Development of Fully-Integrated Optically-Controlled THz Switches for Tunable and Reconfigurable Filters

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***Abstract*—We report our recent progress toward the development of fully-integrated optically-controlled switches for tunable and reconfigurable terahertz (THz) filters. The switches were designed based on optical modulation of photoconductivity using photo-induced free carriers in semiconductors. For different application scenarios, switches employing two different configurations, i.e., series and shunt CPW, were investigated and initially demonstrated. Encouraged by the promising results including low insertion loss (e.g., 0.3 dB), high isolation (e.g., 70 dB), and broadband operation, fully-integrated G-band switches have been designed and fabricated using Si-on-Sapphire (SoS) wafers for the development of tunable and reconfigurable filters in future THz sensing, imaging and communication systems. The theory, design, simulation, prototype demonstration and fabrication of the proposed switches are presented. On-wafer probe testing of the fully-integrated switches will soon be performed. Finally, a dual-band reconfigurable THz notch filter is initially designed and simulated to highlight the promising applications of the switches.**

***Keywords*—Optically-controlled switches, terahertz filters.**

I. Introduction

THE THz spectrum has gained increasing interest due to its promising applications in medical imaging, biological sensing, and communications [1]. As a consequence, tunable and reconfigurable THz circuits such as reconfigurable filters have become more desired in advanced THz sensing, imaging and beyond 5G adaptive communications [2]. High performance RF switches operating in the THz region are one of the crucial elements for realizing such circuits with maximum tunability, reconfigurability and multi-functionality [3]. However, conventional RF switches relying on solid-state devices or phase-change materials suffer significant performance degradation as frequencies transition into the mmW-THz range [4]. MEMS-based RF switches designed for THz frequencies thus far have been bulky and challenging to be integrated into sophisticated systems for achieving more advanced circuit functionalities, despite their complex fabrication and potential reliability issues [5].

To address the aforementioned issues, we proposed to develop high performance THz switches based on optical modulation of photoconductivity using photoinduced free carriers in semiconductors. Fig. 1 shows the conceptual switch design and operation mechanism, taking the series configuration in a CPW with interdigital structure as an example. Different from conventional switch designs, an insulation layer is inserted between the gold contact and the active layer using Si or Ge to form a non-contact capacitive coupling architecture. With light illumination, high carrier concentration in the active layer can be maintained and hence high photoconductivity can be achieved, leading to RF switches with extremely low insertion loss (IL) and superior isolation (Iso) in the THz region.

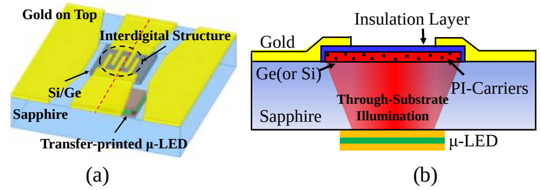

Fig. 1. The concept of optically-controlled THz switches with (a) transfer-printed µ-LED and (b) its cross-section view along the dashed line.

II. Modeling, Simulation and Prototype Demonstration

On the basis of our physics-based model on photoconductivity modulation [6], two types of THz switches with series and shunt configurations, respectively, were designed and simulated using the proposed approach. Fig. 2 illustrates the simulated frequency responses of the proposed fully-integrated optically-controlled THz switches. As depicted, the switch design using series configuration demonstrates an IL of 0.6 dB and Iso of ~35 dB with Ge, while the one with shunt configuration exhibits an IL of 0.3 dB, and Iso of >70 dB. For a proof-of-concept demonstration, D-band and G-band switches assembled using 73 µm-thick Si chips on top of CPW lines were characterized, and the results show promising performance [7]. Specifically, a measured IL of 0.4 dB and Iso of 32 dB have been achieved at 170 GHz (using a light intensity of ~40 W/cm^2) as shown in Fig. 2 (b).

III. Fabrication

Motivated by the promising results shown above, fully-integrated G-band switches using the proposed approach have

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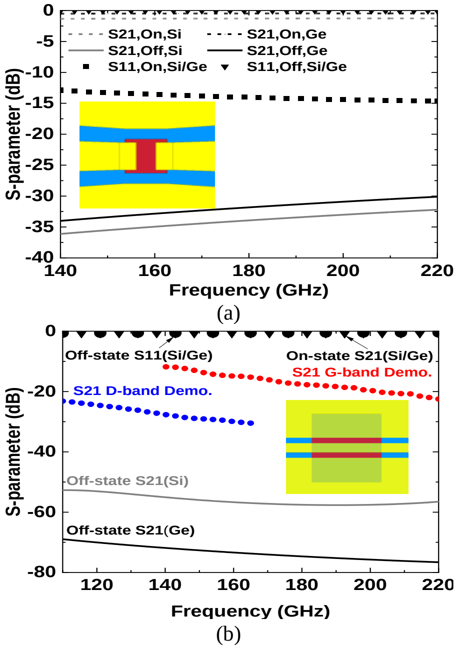

Fig. 2. Simulated and measured frequency responses of the proposed THz switches for (a) series configuration and (b) shunt configuration (with measured data from proof-of-concept demonstration).

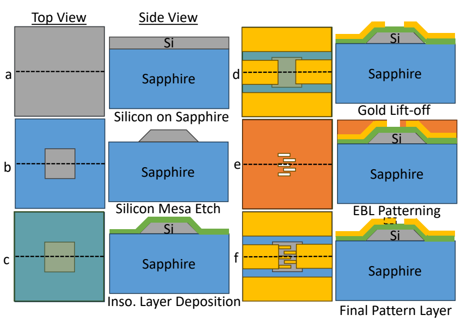

Fig. 3. Process flow diagram for fabricating the proposed optically-controlled THz switches using lift-off on SoS substrates.

been designed and fabricated using Si-on-Sapphire (SoS) substrates for more advanced tunable/reconfigurable THz circuits. The process flow is shown in Fig. 3. The process involves a combination of traditional photolithography and electron-beam lithography (EBL, optional for submicron-scale interdigital structures) followed by lift-off. The initial fabrication results are shown in Fig. 4, and the switches will soon be characterized with on-wafer probe testing.

IV. Applications for Advanced THz Filter

To exploit the potential of this novel switch technology for realizing more advanced tunable/reconfigurable THz circuits, an optically-controlled dual-band reconfigurable THz notch

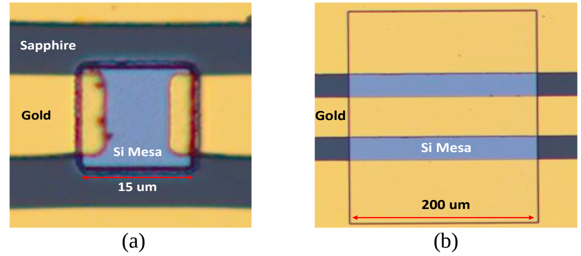

Fig. 4. Microscope images of the fabricated fully-integrated optically-controlled THz switches with (a) series-configuration and (b) shunt-configuration.

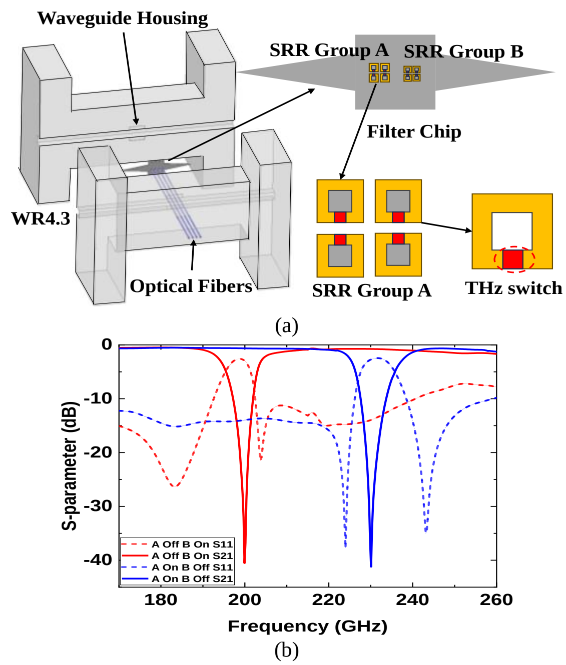

Fig. 5. (a) The concept of the proposed reconfigurable bandstop filter based on WR4.3 waveguide platform and (b) its frequency response.

filter based on WR4.3 waveguide platform has been designed and simulated as shown in Fig. 5 (a). The results show that the center frequency of the bandstop filter can be reconfigured between 200 GHz and 230 GHz by individually turning on/off the split-ring resonator groups A/B (see Fig. 5 (b)). In addition, the in-band suppression is greater than 40 dB. The filter will soon be implemented for measurement.

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