functionalities are independently accomplished via different metasurfaces [14,15]. However, the proposed digital metasurface provides a time-variant multi-functional platform, which allows to realize both functionalities with single metasurface by changing the switching status of the PIN diodes, and enables it to operate either in the scattering mode or the absorption mode.

In the first mode, the reflection phase difference of the meta-atom between the two states (‘ON’ and ‘OFF’ state of diode) approaches 180° within the whole X-band. Thus based on different switching states of the PIN diodes, it is possible to manipulate the reflecting electromagnetic (EM) waves under the incidence of plane wave as desired. In the second mode, the reflection amplitude of the metasurface can be gradually adjusted from 0dB to -25dB in the X-band by applying various bias voltages to all the diodes.

## II. Design Procedure and Simulation

To construct the digital metasuface, a binary unit is firstly proposed, with the schematic diagram illustrated in Fig.1. An H-shaped metallic sheet is located on the top of the F4B substrate, with the left and right arms separated by a PIN diode. The direct-current (DC) feeding lines are designed to turn on or turn off the PIN diodes to achieve different electromagnetic responses, so that the meta-atom can be named ‘0’ and ‘1’ element corresponding to the ‘ON’ and ‘OFF’ states of the diodes. When the biasing voltage is 0.7 V, the PIN diode behaves like a small resistor. On the contrary, in the case of zero biasing voltage, it acts as a capacitor incorporated within the element. To figure out the scattering performance of the meta-atom, the commercial software CST is used to numerically calculate the reflection amplitude and phase characteristics of the unit cell under the excitation of plane wave.

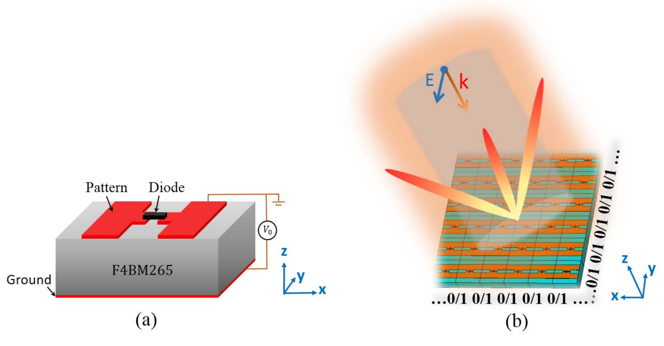
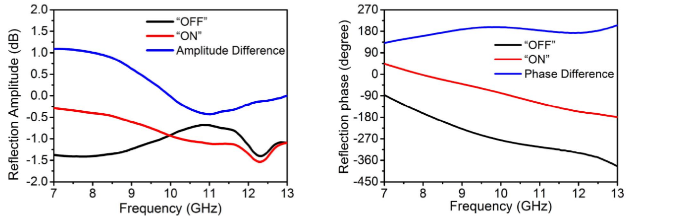


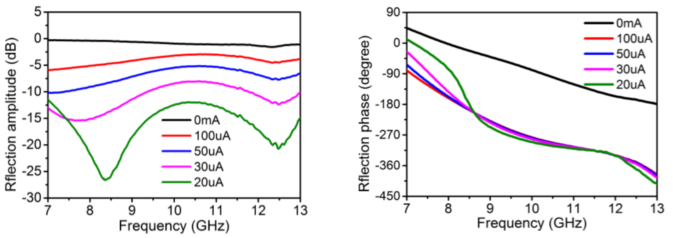

Fig. 1. (a) Schematic of the digital meta-atom, where the diode can be turned ‘ON’ and ‘OFF’ respectively. (b) Beam generation with the digital metasurface.




(a) (b)

Fig. 2. Reflection amplitude characteristics (a) and phase characteristics (b) of the proposed MM particle when the biased diode is "OFF" and "ON".

From the amplitude and phase spectra of the meta-atom shown in the Fig.2, we can find that the reflection phase difference of the two states lies between 160° to 190° from 8GHz to 12GHz. In the meanwhile, the reflection amplitude difference remains less than 1dB at most frequencies. These features indicate that the designed '0' and '1' elements can meet the requirement of ideal binary units approximately in a broad spectrum, and they are suitable for the phase modulation within the whole metasurface and the modification of beam patterns from the coding MMs theory.

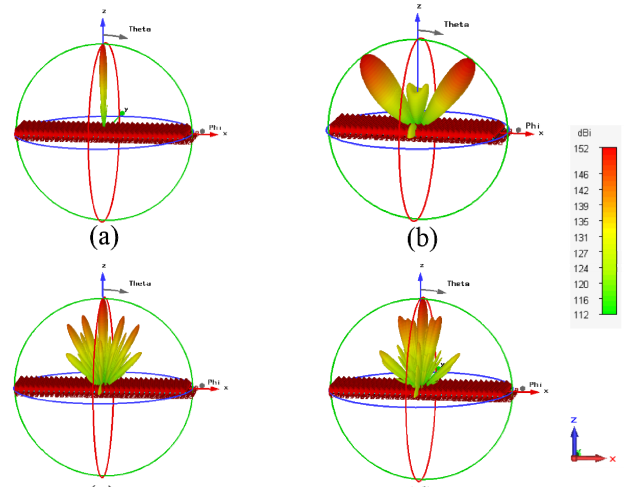



(a) (b)

Fig. 3. Reflection amplitude (a) and reflection phase (b) of the meta-atoms under different biasing currents.

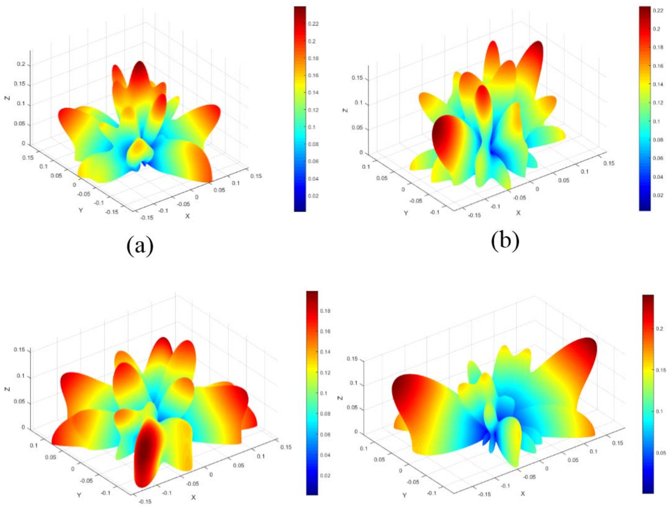
It is worth noting that the reflection amplitude of the meta-atom also sees a gradient decrease in the condition of small biasing currents from 100uA to 20uA, while the reflection phase is nearly kept unchanged. Such phenomena can be easily understood since the PIN diode operates in the nonlinear region, whose equivalent resistor is extremely sensitive to the currents passing through. This also opens the avenue to the amplitude modulation of the reflected waves from the metasurface without affecting corresponding phase characteristics at the same time. The reflection amplitude can vary within the range from 0dB to -25dB under different biasing currents.

In order to demonstrate the extraordinary abilities of the metasurface, a planar array by 30×30 meta-atoms is designed for observation of the scattering patterns. In the case of Fig.4, every five adjacent columns of the meta-atoms share identical coding sequence under the same bias voltage. Four different coding sequences: 000000, 010101, 001011 and 000110 are utilized to validate the multi-beam generation concept, with the simulated far field patterns presented in Figs.4(a)-(d), respectively. Diversified far field patterns can be formed in a broad bandwidth by controlling the coding sequences of the metasurface [16-18], resulting from single beam to multiple beams as shown in Fig.4. In addition, the optimization algorithm is also used to synthesize the metasurface with significant backward RCS reduction based on the random arrangement of the coding sequences for '0' and '1' elements [19,20] in Fig.5. From the simulation results we can find that the RCS reduction can be increased dynamically from 10dB to over 30dB in different scattering patterns, and consequently mimic the scattering features of various objects.




(a) (b) (c) (d)

Fig. 4. Beams generation with the digital metasurface at 10GHz with different coding sequences. (a) 000000, (b) 010101, (c) 001011, (d) 000110.



(a) (b) (c) (d)

Fig. 5. Diffusion scattering patterns based on the digital metasurface at 10GHz, with the backward RCS reduction (a) 10dB, (b) 15dB, (c) 20dB, (d) 30dB, respectively.

## ACKNOWLEDGMENT

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