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Research of the SPiN diodes for silicon-based reconfigurable holographic antenna

Han Su[a,*], Huiyong Hu[a], Bin Shu[a], Bin Wang[b], Wei Wang[c], Jiaxiang Wang[a]

[a] Wide Bandgap Semiconductor Technology Disciplines State Key Laboratory, School of Microelectronics, Xidian University, Xi'an 710071, China
[b] School of Advanced Materials and Nanotechnology, Xidian University, Xi'an, 710071, China
[c] Yunnan Key Laboratory of Opto-electronic Information Technology, Yunnan Normal University, Kunming 650092, China

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ABSTRACT

Silicon-based solid state plasma antennas were characterized by its wide radiation range, good stealth characteristic, and dynamic reconfigurability, which have broad application prospects in the future. In this paper, investigations of surface PiN diodes developed for silicon-based reconfigurable holographic antennas have been demonstrated for using millimeter-wave communication systems. The SPiN diodes have been extensively discussed, and the obtained results (simulations and experiments) confirm the applicability of these devices for dynamically reconfigurable antennas. A carrier concentration of 10^{18}–10^{19} cm^{-3} has been achieved within the optimized SPiN diode. Reconfigurable holographic antennas based on SPiN diodes that were activated by the injection of dc current were demonstrated in this paper. The resonance frequencies at 60 GHz and 64.5 GHz have been easily achieved by turning on or off different sections of the reconfigurable dipole antenna, while the radiation efficiencies were 85.1% and 83.8%, respectively. A double-layer holographic structure was also investigated in this paper. The study reveals that a novel reconfigurable antenna with SPiN diodes has been formed in a single system and has numerous advantages over the traditional antenna.

1. Introduction

Nowadays, with the rapid development of communication technology, the traditional antennas, which were made of metal, have been gradually unable to meet the current communication requirements. Metals greatly reduce the stealth performance of the antenna systems. Furthermore, the conventional antenna has a large weight, low flexibility and great bulk. Thus, a novel intelligent antenna should be developed to meet the increasing modern communication systems. The best solution of this question is to develop a reconfigurable antenna to realize numerous services [1–5].

In general, the reconfigurable antennas were divided into two parts. The first group of reconfigurable antenna was achieved by the fixed separated switches, such as MEMS, PIN diodes. For the second group, the reconfigurability of the antenna was achieved by dynamically defining the plasma regions to change the antenna's radiation structure and realize different operating characteristics. In this paper, a solid state plasma antenna based on surface PiN (SPiN) diodes for the achievement of reconfiguration property has been developed to meet the currently-growing communication requirement [6–9].

In the conventional antenna systems, the method to achieve reconfigurability was to allow reconnectivity between the various predefined metal areas, using multiple switches to change the size of the antenna. In this paper, there were no predefined conductive areas, only well-defined plasma channels on the top silicon layer. The SPiN diodes were the basic building blocks of the plasma channels in which the concentration of carriers should achieve a relatively high level. The high conductivity of silicon is dependent on the number of carriers present, and at sufficiently high carrier concentration it can appear metallic to realize the radiation characteristics of the plasma antenna [9,10]. Since the SPiN diodes were not used as a classical switch, their layouts were significantly different from the standard semiconductor devices. The conventional PiN diode was a vertical device, where the central intrinsic region was stacked between heavily doped P + and N + regions. The intrinsic region dimensions were selected based on the off-state isolation, reverse breakdown voltage, and switching speed goals [11,12]. Our application requires quiet a different structure (surface PiN diode). A variable plasma channel was formed at forward bias, which appeared to be metal-like and conductive at RF frequencies. In the on state, this diode was activated and affects the electromagnetic waves propagation to achieve the antenna's radiation characteristics. In this paper, the objective was to investigate the microwave

* Corresponding author at: East Main Building, No. 2 South Taibai Road, Xi'an, Shaanxi 710071, China.
E-mail address: suhan@stu.xidian.edu.cn (H. Su).

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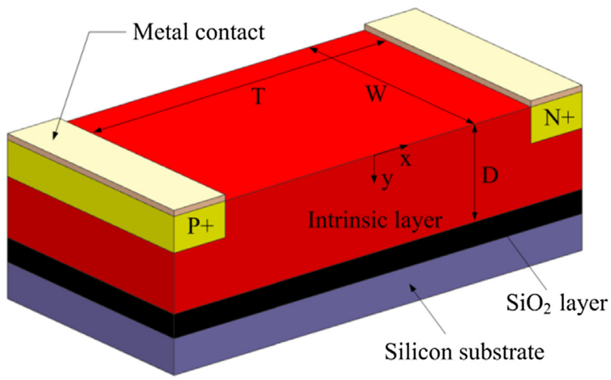

Fig. 1. Structure of lateral PiN diode, length of the intrinsic region = T, its depth = D, its width = W.

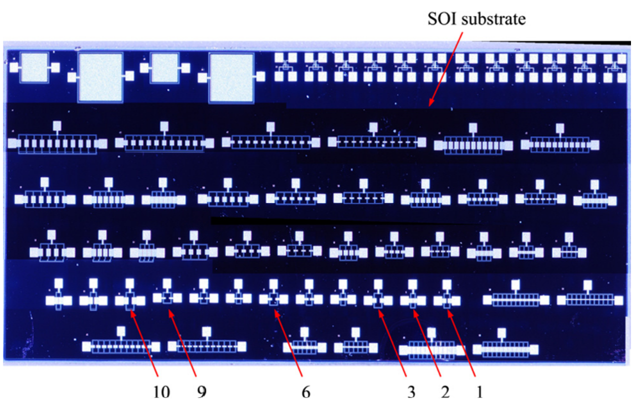

Fig. 2. SPiN diodes realized on SOI.

Table 1
Diodes size.

Diode	T/µm	W/µm
1	50	100
2	20	100
3	100	100
6	100	50
9	100	20
10	100	150

characteristics of the SPiN diode rather than as a classical switch.

In this paper, a novel reconfigurable antenna based on SPiN diodes was presented and investigated. In Section 2, the structure and principle of the SPiN diodes were presented. In Section 3, measurement results of the SPiN diodes at different sizes were contrasted. In Section 4, a novel reconfigurable holographic antenna based on SPiN diodes was discussed. Conclusion was given in Section 5.

2. SPiN diode development

The radiating elements of the reconfigurable antenna were the SPiN diodes, and its structure was significantly different from a conventional PIN diode. These devices were not widely used at the microwave and millimeter-wave range applications. Contrary to a conventional diode, the SPiN diode was a lateral device. It was a very simple semiconductor device, and these diodes act as radiating elements (solid state plasma channel) rather than switches in the traditional antenna system. Similar to the bulk PIN diode, it requires only two regions: N + and P + embedded in a highly resistive substrate with metal contacts, which was illustrated in Fig. 1. In this device, the carriers (electrons and holes) were confined to the upper silicon layer by Silicon-on-insulator

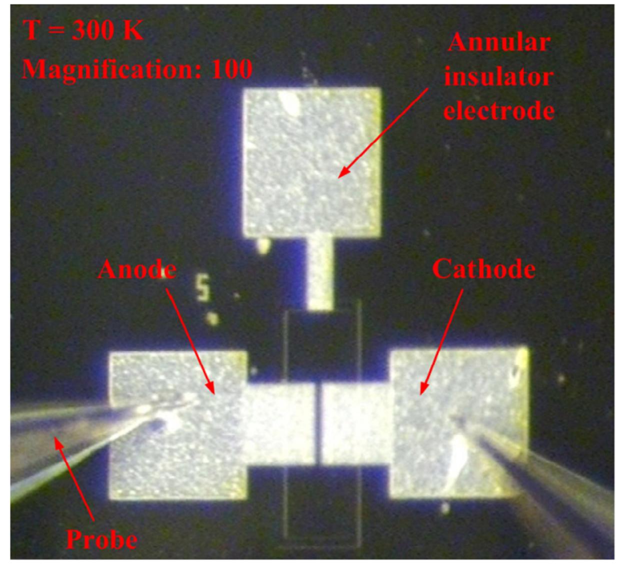

Fig. 3. Fragment of the testing environment.

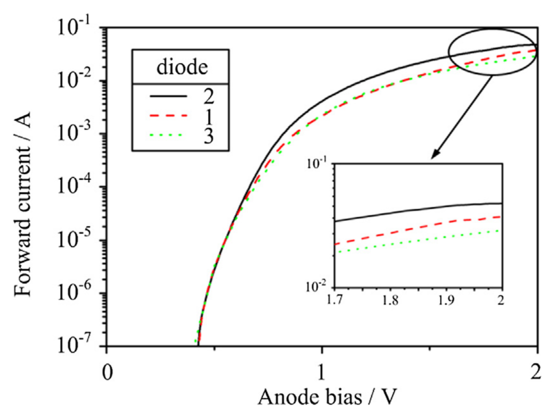

Fig. 4. Measured I-V curves for different lengths of the intrinsic region (T).

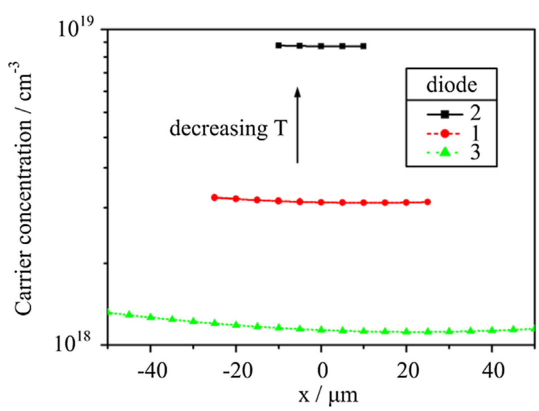

Fig. 5. Comparison of the average carrier concentration for different diodes biased at 2 V.

(SOI) technology. An SOI wafer consists of a monocrystalline Si layer over an insulating layer of thermal silicon dioxide (buried oxide) on a Si substrate. The SPiN diode with 80 µm upper silicon, 5 µm buried oxide, and 350 µm lower silicon was simulated and next fabricated. The resistivity of both n-type FZ silicon ⟨100⟩ layers was 9 kΩ cm. Silicon substrate was used because silicon had good temperature and mechanical properties, and there were several foundries offering customized silicon technology. The Sentaurus TCAD software used for the 2D