Polymer Waveguide Components for Switched WDM Cross-Connects

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Abstract

Cross-connect switches and Bragg grating technologies may be combined in polymer waveguides to produce low-cost, efficient components for wavelength division multiplex applications. Results of polymer gratings, thermo-optic and "bubble" switches are presented.

Keywords

Optical Switch, Bragg grating, WDM, Polymer, Waveguide.

CROSSLINKS for wavelength division multiplexed (WDM) applications must provide the ability to switch and filter (wavelength-route) optical signals. Requirements exist for single-mode and multimode switches in both $1 \times N$ and $N \times N$ configurations. Key device parameters include total insertion loss, loss uniformity between channels and switch states, polarization dependence, and scalability.

Current systems require switching speed less than 50 *ms* but must be scalable to high port counts. Recently stated goals are for 1×8, 8×8, and 32×32 switches with fiber-to-fiber loss of less than 3 *dB* and loss uniformity of better than 1 *dB*. Thermo-optically tuned 2×2 Mach-Zehnder switches, such as the polymer waveguide device shown in Figure 1, are well understood and provide an economical solution for most low-density switching requirements. The primary drawback of the Mach-Zehnder devices is that they are not scalable to large port counts, due to optical loss and photomask size limitations.

Switches based upon total internal reflection resulting from air bubbles in a capillary channel were first reported by Jackel and Tomlinson [1] in 1990. Essentially, a fluid-filled capillary that intersects a pair of crossed waveguides contains an index-matching fluid and an air bubble (see Figure 2). Activation of the capillary either places the air bubble at the waveguide intersection achieving switching or moves the air bubble out of the intersection allowing the index-matching fluid to transmit the incident signal directly across the junction. Much higher port count and port density is achievable in bubble switch configurations. This is because they are not limited by evanescent coupler lengths as in Mach Zehnder devices nor are S-bends required for transitioning closely spaced waveguides to large separations appropriate for fiber pigtailing.

Bubble switches made using glass waveguides rely on etching to produce capillary channels which contain index-matching fluid and air bubbles. In polymer-based bubble switches, the fluid/air capillary is formed by precision laser ablation yielding a much smoother capillary wall. Rough capillary walls, such as those formed by reactive ion etching or acid etching of glass, produce high scattering loss when the air bubble is located at the waveguide intersection. Typical losses of 2.2 *dB* have been reported [2] for glass waveguide devices. Optical surfaces achieved via laser ablation result in polymer waveguide - air bubble loss of less than

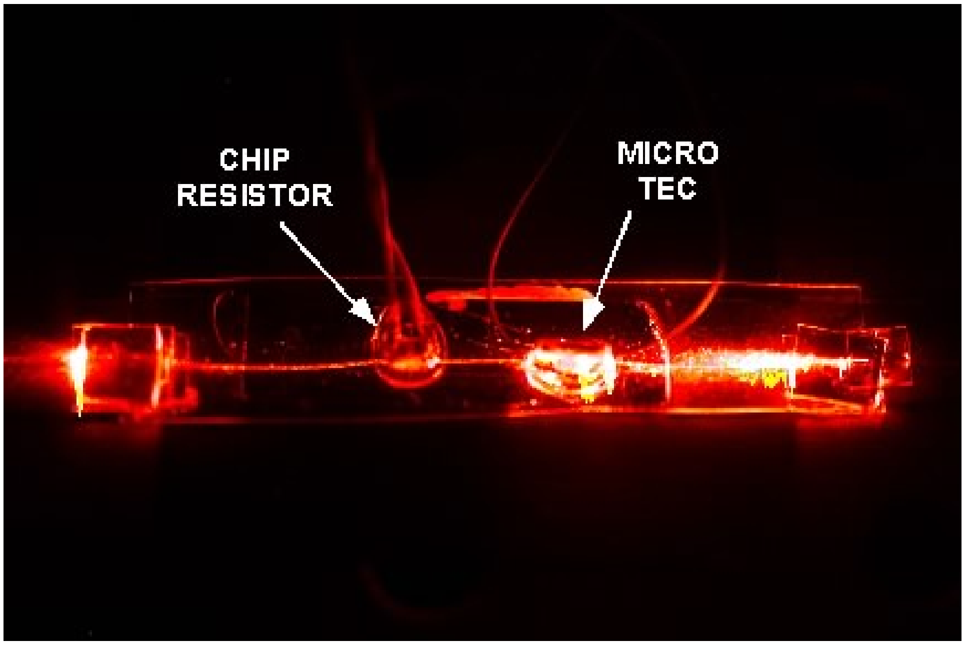

Fig. 1

Optical polymer thermo-optic Mach-Zehnder 2 × 2 switch. Thermal activation may be achieved using either a chip resistor or a micro-thermoelectric cooler (TEC).

0.2 *dB*. When index fluid fills the capillary at the waveguide intersection, loss of 0.1 *dB* is typical for polymer waveguides and glass waveguides. Switching in a polymer waveguide bubble switch is shown in Figure 3.

Polymer waveguide devices have been used for many applications over the last decade. Optical CrossLinks' technology has overcome the primary limitations of previous polymer devices and has demonstrated a broad range of applicability as shown in the above examples. Our waveguides are optically defined in the polymer without "wet chemistry", spin-coating, or embossing. This achieves a process suitable for high-volume manufacturing with low waveguide losses (unlike embossed waveguides). Environmental properties of the fully processed polymer represent a quantum leap in capability compared to other polymer materials. Demonstrated performance includes operational temperature ranges from -55^oC to $+150^oC$, hermiticity ($+85^oC$ at 85% relative humidity for > 500 hours), and IR solder reflow at 230^oC for 30 seconds. More details on the materials can be found in Ref. [3].

Waveguide formation by photopolymerization of the polymer can also generate grating structures throughout the core and cladding of the polymer waveguide. An example of a Bragg grating written in a single mode (6×6 μm core) is shown in Figure 4. This particular grating was written at a 45^o angle to the waveguide longitudinal axis to tap light out of the waveguide. Both reflection and transmission Bragg gratings can be written in the waveguides. Grating formation is a polymerization step yielding high $\Delta n \sim 0.1$ thus requiring shorter grating lengths for the same grating efficiency than those typically found in fiber Bragg gratings (FBGs) whose Δn is limited to 0.005. An order of magnitude reduction in grating length (from 1 *cm* to 1 *mm*) should be achievable by using polymer waveguide

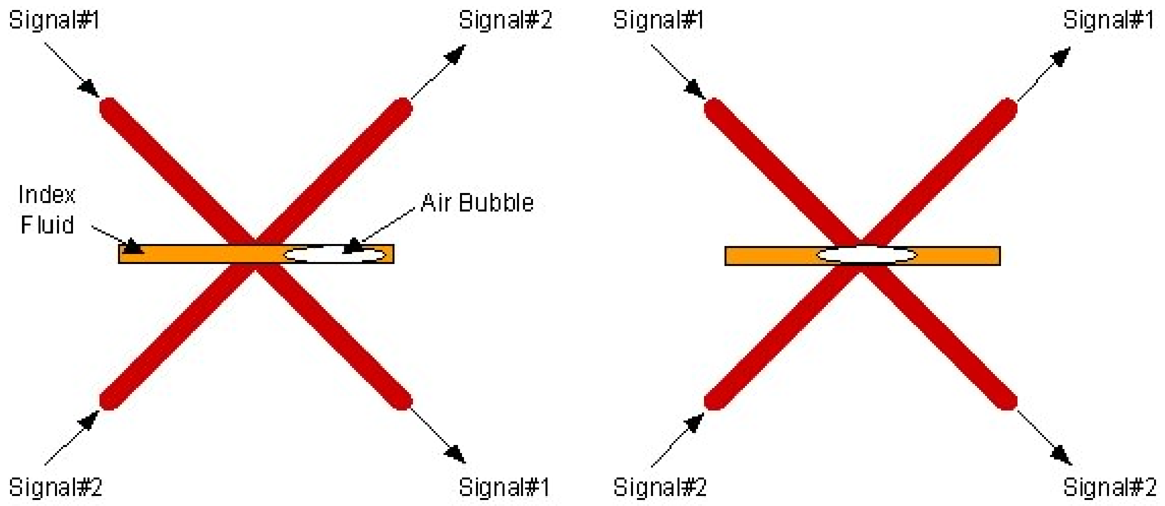

Fig. 2

Optical bubble switch operation. Switch state for 2×2 with (a) index fluid at the waveguide junction is "bar" and (b) air bubble at intersection is "cross".

gratings instead of glass waveguide gratings. Minimizing grating length without sacrificing efficiency increases the component density and minimizes waveguide loss (nominally 0.6-0.7 dB/cm at $\lambda = 1.55\ \mu m$).

Monolithically combining high-density polymer waveguide bubble switches with high-efficiency, very short polymer waveguide Bragg gratings enables production of compact switchable wavelength routers suitable for WDM cross-connect applications. Compatibility of the processes required for making the bubble switch and making Bragg gratings permits fabrication of the switch and grating in a single polymer layer.

References

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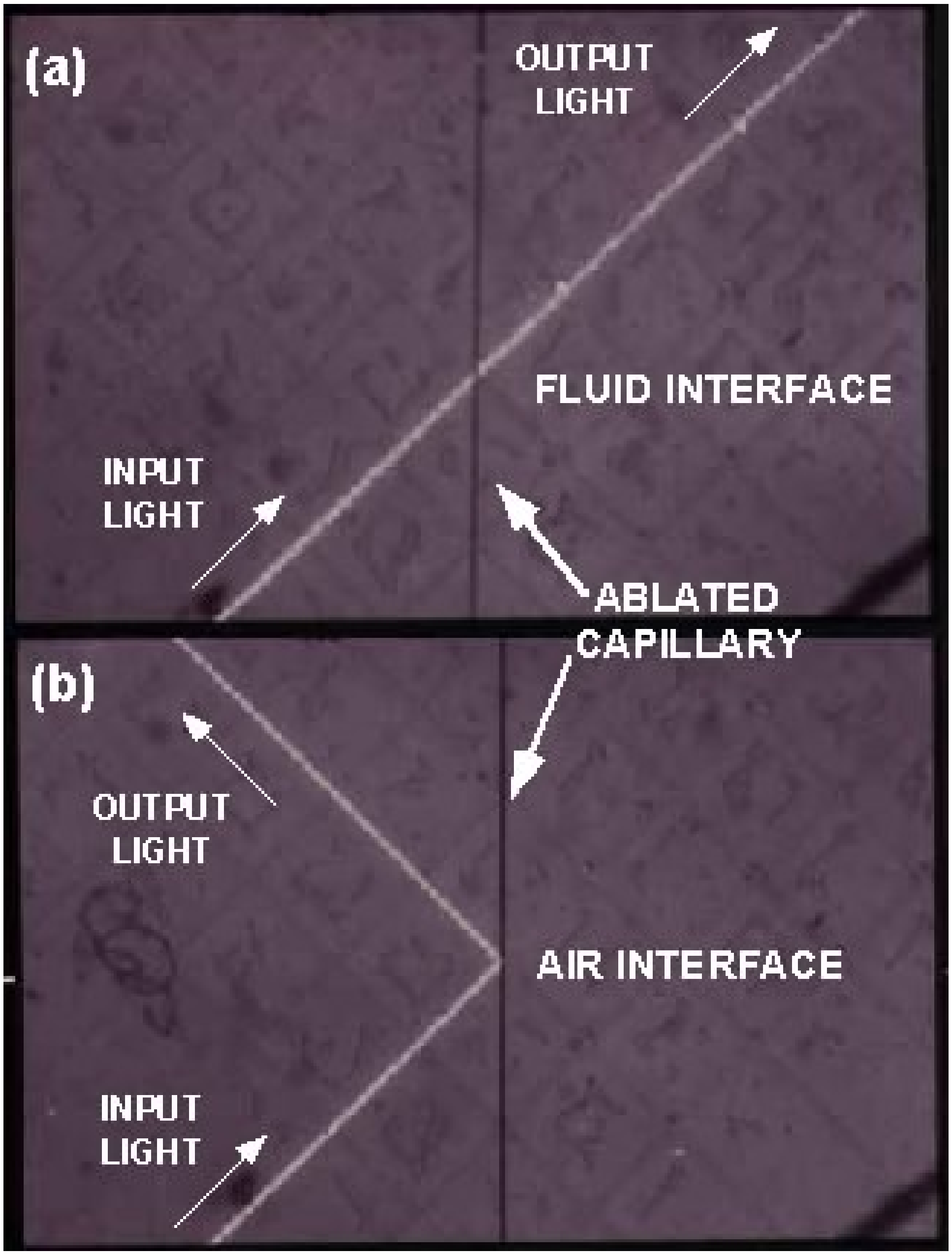

Fig. 3

Photographs of polymer bubble switch with (a) fluid-filled interface for "bar" state and (b) air-filled interface for "cross" state. Device shown is multimode and illuminated with HeNe light for better visibility in the photo.

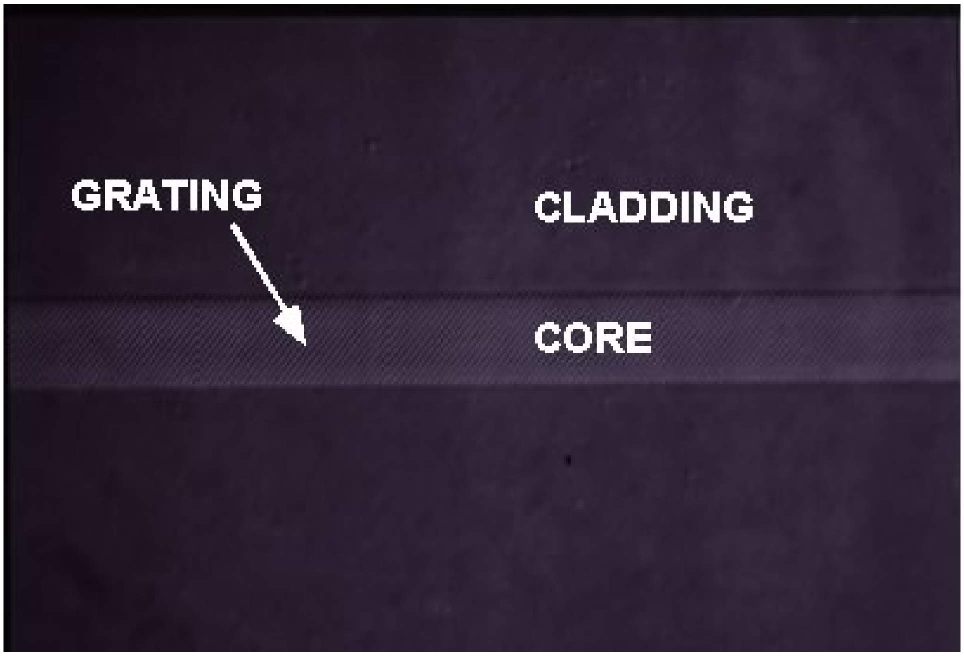

Fig. 4

A Bragg reflection grating written in a single-mode polymer waveguide at 45^o to the waveguide axis is shown. Gratings may be written on the waveguide surface or completely through the core and cladding materials.