Design and Analysis of Active Frequency Selective Surfaces with Organic Semiconductor

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***Abstract*—Frequency selective surfaces (FSS) have been studied for many years and widely used in different fields ranging from microwave engineering to optical system. Recently, Active Freuqency Selective Surfaces (AFSS) having tunable or reconfigurable frequency response received more and more attention. In this study, a new means of active FSS is reported. By printing the unit elements of FSS on an organic semiconductor, the optically controlled frequency response is achieved. The transmission performance of FSS under optical illumination and non-illumination is simulated and compared, the simulated tunable range is 12GHz. The tunable performances of FSS under different illumination densities were also investigated and consecutive transmission performance movement is achieved. Finally, the photo lithography fabrication procedure is mentioned.**

I. Introduction

Frequency Selective Surfaces (FSS) are well known for their filtering characteristics at microwave, millimetre wave and infrared frequency. In the earth observation application, in order to reduce mass and volume, multichannel instruments generally employ a single reflector antenna, and Frequency Selective Surfaces are used as dichroic mirrors to separate or combine beams at different frequencies.

There are two basic types of FSSs: dipole and slot arrays [1]. The dipole FSSs are composed of multilayered arrays of metal patches of arbitrary shape (typically dipoles, rings and crosses) embedded in a stratified dielectric medium. The dipole FSSs usually exhibit band-stop performance. The slots FSSs are composed of single or multiple thick metal screens perforated periodically with arbitrary shape holes (typically squares, circles and crosses). The slots FSSs are mostly used as band-pass filters. The dipole and slot arrays with elements of identical shape are defined as complementary arrays.

Key features in the performance of the Frequency Selective Surfaces include low insertion loss for the transmission and reflection bands, wide operating bandwidth, high cross-polar discrimination (XPD) and so on. These transmission and reflection characteristics depend on the shape and size of the patches or apertures, on the lattice geometry and element periodicity, and on the electrical properties of the substrate material.

Many numerical methods have been used to analyse FSS, such as equivalent circuit model method and modal method. Each method has its own merits and drawbacks. Among these numerical techniques, the Periodic Method of Moments (PMM) is one of the most popular methods for analysing planar, multi-layered periodic structure [2]. In this paper, the electrical performance of the Frequency Selective Surfaces have been analysed by using a frequency selective surface analysis tool based on PMM theory. This frequency selective surfaces analysis tool can analyse the dipole and slot arrays with arbitrary element shape.

In the paper, we demonstrate the feasibility of a new active control strategy which exploits variable dielectric property of organic semiconductor under the optical illumination. This paper is organised as follows. Section 2 introduces the passive FSS and active FSS, and describes the related works on active FSS. Section 3 presents the organic semiconductor and demonstrates the operating theory of active FSS on organic semiconductor. Section 4 shows the design and analysis results of the optical controlled FSS on organic semiconductor. Section 5 presents the fabrication procedures. Section 6 concludes the study.

II. Passive FSS and Active FSS

In most FSS applications, the geometry and material parameters are designed to produce a static frequency response, these FSS are passive FSS. However, for a variety of applications, it would be more attractive to have an electronically controllable property for the selection of frequency as well as FSS reflection and transmission characteristics, these FSS are active FSS or tunable FSS.

A. Passive FSS

For the most part of the applications using these FSS structures require only passive printed conductors on a dielectric substrate or metal screen with holes. In these cases, no possibility exists to change the frequency or polarisation characteristics of the FSS once designed and manufactured.

Two passive FSS are shown in the Fig. 1 and Fig. 2, respectively. Fig. 1 is a two-layer slot type FSS [3], it is designed to transmit at 54GHz and reflect at 89GHz, the element is rectangular slot. Six plastic rings were used to adjust the separation between the two layers of FSS. This FSS has wide transmission band and -1dB insertion loss at 54GHz. Fig. 2 is a single copper plate FSS [4]. It is designed to transmit at 89GHz and reflect at 54GHz. This copper plate is perforated with circular holes on an equilateral triangular lattice. -0.27dB measured insertion loss is achieved at 89GHz.

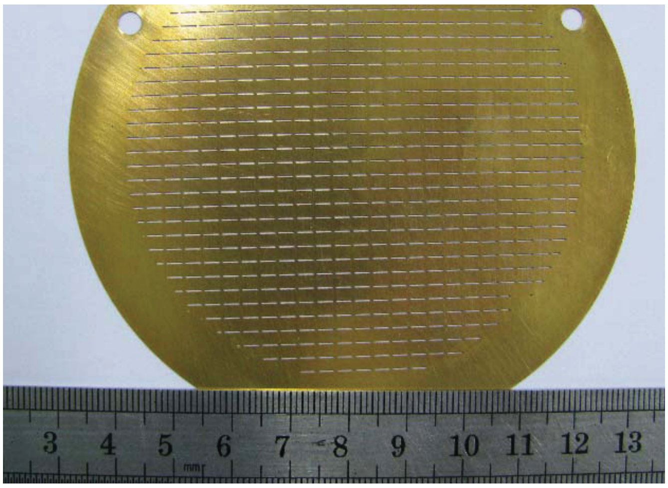

Fig. 1 Photo of 54GHz two-layer FSS

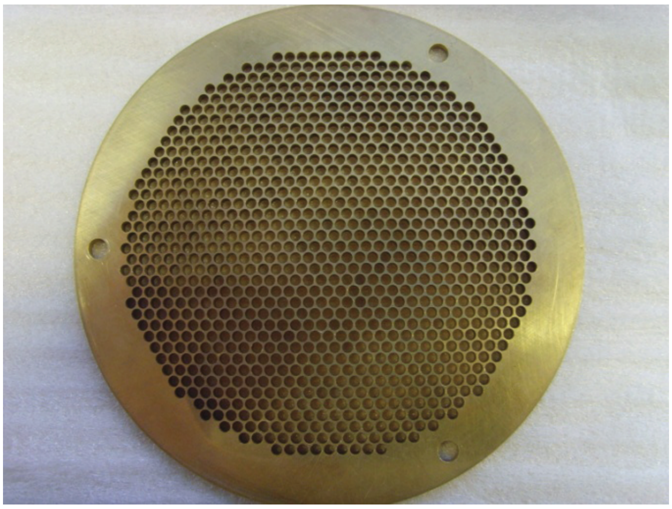

Fig. 1 Photo of 89 GHz single-layer FSS

B. Active FSS

The frequency properties of active FSSs can be varied with time. For example, at a particular time the FSS could be switched from a reflecting to a totally transparent structure or alternatively the transmission performance or reflection performance could be varied with time. Many research efforts have been paid to investigate to active and tunable FSS. T. K. Chang et al. have proposed an active FSS incorporating switched PIN diodes [5]. The PIN diodes placed in a square loop element could be used to switch the basic geometry of the elements and fundamentally change the frequency characteristics. However, there are very high biased currents due to the PIN diodes.

T. K. Chang et al. have reported the results obtained for frequency selective surfaces printed on ferrite substrates which are biased with a DC magnetic field [6]. Biasing the substrate changes its permeability, which in turn changes the frequency characteristics of the FSS so that the resonance frequency may be continuously varied or the surface switched from reflection to transmission. However, the dielectric loss of the ferrite substrates is very high.

W. Hu et al. have proposed a frequency selective surface which exploits the dielectric anisotropy of liquid crystals to generate an electronically tunable bandpass filter response at D Band (110–170 GHz) [7]. The device consists of two printed arrays of slot elements which are separated by a 130-m thick layer of liquid crystals. A 3% shift in the filter passband occurs when the substrate permittivity is increased by applying a control signal of 10 V. However, it needs special structure to seal the liquid crystal.

Bernhard. Schoenlinner et al. have proposed a switchable low-loss RF MEMS ka-band FSS [8]. In this paper, a switchable frequency-selective surface was developed at 30 GHz using RF micro-electro-mechanical systems (MEMS) switches on a 500-µm-thick glass substrate. However, the complicate structures make the fabrication difficult.

III. ORGANIC SEMICONDUCTOR

Organic semiconductors are any organic material that has semiconductor properties [9]. Organic semiconductor polymers have been the focus of many studies because they have shown many advantages, such as easy fabrication, mechanical flexibility and tunable optical properties.

In recent years, the potential application of poly(3-hexylthiophene) (P3HT) in polymer electronics and optoelectronic applications has gained significant attention [10]. The reason is that its relatively high drift mobility and optical absorption properties. An important characteristic of P3HT is its small band gap. It has been reported to be approximately 1.9 eV, and its corresponding absorption in the visible peaks between 450 and 600 nm. It is thus possible to photogenerate charges within the dielectric, and these charges are able to move reasonably rapidly.

The optically controlled frequency response can be achieved by printing the unit elements of FSS on an organic semiconductor, as shown in Fig. 3. When the organic substrate is being illuminated by the light source whose photon energy is greater than the band gap energy of the semiconductor material, an electron-hole plasma region will be induced. This leads to the permittivity different from that of the non-illuminated region. As a result, the dielectric property of organic material will be changed through these activated regions, and then the transmission and reflection performance of the FSS on top of the organic material will be changed. So the performance of FSS can be controlled by the intensity of the optical illumination.

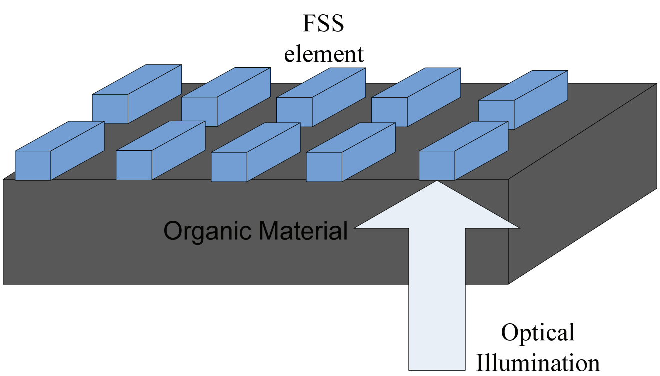

Fig. 2 Optical controlled FSS employing organic semiconductor

IV. DESIGN AND ANALYSIS RESULTS

In this paper, the tunable performance of 54GHz slot type FSS on P3HT polymer was studied. The geometry and dimensions of rectangular element of FSS is shown in Fig. 4. The unit is millimetre.

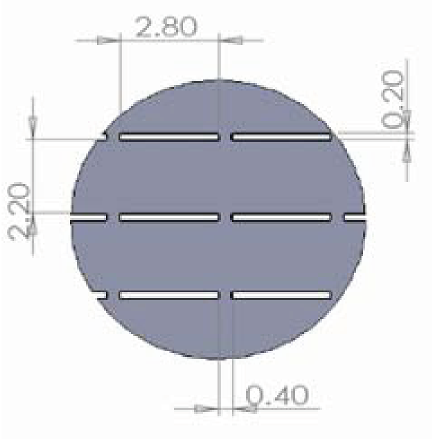

Fig. 4 Geometry of rectangular element

A. Tunable responses between optical illumination and non-illumination

The illuminated P3HT polymer will have a complex permittivity different from that of nonilluminated material. So the tunable response of FSS can be achieved by switching from optical illumination to non-illumination. In this study, we investigate the tunable performance of two-layer FSS with P3HT polymer. The accurate permittivity of P3HT under illumination is difficult to calculate, so we just use the empirical value: $\varepsilon_r = 3.17$, $\tan\delta = 0.02$, for non-illumination; $\varepsilon_r = 2.72$, $\tan\delta = 0.12$, for illumination. Fig. 5 shows the comparison of transmission performance between illumination and non-illumination. The simulation was performed by PMM method with the inclusion of dielectric loss. From the results, we can see the transmission performance is changed obviously due to the optical illumination. The tunable range is 12GHz and the peak insertion loss is increased from 0dB to -4.77dB due to the mismatch when the FSS under illumination.

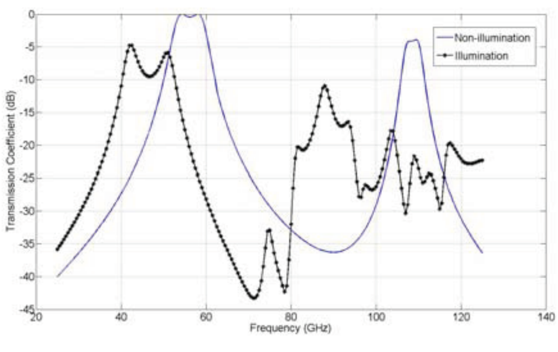

Fig. 5 Comparison of transmission performance between illumination and non-illumination

B. Tunable responses by different intensity of optical illumination

In fact, the permittivity property of P3HT is varied under the different density of optical illumination. At microwave frequency the permittivity varies between 2.2 and 3.2. In this study, the tunable performances of single layer FSS under different illumination density were investigated. The simulated results without the inclusion of dielectric loss are shown in the Fig. 6. It can be seen from the results that a consecutive transmission performance movement is achieved under the different density of optical illumination.

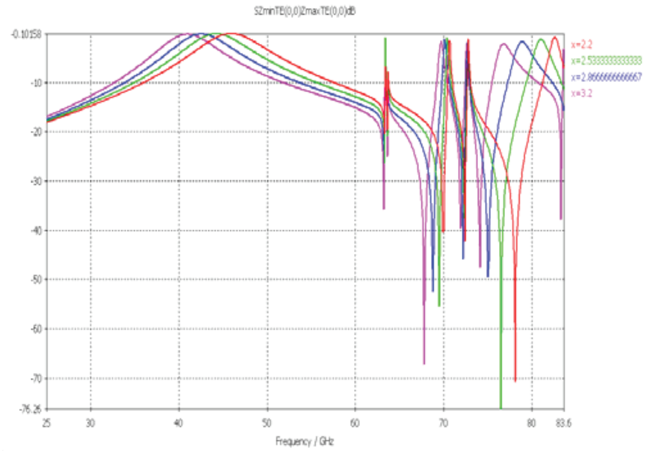

Fig. 6 Tunable transmission performance by different intensity of optical illumination

V. FABRICATION

The active FSS was fabricated by photo lithography technology. Photo lithography is a process used in micro fabrication to selectively remove parts of a thin film or the bulk of a substrate. It uses light to transfer a geometric pattern from a photo mask to a light-sensitive chemical photo resist, or simply "resist," on the substrate.

The main stages of photo lithography fabrication are shown in the Fig.7.

1) A 150 nm thick aluminium layer was deposited over the glass substrate in the evaporation chamber.

2) The photo-resist solution (light-sensitive chemical) was spin coated on the aluminium covered substrate, the photo-resist solution is S1818. There are two types of photo-resist: positive and negative. For positive resists, the resist exposed with UV light is to be removed. Negative resists behave in just the opposite manner, that remains on the surface wherever it is exposed, and the developer solution removes only the unexposed portions. Here, we use positive photo-resist.

3) After heated in the oven, the substrate was exposed to UV lights with photo mask in between. The exposed part of photo-resist is etched.

4) The aluminium pattern was developed by developer solution (25% NAOH, 75% distilled water).

5) The remaining photo-resist was removed by developer solution.

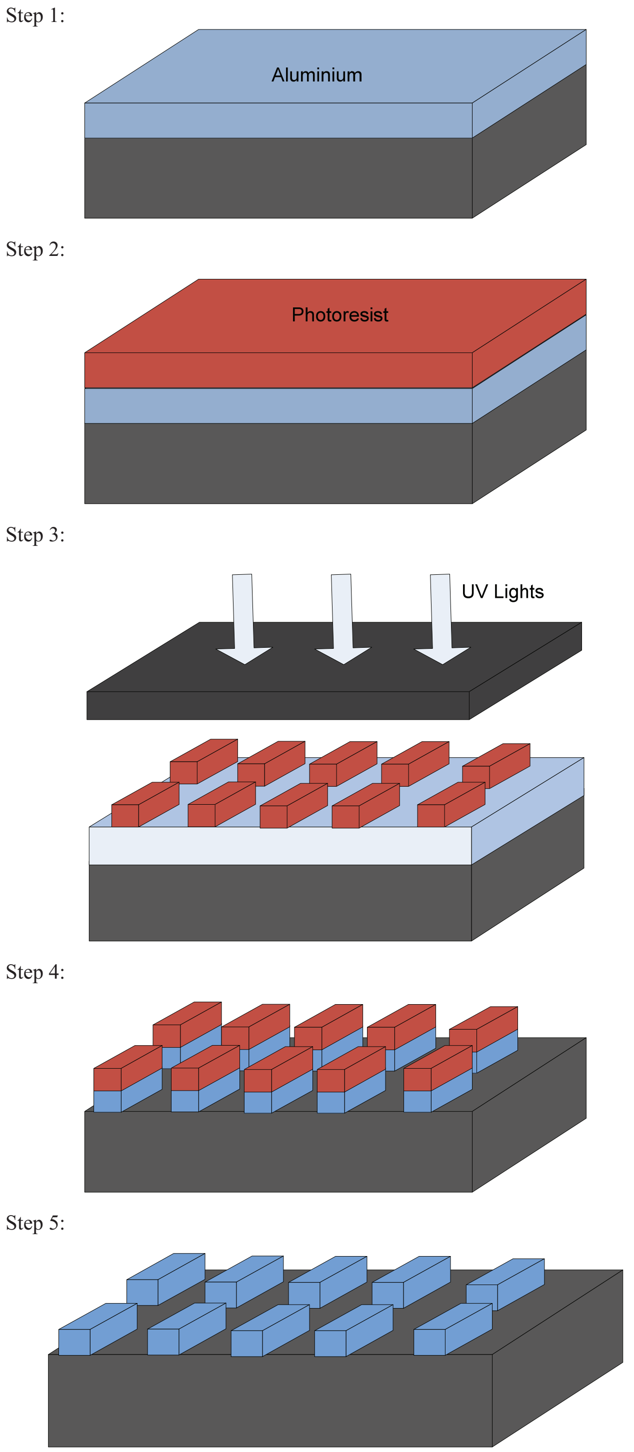

Fig. 7 The fabrication steps of photo lithography

The microscope pictures of samples were checked. From the microscope pictures, we can see the edge of aluminium element is quite straight and some air bubbles exist under the aluminium because of the clean procedure. The variation in thickness of aluminium element is another problem. The depth-profile of the aluminium was checked with profilometer, as shown in the Fig. 3. The thickness is varied between 1400A to 1500A. The fabrication tolerance can be improved by modifying the evaporation temperature and exposing time under UV light.

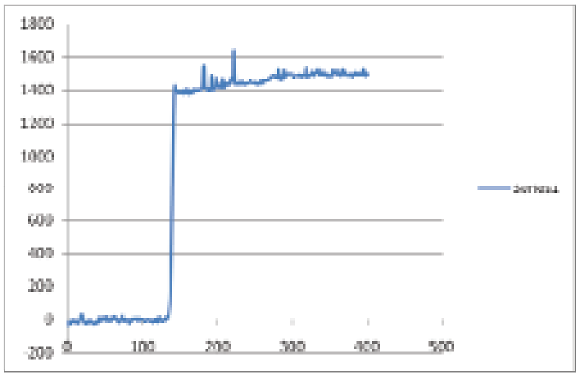

Fig. 8 Depth profiles of aluminium

VI. Conclusions

In this study, the feasibility of a new active control strategy which exploits variable dielectric property of organic semiconductor under the optical illumination is investigated. The optically controlled frequency response is achieved through simulation. The transmission performance of FSS under optical illumination and non-illumination is simulated and compared, the simulated tunable range is 12GHz. The tunable performances of FSS under different illumination density were also investigated and consecutive transmission performance movement is achieved. The active FSS was fabricated by photo lithography technology. Profilometer was used to check the depth-profile of the aluminium and the thickness is varied between 1400A to 1500A.

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