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STUDY ELECTROMAGNETIC WAVE INTERACTION OF ACTIVE-MATRIX THIN FILM TRANSISTORS

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Abstract. Active-matrix thin film transistors (TFTs) on glass substrates with a metal backplane, that are applied for flat panel displays, can be considered as a metamaterial absorber. In this study, TFT structures using doped silicon at source, drain, and channel terminals are investigated. These terminals are unchanged in size of 75 µm square and thickness of 5.3 µm. The electric conductivity is varied at the channel. The simulation results show that the structures with 500 S/m electric conductivity channels absorb incident electromagnetic waves with appropriately 100% at 758 GHz and a wide bandwidth of 20 GHz. As the electrical conductivity increases, the absorption and bandwidth are smaller at the main resonance peak. As the electrical conductivity decreases, the absorption falls at the resonance frequency, but the bandwidth is broadened. In addition, the electric field in the channel may influence the electron in the semiconductor and the electrical current between the source and drain terminals. By observing the electric field at the resonance frequency, we found that it is focused on the sides of channel terminals.

Keywords*:* thin film transistors, metamaterials, metamaterial perfect absorber.

1. Introduction

Thin film transistors (TFTs) on glass substrates are driving elements in the flat panel displays such as liquid crystal displays (LCDs) and active-matrix organic light-emitting diode (AMOLED). Their performance plays the most important role in speeding pixels and display resolution. A TFT is a special type of metal–oxide–semiconductor field-effect transistor (MOSFET) made from deposited thin films of an active semiconductor layer as well as the dielectric layer and metallic contacts over a supporting (but non-conducting) substrate such as quartz and glass [1-4]. In the displays, TFTs are arranged in a matrix on the backplane to drive the pixels. On the other hand, metamaterials with artificial structures being periodically arranged have been attracted much attention for decades due to their special properties. They interact with coming electromagnetic waves as resonance

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circuits including capacitors and inductors. Metamaterials can absorb incident electromagnetic waves with a high rate of appropriately 100% at their resonance frequencies called metamaterial perfect absorber (MPA) [5-10]. Ultra-wideband metamaterial absorber based on doped silicon has been reported [11]. Doped silicon is a conductor with controllable electric conductivities by varying dopant concentration, therefore properties of MPA based on doped silicon are controllable. The matrix of silicon TFTs with n-doped or p-doped silicon pads on a glass substrate with adding metallic backplane can be considered as a metamaterial because of its periodic property. They can be MPA at their resonance frequency that depends on their size and material properties [12-13]. At the resonance frequency, the carriers in the semiconductor channel can move by interacting with the electric field vectors of incident waves and make a change of the electrical current in the channel. This phenomenon can affect the performance of transistors [14, 15]. In this work, we study the interaction of TFTs structures on glass substrates with a metal backplane with electromagnetic waves.

2. Content

2.1. Design structures

Figure 1 shows the configuration of a unit cell of simulated structures that include three basic layers: The backplane, dielectric layers, and active regions at the top layer. The unit cell exhibits a rectangular shape with a length of 350 µm and a width of 200 µm. The active regions of TFTs include three terminals as source (S), drain (D), and channel (C) shown in Figure 1. The cooper material of the backplane remains with high electric conductivity of 5.8×10^7 S/m and the dielectric is unchanged with a glass of permittivity of 4.82. The top layer is changed into different materials as a cooper and doped silicon with various values of electric conductivity. The electric conductivity of doped silicon can be varied from 10^{-6} to 10^6 by changing dopant density from 10^{12} to 10^{21} cm^{-3} [14]. The thickness of the backplane and electric layers are unchanged at 5.3 µm and 200 µm, respectively. Each terminal of the active region has a square shape with a length of 75 µm and a thickness of 4.8 µm. The channel length is selected as the length of practical TFTs for being invisible. It is These simulated thickness values are chosen to be suited for applicable TFTs.

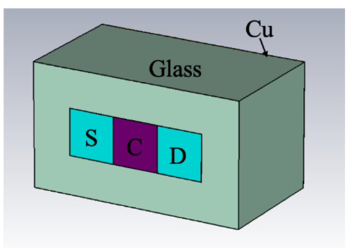

Figure 1. Schematic of simulated structures

CST Microwave software based on the FIT (Finite Integration Technique) algorithm is used for the calculation of electromagnetic response for structures. The most important parameter of MPA is absorption. It represents the percentage of the energy of the incoming electromagnetic waves which are absorbed by the material. In this study, the absorption is calculated by the following formula:

$$A(\omega) = 1 - R(\omega) \tag{1}$$

where R(ω) is the reflectance that can be calculated according to the formula relating to the reflection coefficient

$$R(\omega) = |S_{11}|^2 \tag{2}$$

transmission is zero due to the metal backplane.

2.2. Simulation results

At first, all three terminals of TFT structures are designed with cooper. Cooper is a popularly good conductor and is usually used to study on MPA. Sequentially, their material is changed to doped silicon with a high concentration and high electric conductivity of 10^5 S/m. Figure 2 shows the absorption spectra of simulated structures with cooper and doped silicon. It is found two resonance peak is observed with the structure using cooper at the active region of TFTs. The absorptions of these peaks are very small with below 10% at 765 GHz and appropriately 87% at 802 GHz. Narrow bandwidth is smaller than 1 GHz seen at the larger peak.

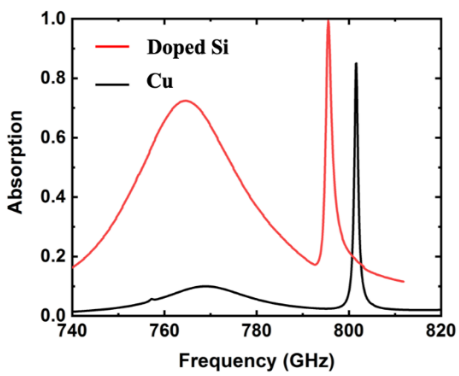

Figure 2. Absorption of active region structures of TFTs using cooper and doped silicon

Secondly, copper material is changed to doped silicon with an electrical conductivity of 10^5 S/m. This value is lower than that of copper. It is seen that two resonance peaks are also observed, the frequencies of these peaks are slightly smaller than those of the structure using cooper. However, their absorptions are much higher with appropriately 100% at 788 GHz and 70% at 762 GHz. Especially, the full half-width medium (FHWM) of the lower peak is really large with 20 GHz. This result indicates that using doped silicon with lower electrical conductivity can improve the absorption as well as broadening bandwidth.

The electrical conductivity of doped silicon depends on dopant concentration. As electrical conductivity is varied, the absorption of structures using doped silicon is changed. The source and drain terminals remain with high electrical conductivity doped silicon of 10^5 S/m. The electrical conductivity of the channel terminal is varied from 50 to 5000 S/m. Figure 3 shows the absorption of active region structures of TFTs using a doped silicon channel with various electrical conductivities of 50, 500, and 5000 S/m. Comparing with the high conductivity channel shown in Figure 2, these structures with lower electrical conductivity of doped silicon also have two resonance peaks at around 760 GHz and 786 GHz. They have higher absorption and larger bandwidth. The absorption reaches a maximal value with 500 S/m electrical conductivity of doped silicon. As the electrical conductivity decreases to 50 S/m, the absorption falls down at both resonance peaks, but the bandwidth is broadened at the lower resonance frequency. On the other hand, as the electrical conductivity increases, the absorption peak is larger at the higher resonance frequency but smaller at the lower one. In addition, the bandwidth is narrowed at a smaller frequency peak.

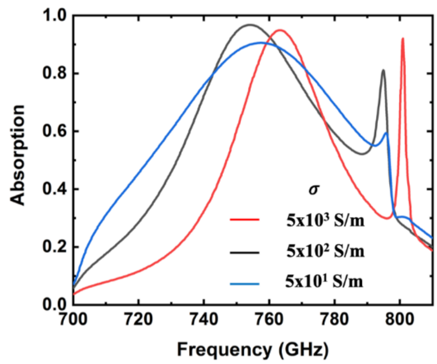

Figure 3. Absorption of active region structures of TFTs using doped silicon with various electrical conductivities at the channel terminal

2.3. Distribution of electric field

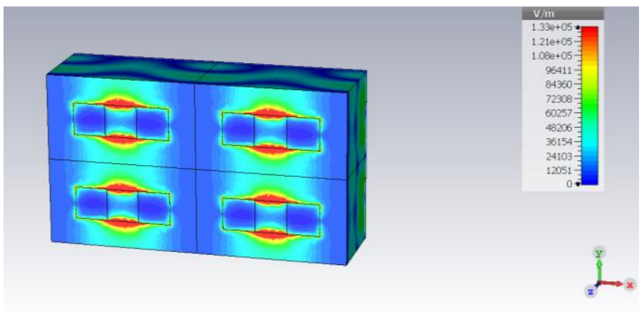

Figure 4. Distribution of electric field at 758 GHz with the structure of 500 electrical conductivity doped silicon

The distribution density of the electric field in layers at the resonance frequencies is observed to understand the interaction of electromagnetic waves with the structures and the energy absorption mechanism of the structure. Figure 4 shows the three-dimensional view of electric field distribution on the top layer and its color chart shown on the right side. TFT structures using a doped silicon channel with electrical conductivities of 500 S/m are used for this simulation. The field is observed at the largest absorption peak of 758 GHz. It can be seen that the electric field is focused on the sides of channel terminals. The field is gradually reduced from the sides to the center of the channels. A small electric field exists between channels. The electric field in the channel may influence the electron in the semiconductor and the electrical current between the source and drain terminals.

3. Conclusions

In this report, we study the interaction of active regions of TFT structures with electromagnetic waves like a metamaterial perfect absorber (MPA) at an appropriately THz frequency regime. While the TFT structures interact with electromagnetic waves, the performance of TFTs can be influenced. The top layer is designed with the structures of active regions of TFTs. The dielectric layer is glass that is suitable for the application of TFTs in the flat panel displays. Doped silicon is used for the material at the top layer. The electric conductivity of doped silicon is varied from 50 to 10^5 S/m. The simulation results indicate that TFT structures using doped silicon at the top of the glass substrate with a copper backplane is considered as a metamaterial perfect absorber. Their absorption is appropriately 100% and their bandwidth is wide. The absorption can be varied with electric conductivity.

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