

Semiconductor-Based Reflector Antenna Using Integrated PIN Diodes

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Abstract - This paper presents a semiconductor reflector antenna for use in reconfigurable telecommunication systems. The quasi-metallic reflector characteristic was obtained by formation of high conductivity plasma regions placed at PIN diodes, thereby controlling the beam direction and the gain of the reflector antenna. The constant current regulator was necessarily designed to obtain expected carrier density and maintain the stable operation of the diodes. The measured reflection coefficient and peak gain of the antenna around the center frequency of 5.5 GHz were -13.5 dB and 5.4 dBi, respectively.

Index Terms — Semiconductor reflector antenna, PIN diode, reconfigurable antenna, thermal runaway.

1. Introduction

Reconfigurable antennas have been known as a promising technology to meet the increasing requirements of the modern wireless systems. A typical method of the reconfiguration may be achieved by switching elements such as PIN diodes, which temporarily create conducting area at the surface of silicon devices [1], [2]. This area can be easily switched between an ON state and an OFF state with a control signal. At the ON state, the high forward bias allows plasma of carriers in the intrinsic region, which starts to behave as a highly conductive medium. In contrast, at the OFF state, the diode provides a high resistance medium. The semiconductor reconfigurable antenna is generally implemented by using such characteristics of the PIN diodes. However, the high forward voltage creates a larger amount of heat within the diode, resulting in thermal runaway. Thus, the diodes should be driven by a constant current rather than by a voltage source in order to maintain the high electrical conductivity and the stable operation [3]. Nevertheless, recent works in the literature [1], [2] do not perform a proper bias control; thus may suffer from nonideal effects of PIN diodes to achieve high carrier concentration. In this paper, we present a semiconductor reflector antenna composed of integrated PIN diodes and design a current regulator to keep the silicon reflector more stable and maintain higher carrier density.

2. Semiconductor Reflector Antenna

A photograph of the prototype semiconductor reflector antenna is shown in Fig. 1. This antenna, similar to conventional Yagi-Uda antenna [4], is composed of a single driven element with SMA connector, three microstrip

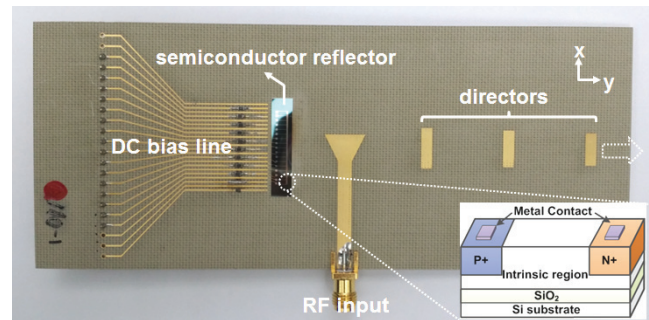


Fig. 1. Semiconductor reflector antenna.

directors, and a semiconductor reflector with DC bias lines and is printed on a 145x6x1 mm³ RF-35 substrate. In this antenna, the semiconductor reflector determines the directional radiation pattern according to the PIN diodes states. The structure of a single PIN diode used in the semiconductor reflector is shown in inset of Fig. 1. An silicon-on-insulator substrate is adopted here, concerning the microwave losses [1], [2]. The PIN diode requires two regions of N+ and P+ embedded in a highly resistive substrate with metal contacts. When a forward bias is applied on the diode, the electrons and holes will be injected into the intrinsic region from reservoirs. The carrier concentration is increased and an effective plasma channel for the reflection of electromagnetic wave can be achieved. The radiation pattern might be defined by a binary sequence sent to the control circuit which enables reconfigurable function to the antenna. The reflector is composed of a multi segment structure which comprises a series connected diode array.

3. Constant Current Regulator

As expected, increasing the forward voltage leads a good reflector performance but, it translates to a higher power loss in the diode, thus creating a larger amount of heat within the diode. This thermal energy produces more current at the fixed voltage, accelerating the thermal runaway. Fig. 2 shows measured surface temperature of the reflector with different forward voltages. At 10-V forward bias, the semiconductor reflector operates within safe operating range. But, the temperature of the diodes abnormally rises at 20-V supply, which eventually destroys the device. The forward bias voltage should be controlled within the stable region, even if that limits the carrier

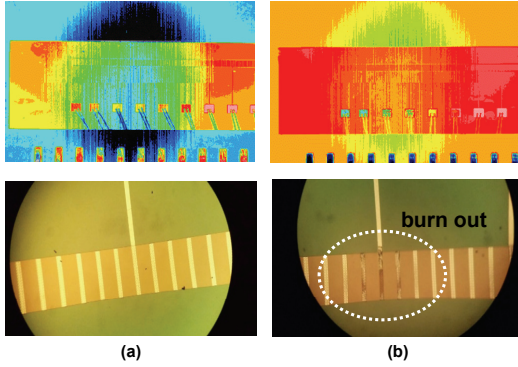


Fig. 2. Surface temperature measurement. (a) 10V. (b) 20V.

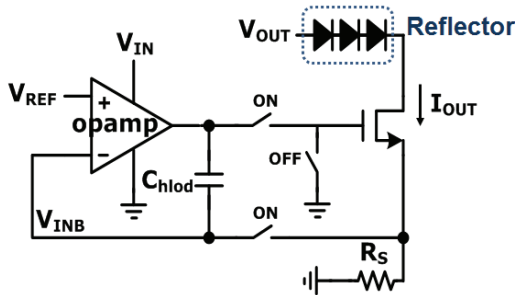


Fig. 3. Proposed constant current regulator.

concentration. The PIN diode control with the constant current driving can overcome this drawback. The concrete reasons for this driving are as follows: First, keeping the maximum current and maintain the reliability. Second, obtaining expected carrier density for each diode. Finally, removing complicated bias lines with the driving circuitry. The proposed current regulator is shown in Fig. 3. It is composed of an opamp, an n-channel transistor, a resistor, and control switches. A feedback circuit can adjust the carrier density through the reference voltage (V_{REF}) control, R_s determines the maximum current for the diode array, three switches manage ON and OFF states of the PIN diodes and holding capacitor (C_{hold}) is used to ensure fast transient response. To satisfy the current error requirement of 0.1%, the opamp employs a two-stage topology with feedforward-compensation [5].

4. Measurement Results

The measured reflection coefficient of the proposed antenna for different values of bias current is shown in inset of Fig. 4. It reveals a good matching performance over a significant bandwidth and confirms the influences of forward bias current. If a higher current is applied to PIN diodes, the more amount of high conductivity plasma can be created. Thus, the reflection coefficient is significantly improved corresponding to the diode bias level.

Fig 4 also shows gain characteristics of the semiconductor reflector antenna with the PIN ON and OFF. When the PIN OFF, the gain difference between front-side and back-side is negligibly small, thus the antenna has

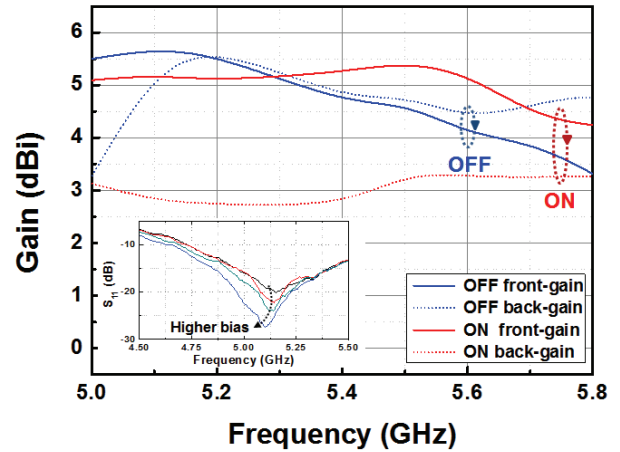


Fig. 4. Measured antenna performances.

bidirectional radiation pattern. When the PIN ON, the antenna shows large gain difference, leading the beam to radiate in positive y direction. The measured pattern presents a gain difference of more than 2 dBi with the PIN ON and OFF ranging from 5.1 GHz to 5.6 GHz, which means that the semiconductor reflector successfully carries out a quasi-metallic function, thereby controlling the beam direction and gain. A 5.4 dBi peak front-side gain is achieved at 5.5-GHz center frequency and a 5.8 dB front-to-back ratio is observed at 5.4-GHz band.

5. Conclusion

A semiconductor reflector antenna using PIN diodes was presented. The relationship between the carrier concentration and the bias current was figured out and the controllability of front-to-back ratio was confirmed with the PIN ON and OFF. These results shows that the silicon based plasma channel is very promising for future reconfigurable antennas.

Acknowledgment

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