220 GHz SPST switch based on PIN diode with low insertion loss and high isolation

Xiaolin Hao[1], Guodong Gu[1], Shixiong Liang[1], Yuanjie Lv[1], Xubo Song[1], Lisen Zhang[1], and Feng Zhi Hong[1]

[1]Hebei Semiconductor Research Institute

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Abstract

In order to address the issue of 220 GHz receiver protection, a single-pole single-throw (SPST) switch based on GaAs PIN diodes is introduced in this research. The PIN diode with an I layer thickness of 400 nm and a cut-off frequency over 1.5THz was created in order to enable the SPST switch to operate in the terahertz frequency range. Therefore, a 220 GHz quasi-MMIC SPST switch was designed using GaAs PIN diodes and a 50 µm thin-film quartz foundry. The measurement reveals that the isolation is > 29 dB, insertion loss is < 3.2 dB in the frequency range of 220 GHz to 230 GHz and IP1dB is 17 dBm at 220 GHz.

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National Key Laboratory of ASIC, Hebei Semiconductor Research Institute, Shijiazhuang 050051, China

Email: ga917vv@163.com.

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Introduction: Switch circuits are crucial for enabling the on-off of signals in millimeter-wave systems including radar, communication, sensing, imaging, and measurement [1]. Applications of switches include transmitters, receivers, time division systems, antennas, etc. Switches need to block the signal with low insertion loss and high isolation, which are used to protect other components of the system.

Switch design is possible using a variety of process technologies. The use of field effect transistors (FET) [2] or diode-based semiconductor [3, 4] processes is a common means of fabricating switches. In addition to these, MEMS techniques [5], phase change materials [6], and 2D materials [7] can be used to enhance the performance of switches. Switches from 220 GHz to 325 GHz are reported using InP DHBT technology with insertion loss of 3.5-4.1 dB and isolation of 36 dB [8]. The switch that can operate at frequencies ranging from 122 GHz to 330 GHz is realized using 50 nm InGaAs mHEMT technology [9], although the isolation and insertion loss are subpar at high frequencies. Compared with those technologies, PIN diodes increase the cut-off frequency by changing the thickness of the I layer, enabling operation at millimeter waves and even higher frequencies.

In this letter, an SPST switch operating at 220 GHz is shown, using 50µm thick quartz circuits and GaAs PIN diodes. The structure of the PIN diode is optimized to reduce the on-resistance and parasitic parameters of the diode, so that the designed SPST switch can work at 220 GHz.

*Design of the SPST switch:*Figure 1 (a) depicts the structure diagram of the PIN diode designed in this work. Through material structure optimization and the use of an I-layer material structure with a thickness of 400 nm, the PIN diode's on-resistance is decreased in this study to increase the cut-off frequency of the PIN diode. The parasitic parameters of the PIN diode can be effectively reduced by using the point-supported arched air bridge and the 15 µm substrate thinning process. Figure 1 (b) displays the results of the DC tests performed on the PIN diodes created in this work. Through the extracted junction capacitance and on-resistance, the cut-off frequency ($f_c = \frac{1}{2\pi R_{\text{on}} C_{\text{off}}}$) [4] of the PIN diode can be calculated to reach more than 1.5 THz, and this PIN diode can work in the terahertz frequency band.

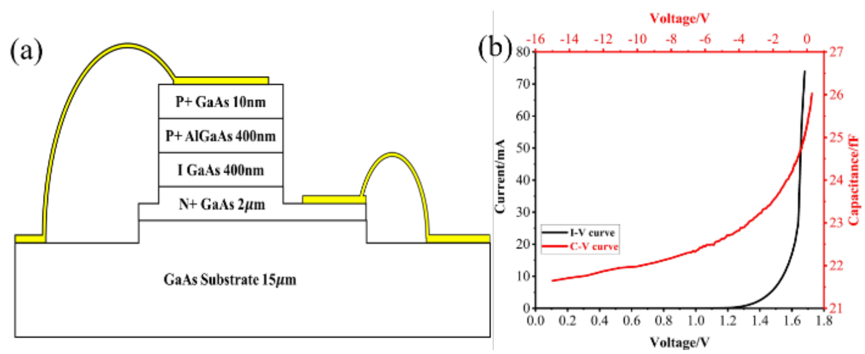

Fig 1 *(a) The schematic diagram of PIN diode structure; (b)*

The I-V curve and the C-V curve of the PIN diode.

The SPST switch circuit chip is depicted in Figure 2 (a), which is designed using the principle of a parallel switch between PIN diodes and microstrip transmission lines. To improve isolation, three GaAs PIN diodes are chosen to be impedance matched in cascade to achieve the best performance index. The bypass with PIN diode and sector low-pass filter are matched on the high-impedance line of the SPST switch to reduce the insertion loss of the device. The PIN diode can loop in the circuit by bonding to the ground at the opposite end of the high-impedance line. The on state of the switch corresponds to the reverse state of the PIN diode, and the off state of the switch corresponds to the forward state of the PIN diode.

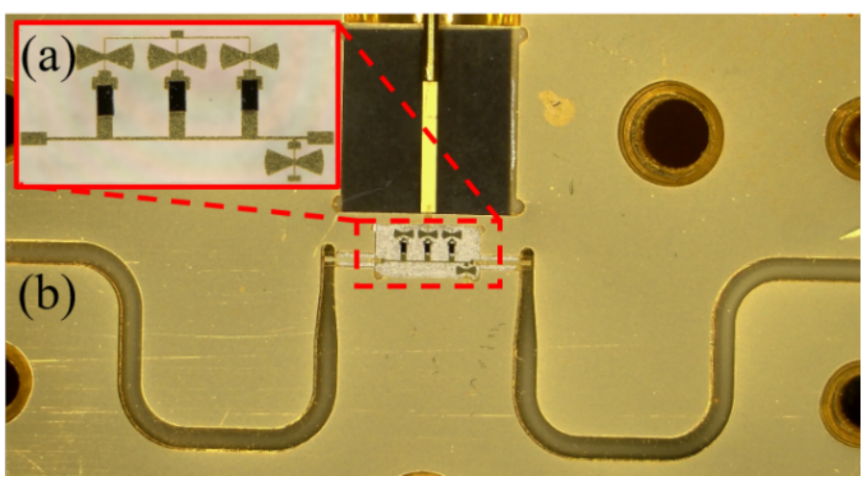

Fig 2 *The picture of the SPST integrated switch. (a) The area of 50um thickness SPST switch chip is 2.75mm^2; (b) The SPST switch chip was packaged in a waveguide for testing the performance of the switch chip.*

The SPST switch chip is packaged in the waveguide with port WR4, as shown in Figure 2 (b). In order to introduce terahertz waves into the SPST switch, quartz probes are employed as transition structures to link on both sides of the SPST switch chip. Place the PIN diode in the appropriate location on the quartz circuit that has been manufactured, then secure it with conductive glue. Gold wire connects the quartz probes to the SPST circuit.

Measurement of the SPST switch: A bias voltage is applied to the switch while a vector network analyzer was used to measure the SPST switch's cavity. To obtain accurate measurement results of the switch chip, the existing results need to be de-embedded, minus the loss of quartz probes and gold wires, as illustrated in Figure 3(a). The insertion loss is $<$ 3.2 dB from 213 GHz to 230 GHz. The isolation is $>$ 29 dB from 220 GHz to 230 GHz. The results from the measured curve follow the same trend as those from the simulation. The applied voltage range of the SPST switch is from 0 to 1.4 V to achieve a good switching effect, which working current is 10 mA.

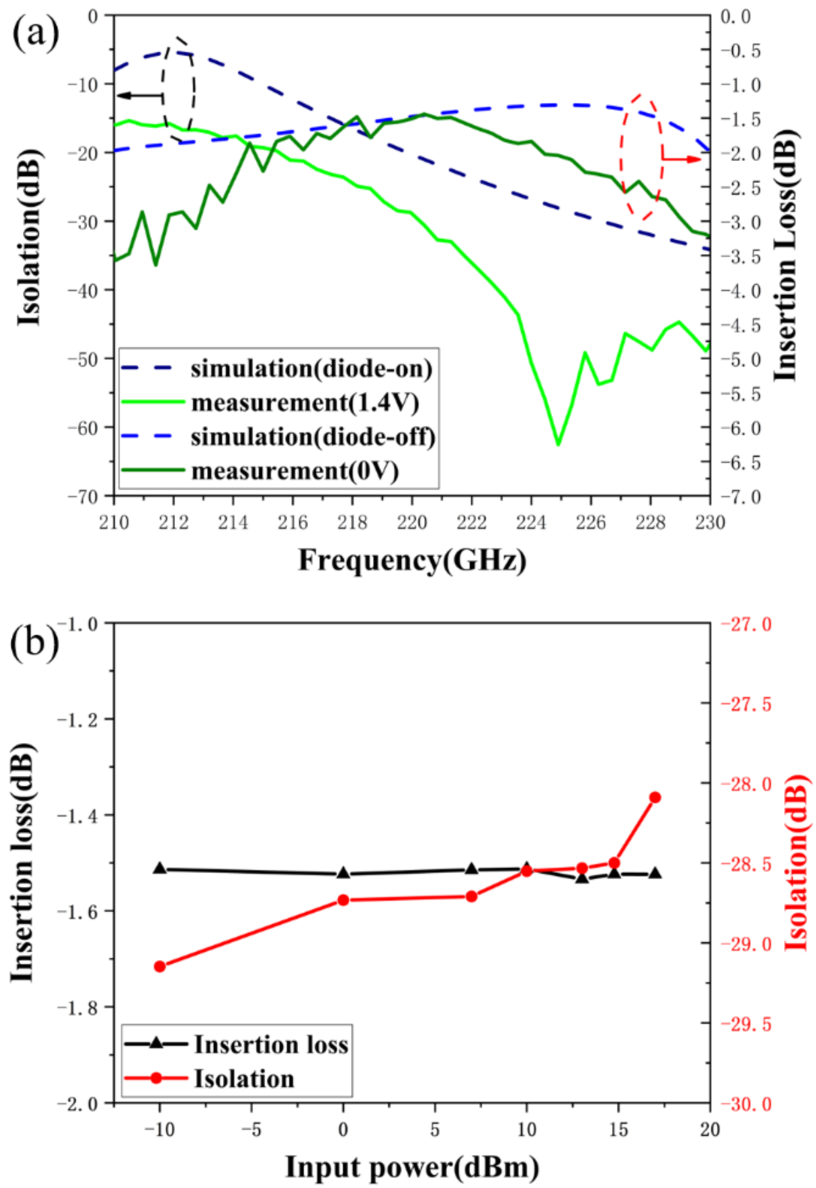

Fig 3 *Measure performance of the SPST switch. (a) Compare with simulation results, measured and de-embedded insertion loss and isolation from 210 GHz to 230 GHz, (b) Measured insertion loss and isolation versus input power at 220 GHz.*

The power measurements of the switches were tested at 220 GHz using an external power source and power meter. Through the external power source's adjustable attenuation, the input power value is changed. Due to the loss of the quartz probe and the gold wire, the actual power fed into the switch chip is reduced, which is compensated by increasing the external input power. Figure 3(b) plots the processed output power against switch insertion loss and isolation measurements. When the input power reaches 17dBm, the isolation is significantly reduced by 1dB.

Conclusion: This letter provides an example of a high-frequency switch with minimal insertion loss and high isolation that was made using GaAs PIN diodes. To enhance the switch's functionality, three PIN diodes are connected in parallel on the transmission line. This work's SPST switch exhibits insertion loss performance of < 3.2 dB, isolation performance of >29 dB from 220 GHz to 230 GHz, and IP1dB performance of 17 dBm at 220 GHz. The switch of this work can be applied to high-power applications such receiving protection systems.

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