A Reconfigurable Solid-state Plasma Dipole Antenna Based on SPiN Diodes

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Abstract. This paper proposed an innovative reconfigurable antenna concept based on the dynamic definition of metal-like conductive plasma in high-resistivity silicon that are activated by the injection of dc current. Based on investigations of the solid-state plasma characteristics, the metallic properties of solid plasma were verified. And a demonstration prototype solid-state plasma frequency reconfigurable antenna containing 36 SPiN diodes was designed, fabricated, and tested. This antenna can work at three different states by turning SPiN diodes on or off selectively, in turn, working at the desired frequency state. The results show that this type of antenna possesses the unique characteristics compared with the conventional one.

Introduction

With the rapid development of information technology and the continuous progress of the electronic reconnaissance means, there is a tremendous effort to dramatically change the antenna characteristics, such as dynamic reconfiguration and stealth [1, 2]. The antenna with reconfigurable can be dynamically modified to enable different functions at different times, which increase their capabilities, expand their functionality, and widen their operating bandwidths [3, 4, 5].

In this paper, the metal-like properties of SPiN diodes under forward bias have been analyzed. According to this important characteristic, a new-type solid state plasma antenna has been designed and fabricated, which can require frequency reconfigurable by turning on or off the SPiN diodes, selectively. This antenna has exhibited more advantage compared with the conventional one.

Solid State Plasma Formation Principle

The reconfigurable properties of plasma antenna mainly depend on the temporary formation of solid-state plasma regions with fairly high electrical conductivity placed at on the surface of the silicon, therefore, the key reconfigurable element is SPiN diode[6].

Our application requires the SPiN diode must be lateral, with the I-region fully exposed from the top of the wafer. The structure of lateral SPiN diode is shown in Figure 1, which comprises a P+ region and an N+ region, separated by an I-region. The metal electrodes are used to connect adjacent diodes. All fabrication steps are compatible with processing on a standard silicon line.

![Figure 1. Structure of lateral SPiN diode.](image)

In such a semiconductor diode, when activated, the solid-state plasma with high concentration is formed in the intrinsic region (I-region), so the plasma will appear to be of metal-like characteristic
due to fairly high electrical conductivity [7]. The simulation of the concentration distribution for a slight forward biased (1V) is shown in Figure 2.

![Figure 2. Concentration distribution of the carriers in the I-region.](image)

Figure 2. Concentration distribution of the carriers in the I-region.

The distribution of carriers, as a function of the forward bias voltage, in the y=2μm, is presented in Figure 3. The results show that carriers density is larger for a higher anode bias voltage until carriers reach saturation. Simultaneously, the J-V characteristic curve of the SPiN diode is shown in Figure 4, which has the same trend as the carrier density with the anode bias voltage. As a consequence, the I-region of the SPiN diode under the forward bias voltage behaves like metal.

**Experimental Results and Discussions**

The solid-state plasma should be conductive enough that it becomes equivalent to a quasi-metallic layer. Hence, a reconfigurable antenna based on the SPiN diodes have been designed and fabricated. Its process layout as shown in Figure 5 and Figure 6 shows the solid-state plasma dipole antenna prototype with reconfigurable aperture.

![Figure 5. The layout of the designed dipole reconfigurable antenna.](image)
We have demonstrated the antenna’s reconfigurability by turning on or off various sections, to change the active length of the assembled dipole antenna structure. Different working state of the antenna is shown in Table 1. The simulated return loss ($S_{11}$) curve is shown in Figure 7 and the E-plane radiation pattern is presented in Figure 8. We can see that the operating frequency at 69GHz, 64.3GHz and 60GHz can be easily achieved in one solid state plasma antenna when in three different working states.

### Table 1. Different working state of the antenna.

| Working state | P3, P6, P11 | P2, P7, P10 | P1, P8, P9 |
|---------------|-------------|-------------|-------------|
| S1            | ON          | OFF         | OFF         |
| S2            | ON          | ON          | OFF         |
| S3            | ON          | ON          | ON          |

Figure 7. Return loss curve ($S_{11}$).  
Figure 8. E-plane radiation pattern.

### Table 2. The radiation characteristics for the three operating states of the antenna.

| State | Gain | Radiation efficiency |
|-------|------|-----------------------|
|       | Simulated | Measured | Simulated | Measured |
|       | GHz | dB | GHz | dB | GHz | % | GHz | % |
| S1    | 69.0 | 1.564 | 69.4 | 1.103 | 69.0 | 81.32 | 69.4 | 70.85 |
| S2    | 64.3 | 1.563 | 63.5 | 1.156 | 64.3 | 82.65 | 63.5 | 72.32 |
| S3    | 60.0 | 1.643 | 58.2 | 1.223 | 60.0 | 84.23 | 58.2 | 75.83 |

The results measured show that the dipole antenna (if the antenna works at S1) operates at 69.4GHz, which agree well with the simulated results, where the peak is at 69GHz. When the antenna works in S2, the operating frequency of the antenna will shift down to 63.5GHz. Similarly, when the antenna works in S3, the operating frequency shifts further down to 58.2GHz. We also have measured the dipole antenna radiation characteristics (Table 2) at various operating frequencies. The gain of the plasma antennas was approximately 1.5dB.
Conclusion
This paper presents a plasma dipole reconfigurable antenna with frequency selectivity, based on the silicon SPiN diode. The antenna frequency can be transformed among three different situations. The resonance frequencies at 69.4GHz, 63.5GHz, and 58.2GHz were easily achieved by turning on or off different sections of the antenna. The radiation efficiencies of the antenna are 70.85%, 72.32%, and 75.83%, respectively, which showed good agreement with the simulation results, proving the feasibility of this approach.

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