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Polymer based resonant waveguide grating photonic filter with on-chip thermal tuning

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ABSTRACT

In this paper, we present the development of a multilayer polymer resonant waveguide grating (RWG)-based optical filter with an integrated microheater for on-chip thermal spectral tuning. RWG optical filter is fabricated using polymer-based materials. Therefore, its integration can be applied to different material platforms. Typical RWG structure is sensitive to back optical reflection from the structures below. To reduce the effect of back reflection from the metal heater and improve the quality of the integrated RWG filter output, an intermediate absorption layer was implemented utilizing an epoxy based carbon coating. This approach effectively suppresses the background noise in the RWG characteristics. The central wavelength of the reported filter was designed around 1550 nm. Experimentally, wavelength tuning of 21.96 nm was achieved for operating temperature range of 81 °C with approximately 150mW power consumption. Based on the layer-by-layer fabrication approach, the presented thermally tunable RWG filter on a chip has potential for use in low cost hybrid communication systems and spectral sensing applications.

1. Introduction

Tunable filters are indispensable components of optical communication systems [1,2]. In addition, integrated photonic filters have shown promise in diverse areas such as sensor technology, biology, imaging systems and manufacturing [3–6]. Optical filters having wide passbands of 40 nm have been utilized to detect volatile organic compounds at infrared (IR) frequencies [4]. On the other hand, tunable filters with very narrow passbands (0.33 nm) are suitable for applications in LIDAR measurements and astronomical observations [5]. Also, fluorescent filters with 0.5%–1% (3–5 nm) tunability have been employed to perform fluorescence imaging at visible wavelengths [6]. Different operating principles and mechanisms such as interferometric phenomena [7,8], optical mode coupling [9,10] and stimulated Brillouin scattering [11,12] have been utilized to realize optical filters. Wavelength tunability is achieved with the help of mechanical [13,14], thermal [15,16], acousto-optic [17,18], electro-optic [19,20], magneto-optic [21,22] and MEMS [23,24] based tuning schemes. The miniaturization of photonic integrated systems is hindered because best available photonic components are based on different material platforms and incompatible fabrication processes [25,26]. Polymers as a structural material for tunable integrated filters provide exciting opportunities due to their low cost, low processing temperatures, ease of fabrication and potential for hybrid integration [27–29]. Multiple polymer layers can be stacked to realize hybrid microsystems with increased functionalities, due to their excellent adhesion with different materials [30,31]. As the optical properties of polymers can be easily altered using thermal excitation, thermal tuning is widely accepted for polymer based tunable photonic filters. Thermally tunable polymer photonic filters based on Bragg reflectors and grating, Mach–Zehnder interferometers and Fabry–Perot structures have been demonstrated in literature [32–35]. Zhang et al. [32] demonstrated polymer embedded thermally tunable Bragg filters with wavelength tuning of 57 nm. To achieve the wavelength tunability the operating temperature of the filter was around 445 °C making it unsuitable for practical applications. Shin et al. [35] reported a polymer based tunable filter providing 10 nm wavelength tuning at communication wavelengths for applied heater power of 377 mW. Wang et al. [34] demonstrated a low power ring resonator based tunable filter which suffers from low wavelength tuning range of 0.11 nm and tuning efficiency of 8.2 pm/mW. The reported filter structures have their own advantages and disadvantages in terms of device footprint, thermal tuning and efficiency. Therefore, there is a need to develop low cost thermally tunable polymer optical filters operating at acceptable temperature ranges with reduced footprint, increased thermal sensitivity and efficiency.

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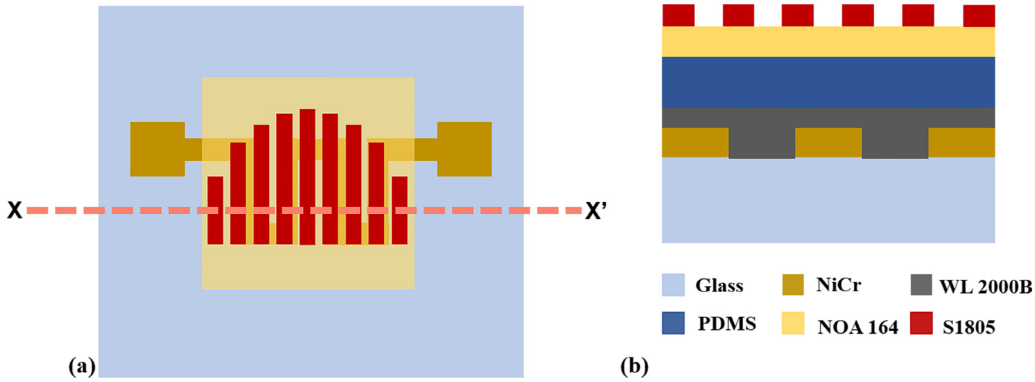

Fig. 1. Schematic of the integrated filter structure. (a) Top view. (b) 2D cross section view along the line XX'.

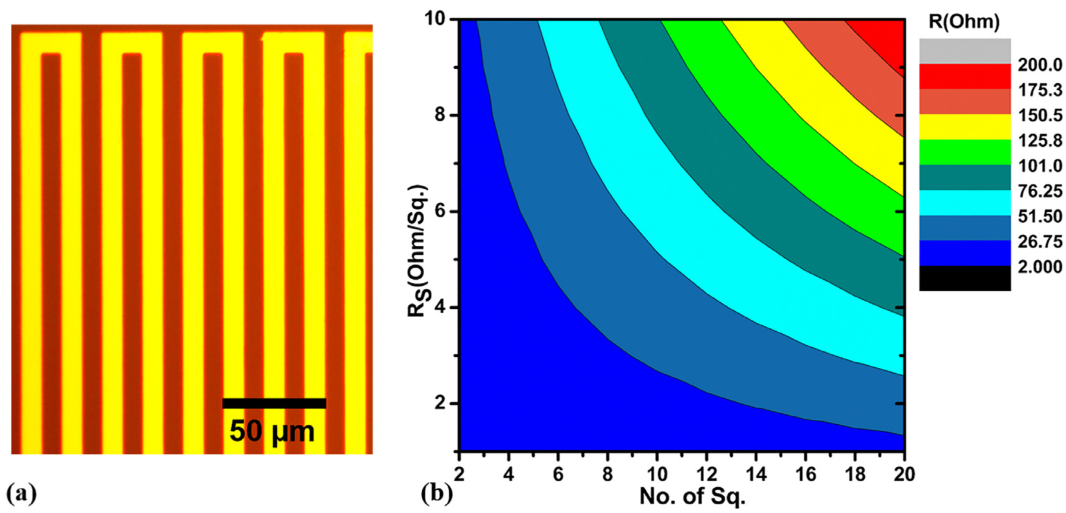

Fig. 2. (a) Optical micrograph of the fabricated meandered heater. (b) Variation of total heater resistance with sheet resistance (R_S) and number of squares (N).

Resonant waveguide grating filter structures have attracted considerable attention over conventional filter geometries due to their compact size, high reflection/transmission efficiencies, excellent control over frequency response and relative ease of fabrication [36–38]. Multiple polymer layers can be spun on top of a host substrate to fabricate these guided mode resonance based (GMR) periodic photonic structures [30,39]. Enemuo et al. [40] reported an all polymer based RWG device demonstrating high thermal sensitivity of the resonant peaks. The resonant wavelengths were tuned utilizing an external heater. The resonant peak shift was mainly contributed by the change in optical constants of the polymer waveguide layer. This work describes the development of a multilayer polymer RWG photonic filter with integrated microheater for on-chip thermal tuning. The central wavelength of this filter was designed around 1550 nm. 21.96 nm wavelength tuning was experimentally achieved for operating temperature range of 81 °C. To the best of our knowledge, this current device demonstrates the highest thermal sensitivity among all reported thermally tunable polymer based integrated photonic filters.

2. Fabrication and integration

Fig. 1(a–b) represents the schematic of the integrated filter structure. 1 mm thick glass slide was chosen as the substrate. First, meander shaped nichrome (NiCr 80/20) thin film microheater was fabricated on the substrate. The thin nature of the microheater allows layer-by-layer integration of the subsequent functional blocks. Subsequently, a multilayer polymer-based RWG structure was realized on top of the heater. The polymer based periodic grating acts as the wavelength selective component of the integrated filter. To reduce the effect of back reflection from the metal heater and improve the quality of the integrated filter output, an intermediate absorption layer was implemented utilizing an epoxy based wafer level coating. Every functional block and layer was designed and realized utilizing their preferred materials and fabrication protocols. The detailed fabrication and integration processes of different components of the integrated filter is described in the following subsections.

2.1. Implementation of microheater

2.1.1. Design

Thin film microheaters are widely used in the fields of chemical sensors [41,42], gas sensors [43,44], microthrusters [45] and tunable filters [34]. To develop high-valued, low power thin film based resistive microheaters, both structural material and the heater geometry should be optimized. Among the different materials used for fabricating microheaters, NiCr (80/20) is the most popular due to its high resistivity, low temperature coefficient of resistance (TCR) and high stability [46,47]. Meandered shape microheaters (Fig. 2(a)) provide more resistance compared to a bar resistor because the meandered geometry can be reconstructed using more square shaped elements for a constant linear dimension [48–50]. The total resistance of the microheater can be determined from the sheet resistance (R_S) of the deposited heater material and the number of effective squared elements (N) required to trace the resistor geometry [51]. Fig. 2(b) depicts the variation of total