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Parametric Design Study of Monolayer Graphene based TeO_2 Waveguide Saturable Absorber

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ABSTRACT

2D materials, led by graphene, have been widely explored in the last decade as saturable absorber (SA) materials. Most of this work has focussed on fibre compatible designs for use in fibre lasers (e.g. fibre connector sandwich, D-shaped fibre). Realising chip based mode locked lasers is an important challenge, and little work has been carried out on planar waveguide SAs. Here, simulation results for the absorption performance of two types of graphene based TeO2 waveguide SA designs with suitably high absorption and low saturation threshold are presented.

Keywords: Integrated optics, saturable absorber, graphene, TeO_2 waveguide

1. INTRODUCTION

Although several mature and well-understood passive mode-locking techniques are utilised for simple mode locked laser (MLL) construction today, the most significant technical barrier for realizing the fully integrated MLL is still how to implement those methods in an integrated form. Graphene, the representative of 2D materials which has many unique optical properties, makes the on-chip saturable absorber (SA) possible. So far, several graphene based Si and Si_3N_4 waveguide SAs have been demonstrated [1-2]. However, some key areas of performance (e.g. modulation depth) are unclear, which might be caused by high insertion loss (e.g. 17.2 dB for the Si_3N_4 waveguide without graphene [2]). These waveguides are not suitable for real applications due to their air upper cladding design. In this work, two types of monolayer graphene based waveguide SA designs are proposed. Both have been simulated with Rsoft FEMSim and Labview and are designed on a TeO_2 waveguide platform with SiO_2 as upper cladding. TeO_2 is used because it offers low loss at 1550 nm (~0.1 dB/cm [3]).

2. GRAPHENE BASED SA DESIGN AND SIMULATION

The first approach is graphene coated on the TeO_2 waveguide, (Fig. 1(a)), which has the graphene transferred on top of the waveguide after the waveguide etching process is completed. Such a transfer has already been demonstrated as shown in Fig. 1(c) [4]. The second option (Fig. 1(b)) is to transfer the graphene to a TeO_2 film that is half the final core thickness before depositing the remaining core thickness and patterning the waveguide core. This has the benefit that the graphene transfer is much simpler to do and more reliable, but at the expense of an increased number of fabrication steps.

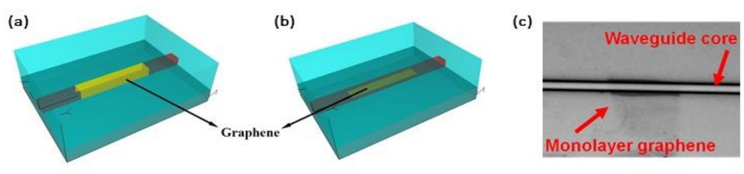

Figure 1. (a) graphene coated; (b) graphene-sandwiched TeO_2 SA, (c) optical microscope of the graphene coated TeO_2 SA.

Figure 2 shows the graphene linear absorption loss for the fundamental TE and TM mode, which varies the TeO_2 waveguide's thickness from 0.2 to 0.9 μm and width from 1 to 5 μm. This image shows that the TE mode is maximised in the smaller thickness region, its maximum absorption is about 0.5 dB/μm with a thickness and width of 0.2 μm and 4.5 μm respectively. At all widths and thicknesses, the TE mode absorption is stronger than the TM mode, which reaches a maximum absorption of 0.24 dB/μm in the simulation region, about half the maximum TE value. Similar results for peak power intensity can be found from Fig. 2 (c) and (d), with 10 W assumed light mode power, the maximum peak

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intensity for TE and TM mode are around 0.95 GW/cm^2 and 0.56 GW/cm^2 respectively. Hence, it is favourable to build the SA at TE mode since it shows better performance with a wide waveguide and thereby reducing the propagation loss.

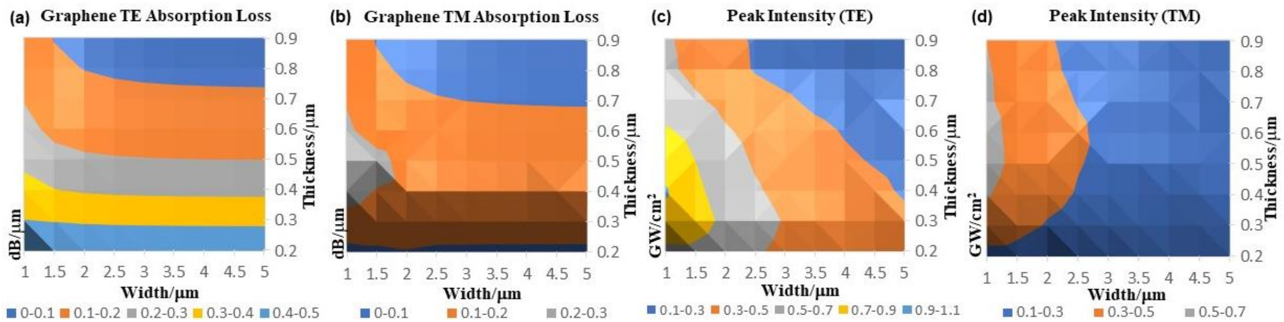

Figure 2. linear absorption loss and peak power intensity for graphene coated TeO_2 waveguide: (a) and (c) are TE mode; (b) and (d) are TM mode. The mode power is assumed 10 W here.

In terms of the graphene-sandwiched TeO_2 SA design (Fig. 1(b)), its in-plane electric field components of the TE mode reach a maximum at the waveguide centre, resulting in strong optical absorption. In contrast, the TM mode becomes transparent. The calculated maximum graphene linear absorption for TE and TM are 0.65 dB/μm and 0.11 dB/μm within the waveguide dimension region of thickness from 0.2 to 0.9 μm and width from 0.5 to 3 μm. As shown in Fig. 3, it is noticeable that the maximum fundamental TE mode peak intensity at graphene can be effectively increased to 1.3 GW/cm^2 for 10 W peak, which should easily saturate the graphene based on previous reports [5].

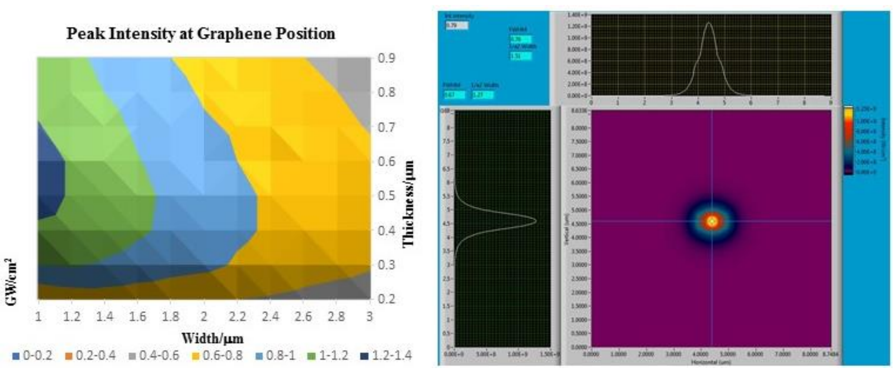

Figure 3. Peak intensity at graphene position of the graphene sandwiched TeO_2 nanowire for TE mode

3. CONCLUSION

We have described promising performance for the graphene-based SA design, and the graphene transfer to waveguide has already been achieved. Real SA devices fabrication and testing is currently underway.

4. ACKNOWLEDGEMENTS

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