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Spectral detection of graphene and graphene oxide with SU-8 based asymmetry tripled-Arm Mach Zehnder

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ABSTRACT

This paper reports the experimental application of the fabricated SU-8 based triple arm Mach-Zehnder interferometer (MZI) in the detection of graphene and graphene oxide. A standard MZI has two arms in its structure. In our design, we combine two MZIs with different dimensions together in a way that a short arm MZI replaces one longer arm of the larger MZI. The parallel connections of the two MZIs with a common arm would enhance the overall sensitivity of the sensor. The measurands graphene and graphene oxide with almost similar refractivity has been applied to sensing arms of the MZI in separate steps. The equidistance picometric spectral shifts corresponding to each measurands over the operating wavelength of 1550 nm are observed and is suitable for detection of graphene and graphene oxide.

1. Introduction

Optical lithography has shown great potentials for fabricating and patterning structures with micro/sub-micron dimension scale [1]. The UV exposure allows transferring the mask pattern to photosensitive chemicals (photoresist) such as SU-8. For Micro-Electro-Mechanical Systems (MEMS) and Micro-Opto-Electromechanical Systems (MOEMS), the UV-lithography of ultra-thick photoresist layer with high sidewall quality, high aspect ratio, and good dimensional control is very important [2]. To fabricate various high aspect ratio MEMS, such as electrostatic sensors, actuators and microfluidic channels, the ultra-thick photoresists can be used [3]. On of the most important sateg to obtain SU-8 microstructure is to remove the non-polymerized SU-8 [4]. To perform this stage, the microstructures are immersed in a container including the SU-8 developer. In micro fabrications, high surface area and increased fluid throughput caused by the deep and wide micro-channels.

The SU-8 has the refractive index (RI) of n = 1.668 at λ = 365 nm and n = 1.650 at λ = 405 nm [5]. The supplier's recommended UV dose is typically suitable for fabricating sparse high aspect ratio SU-8 microstructures. The SU-8 can be lithographed in several thickness with very high aspect ratios due to its low optical absorption in the range near-UV. If the reflection between the substrate surface and the SU-8 is significant, under partial exposure, the thickness after development of SU-8 structures will be affected and altered [6]. The mask and the photoresist surface could be brought into perfect contact without any gap in an ideal contact exposure. The edge bead which resulted from the spin coating, leads to an air gap

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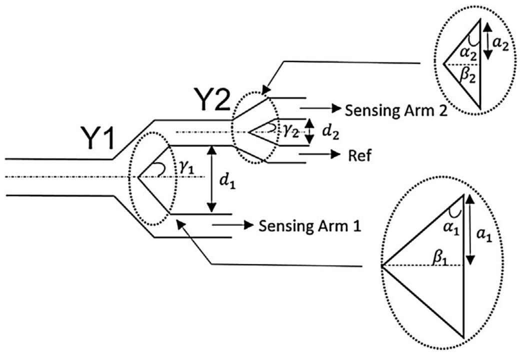

Fig. 1. Schematic of triple arm MZI with different path lengths and arm angles.

between the SU-8 coating on the wafer and the mask and intensifies the stray light beneath the dark-fields [3]. Air gaps of 10–100 μm are very common for thick resist [7].

The miniaturized size, low cost and integration ability make graphene-based sensors more suitable for future micro/nano-scale sensing systems. Its low fabrication cost, simple configuration and high sensitivity make this sensor have potential applications in chemical and biological sensing. The sensor also shows strong stability and good reversibility, and may be potentially used in temperature sensing applications. In another embodiment, separate tunable lasers are used for the sensor and reference interferometers. Graphene materials and their composites offer an attractive way to fabricate sensor devices in different waveguide materials and structures. Highly sophisticated techniques are required for the fabrication of ultrathin graphene layers.

The Mach-Zehnder Interferometer (MZI) can be used in many applications in photonics sensing and modulators [8,9]. The principle working of the Mach-Zehnder modulator is presented in many research works, where splitting the incoming optical wave occurs, which are then fed into two arms of the device. The phase of the optical wave will be controlled and manupulated in each arm [10,11]. At the output port, therefore two optical signals can be combined, and if the relative phase between the two arms is 0^0, constructive interference will occur, where the output intensity will be the same as original input. If the relative phase is 180^0, destructive interference will occur and the output shows very low power [12]. The MZI sensors have attracted many rsearchers in the sensing applications [13,14]. If the optical waveguide is used as MZI sensor, it should be fabricated in single-mode [15]. In the multi-mode optical waveguides, the optical power will be devided between the generated modes, where each mode will be interacting with the variations of the outer medium [16]. Compared to surface plasmon resonance (SPR) based sensors, the MZIs are more sensitive in practice [17].

In this work, a single mode tripled-arm MZI is fabricated by combining two MZIs with different dimensions together in a way that a smaller MZI replaces one arm of the larger MZI. One of the arms is used as reference arm and the second arm as sensing arm. The region for sensing arm is in contact with the graphene nano particles and the graphene oxide flakes. The results show the sensing by shifting the wavelength with respect to the reference wavelength.

2. Theory and principle operation of triple arm MZI

A triple-arm waveguide MZI fabricated from SU-8 polymer is used to study the three-beam interference as a result of the amplitude splitting of incoming wave flows on each arm. The MZI structure as shown in Fig. 1 consists of two splitters (the left Y_1 and Y_2 junctions) and two beam combiners (the right Y_1 and Y_2 junctions). Also, the straight waveguide structure has been selected as the interface mediums between splitters and combiners of triple-arm MZI. Here, the three waves travel along three distances in which two of them are equivalent and the remaining one is longer than the two others. The branching angles of Y_1 and Y_2 are different, resulting in a non-zero path length differences between the arms. The branching angles of Y_1 and Y_2 are shown as γ_1 and γ_2 in Fig. 1.

The spacing d_1 and d_2 in the triple-arm MZI can be calculated through the following expressions [18]:

$$\frac{d_1}{2} = a_1 = \beta_1 Cot\left(\alpha_1\right) = \beta_1 Cot\left(\frac{\pi}{2} - \gamma_1\right) \tag{1}$$

$$\frac{d_2}{2} = a_2 = \beta_2 Cot\left(\alpha_2\right) = \beta_2 Cot\left(\frac{\pi}{2} - \gamma_2\right) \tag{2}$$

Interaction of monochromatic optical waves propagating in the sensing arms (i.e. Sample 1 or 2 in Fig. 2) which is in direct contact with the measurands (i.e. graphene or graphene oxide) alters the output behavior of the waves as a phase shift of $\Delta\phi$ is introduced and results in different interference characteristics with the optical waves from the Ref arm as it is shown in Fig. 2 The amount of wavelength shifts after recombination at the combining junctions are remarkably under the influence of the length and the effective index of the Ref arm and sensing arms.