Reconfigurable Thermo-Optic Polymer Switch Based True-Time-Delay Network Utilizing Imprinting and Inkjet Printing

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Abstract: Reconfigurable true-time-delay lines, comprising of 2x2 thermo-optic polymer switches and rib waveguides are fabricated utilizing a combination of roll-to-roll (R2R) compatible UV imprinting and ink-jet printing, which promises high throughput and low cost photonic devices.

OCIS Codes: (130.4815) Optical switching devices; (130.3990) Micro-optical devices; (220.4000) Microstructure fabrication; (130.5460) Polymer waveguides; (160.6840) Thermo-optical materials

Introduction

Thermo-optic (TO) polymer switches have found widespread applications in several areas, such as communication and radar, add/drop multiplexing, by pass switching in the event of a network failure or network jam, packet switching. Specifically, reconfigurable true-time-delay (TTD) lines comprising of TO switches and rib waveguides, are able to deliver precise delays for phased array antenna (PAA) applications [1-6].

In our previous work, we demonstrated a printed TO switch utilizing a combination of UV imprinting and inkjet printing [7]. In this work, we further explore a complete 4-bit true-time-delay unit, comprising of an array of interconnected TO switches and polymer delay lines. By controlling the ON/OFF states of the individual switches, true-time-delay behavior over a broad RF bandwidth can be obtained. The roll-to-roll (R2R) compatible printing process, unlike photolithography or e-beam lithography, enables development over large areas, on flexible substrates, and at high-throughput, thus drastically reducing the cost. Moreover, these devices can be integrated with other printed photonic and electronic components, such as light sources, modulators, antennas on a single substrate, thus achieving an integrated system that can be conformably integrated on any platform.

Design of TO polymer switch based reconfigurable TTD network

A schematic of a 4-bit TO polymer switch based TTD network is shown in Fig. 1(a). It consists of five 2x2 TO polymer switches, interconnected via judiciously chosen lengths of polymer waveguide delay lines. The minimum length delay step (ΔL) determines the minimum achievable time delay step ($\Delta\tau$) according to $\Delta\tau=n_{eff}\cdot(\Delta L/c)$, where n_{eff} is the effective index of the mode in the waveguide and c is the speed of light in vacuum. At the first switch (n=1), the optical signal is delivered to reference waveguide (length L) or delay line (length $L+\Delta L$), depending on the chosen state of TO polymer switch. Then, the second switch (n=2) couples the optical signal into two more waveguides with lengths L and $L+2\cdot\Delta L$. This sequence is continued, until a last switch delivering optical signal to two waveguides with lengths L, and delay line, $L+2^3\,\Delta L$ (for a 4-bit delay network) is reached. The last switch (n=5) of the 4-bit delay TTD line is used to control the optical signal to couple into the output waveguide. A top view schematic of a single 2x2 TO switch [7] is shown in Fig. 1(b). The rib waveguide forming the device comprises of a 3.5 μm UV15LV bottom cladding layer. The core region comprises of a 1.8 μm thick slab and a 5 μm × 0.5 μm strip made of SU8. The top cladding comprises of a 3 μm thick UFC-170A layer. The gold heating electrode is 8 μm wide and 500 μm long. A single TO switch was demonstrated to consume 100 mW power to switch from one state to the other [7].

In order to fabricate the entire TTD network, we first fabricate a flexible mold containing the 4-bit TTD core pattern from a silicon hard mold. The core region in a UV15LV bottom cladding layer is fabricated by the flexible mold, using UV imprinting technique. The core layer and trench are filled by SU8 2000.5 using inkjet printer. Inkjet printing of SU8 produces a flat surface profile on top, which can be used for subsequent material printing. The top UFC-170A cladding layer is then coated on top of the core layer. The SEM cross-section view of printed layers in one switch [7] is shown in Fig. 2(a). Finally, gold metal heater is deposited on the top cladding layer. Alignment marks are utilized to aid in heater placement. The microscopic top view of a fabricated switch [7] is shown in Fig. 2(b). The optical response at 1 kHz is measured using an oscilloscope [7] and shown in Fig. 2(c). The square wave signal at 1 kHz is generated by a function generator and applied across the heating electrode. It can be seen that the TO polymer switch operates up to 1 kHz. The rising and falling time is 0.46 ms and 0.40 ms, respectively.

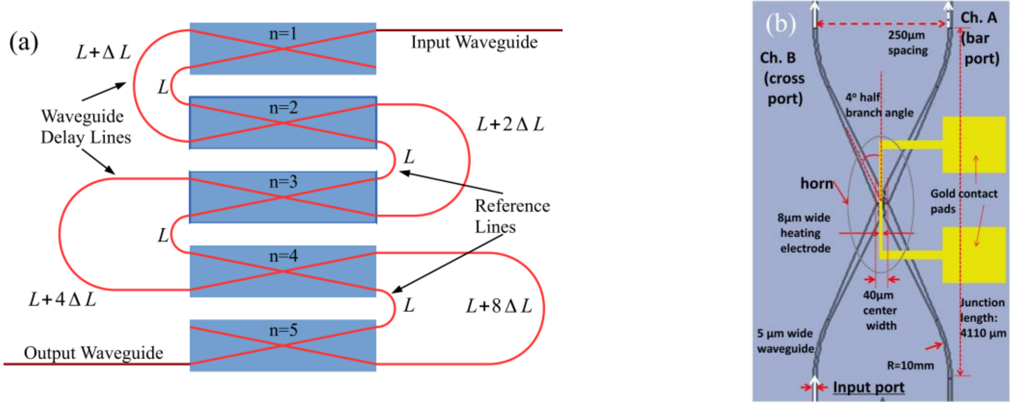

Fig. 1 (a) Schematic of a 4-bit TTD device using 2×2 TO polymer switches. (b) Top view of a single 2×2 TO polymer switch [7].

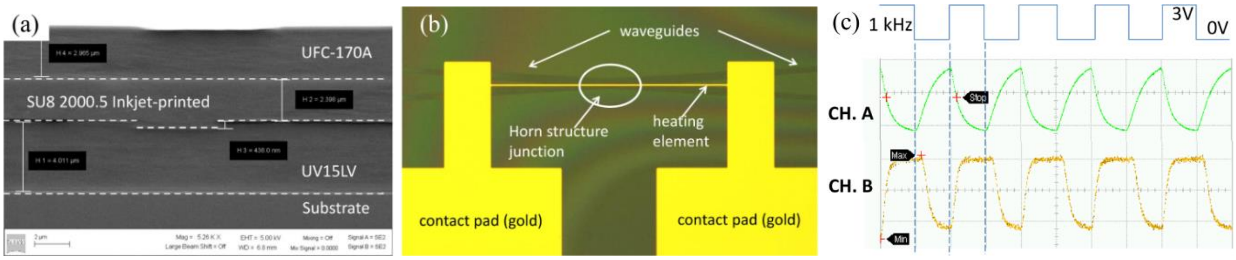

Fig. 2. (a) SEM cross-section view of printed layers in the TO polymer switch. (b) Microscopic top view of a fabricated 2×2 TO polymer switch. (c) Optical response with square wave function applied across the heating electrode at 1 kHz frequency (CH. A represents bar port and CH. B represents cross port). [7]

We are currently in the process of completing fabrication and characterization of the devices, and we will have measured data from the TTD network prior to the conference.

Conclusion

A scheme to achieve roll-to-roll fabrication of reconfigurable thermo-optic polymer switch true-time-delay lines using compatible printing techniques for phased array antenna application is shown in this work. The TTD network comprises of 2×2 TO polymer switches and rib optical waveguides, and fabricated utilizing UV imprinting and inkjet printing techniques. The R2R compatible process holds great promise for the roll-to-roll manufacturing of true-time-delay feed networks for phased array antennas on rigid as well as on flexible substrates. The fabrication and testing of TTD network is currently in progress and the results will be shared during the conference.

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