DESIGN AND FABRICATION OF INP FREE-STANDING OPTICAL WAVEGUIDES FOR MEMS

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ABSTRACT

We present the design and fabrication of an optical MEMS device on InP platform. The device is based on a suspended parallel waveguide configuration with side pillars supports. Electrodes are integrated on the device layer to provide MEMS actuation functionality to the waveguides. The device is designed to be used as an optical buffer for telecommunication applications.

INTRODUCTION

It has been reported recently that a continuously tunable optical buffer can be realized using two actuated waveguides [1]; theoretical calculations were based on using silicon as the active material. In this paper, we report the design and fabrication of such a device on an InP platform. III-V materials such as InP and GaAs have several major advantages over silicon based materials. In terms of optical properties, optical gain can be achieved in III-V materials, due to the direct nature of their bandgap. From a technological point of view, lasers and other optical components for optical communications are well established in the InP platform [2], and hence our device can be monolithically integrated into the same circuit.

WAVEGUIDE DESIGN

The design for an optical buffer [1] requires two free-standing optical waveguides with an optimal size of ~200nm×300nm. By MEMS actuation the separation between the waveguides can be changed continuously between 50nm and 500nm leading to up to 100% change of the pulse propagation delay time.

In order to achieve substantial delay times, a long device is required, e.g., 1mm length for a 10ps delay. Minimizing propagation losses is therefore of paramount importance and various loss mechanisms need to be considered. First, surface roughness as determined by the fabrication procedure leads to light scattering and losses of typically 1dB/cm. To minimize these losses we consider a TE (y-polarization in Figure 1) rather than a TM (x-polarization) mode for operation, as this mode has weaker electric fields at the side walls.

For the envisaged buffer functionality, a significant fraction of light must be propagating in the air around the waveguides, which may lead to leakage of power into any nearby material. Numerical simulations suggest that to keep these losses below 1dB/cm the waveguides should be suspended ~3μm above the substrate and ~4μm away from any side walls.

The pillar supports required for the suspension of the waveguides will also introduce additional scattering and leakage of light. The waveguides are therefore designed with S-shaped tapers at the pillar connections as shown in Figure 1, confining the light more strongly inside the tapers and thus reducing losses at the pillar connection. A loss of ~0.2dB per pillar is calculated for tapers of 600nm thickness and 7-8μm length, while a loss >1dB is expected without tapers. S-shaped sections are designed on both waveguides at each pillar attachment point to ensure symmetrical optical modes propagating.

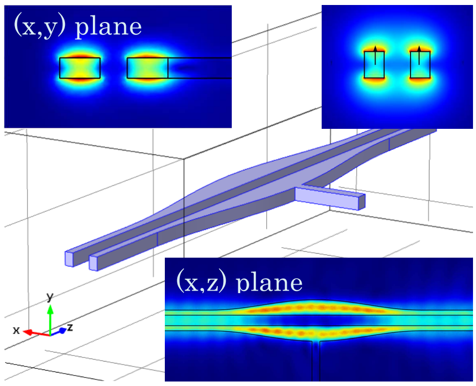

Figure 1. Geometry of suspended waveguides with S-shaped tapers at the pillar connection. Insets: electric field profile of TE mode in the waveguides (right) and in the S-shaped taper (left).

FABRICATION

The sample was grown on an n-type InP substrate by Molecular Beam Epitaxy (MBE). The device layer consisted of a 300nm layer of InP. A 3μm layer of $In_{0.57}Ga_{0.43}As$ was sandwiched between the device layer and the substrate. This served as a sacrificial layer, etching of which allowed the waveguide structures written into the InP layer to be released. The sample structure is shown in Figure 2.

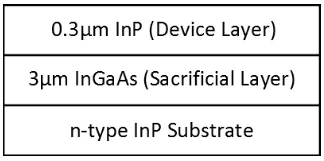

Figure 2. Layer structure of the InP MEMS waveguides.

The device was fabricated on a 1cm by 1cm InP chip. Following deposition of the $In_{0.57}Ga_{0.43}As$ sacrificial layer, the waveguides, supporting side pillars and electrode pads were all fabricated on the same InP device layer.

The patterning of the gold electrode pads was done by using electron beam lithography (Raith150-TWO). The gold electrodes were deposited by thermal evaporation and lift-off in acetone.

The patterning of the parallel waveguides was carried out using hydrogen silsesquioxane (HSQ) electron beam resist as a negative mask. The dimensions of the written waveguides were 250nm in width and 200µm in length. The spacing between the waveguides was approximately 300nm. Pillars were patterned in the same step as the waveguides. The spacing between pillar supports was 40µm, and each pillar was composed of two parts: an S-shaped area that attached to the waveguide and a rectangular section that linked the S-shaped area to the large contact pad. The length of the S-shaped area was approximately 5µm and the width was 500nm. The length of the rectangular section was 3µm. Pillar positions on the waveguides were staggered to allow the waveguides to be pulled apart by the applied field. A section of the pattern is shown in Figure 3.

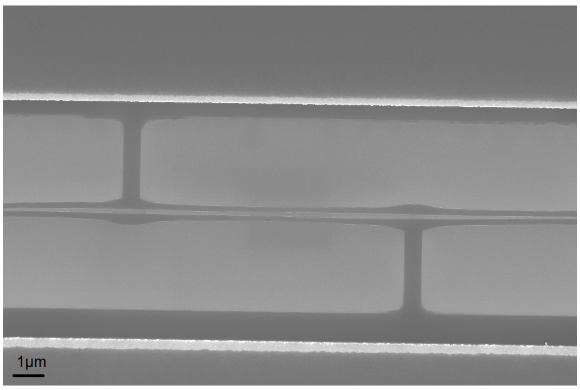

Figure 3. Top view of the waveguide and pillar pattern.

After the waveguides and pillars were patterned, the device layer was etched by reactive ion etching (RIE) with a cyclic methane-hydrogen/oxygen plasma. The resulting etched structure has a sidewall profile better than 80 degrees. The waveguides were released using $HF:H_2O_2:H_2O$ (1:1:8) solution. This step etches away the $In_{0.57}Ga_{0.43}As$ layer with the mask cleanly, without leaving any remnant on the waveguide surfaces.

RESULTS

Figure 4 shows an SEM image of the released waveguide structure. The dimensions of each waveguide were approximately 300nm (height) x 200nm (width) x 200µm (length). The gap between the waveguides was approximately 400nm. The free standing waveguides did not collapse after release.

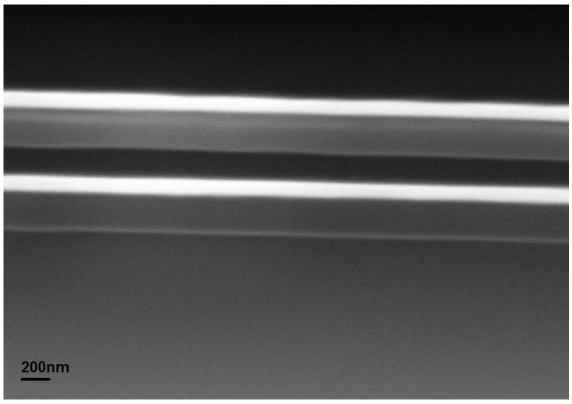

Figure 4. Free-standing waveguides after HF etch.

CONCLUSION

We have demonstrated the design and fabrication of suspended waveguides on an InP platform with MEMS functionality. Current and future work will focus on optimizing the fabrication steps to match closely the designed dimensions, and demonstrate full functionality as a tunable optical buffer.

This work was supported by the EPSRC "Continuously tunable optical buffer" project (EP/J012823/1 and EP/J012874/1).

REFERENCES

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