Wet thermal oxidation technique for current guiding in membrane lasers

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Electrically pumped membrane lasers have great promise for compact, high-contrast, photonic integrated circuits. To reduce the threshold current of such lasers, it is important to avoid current spreading. Here a method is described to achieve this. An InAlAs-layer, lattice-matched to InP, is grown as part of the membrane. During the processing of the membrane laser wet thermal oxidation is partially performed on this layer. This oxide blocks the current and forces it through the adjacent layers towards the active region where the mode is present. The oxidation parameters are investigated and good control of the oxidation depth is demonstrated.

Introduction

InP membrane on Silicon (IMOS) generic technology can pave the way for reduced footprint and low-cost photonic integrated circuits [1]. Compact passive components with good performances have already been reported on this platform. The next step in its development is to design and fabricate active components, starting with an electrically pumped laser. A mesa structure etched in a typical layer stack to achieve this is shown in Fig.1. Feasibility for the operation of an active component on such a stack is studied in [2] and the design of laser circuits is reported in [3]. For carrier and mode confinement, the stack includes a layer of InAlAs. This layer can be selectively oxidized into an electrically isolating dielectric with a lower index [4].

As part of the fabrication flow for the laser circuit, one of the steps involves lateral oxidation of InAlAs to a certain depth. This oxidation depth has to be well-defined in order to optimize the electrical and optical waveguiding properties of the membrane laser. To have a good control over the depth, time dependence and uniformity studies are carried out. The oxidation setup used, the methodology and the tests performed are described in the next section. The results and discussion section presents the oxidation rate and uniformity of oxidation depth in a single run and reproducibility over different runs. Furthermore, possible explanations for the observed behaviour are also discussed.

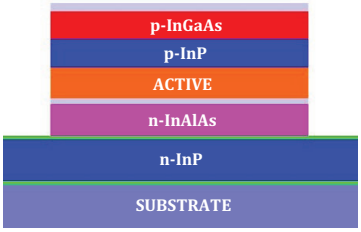

Fig.1: Mesa structure for active component fabrication.

Oxidation setup and methodology

Oxidation setup

The oxidation setup used is shown in Fig.2. It consists of a furnace with three internal zones, with the outer two controlling the temperature in the central zone. A quartz tube running through the length of the furnace acts as the chamber where oxidation takes place. One end of this tube is connected to a water bubbler where water is heated to 98°C. Nitrogen gas is constantly fed through it and carries the water vapour to the sample in the chamber. The other end of the quartz tube is used to load the sample that needs to be oxidized. This end of the tube also has an exhaust for the gas flow.

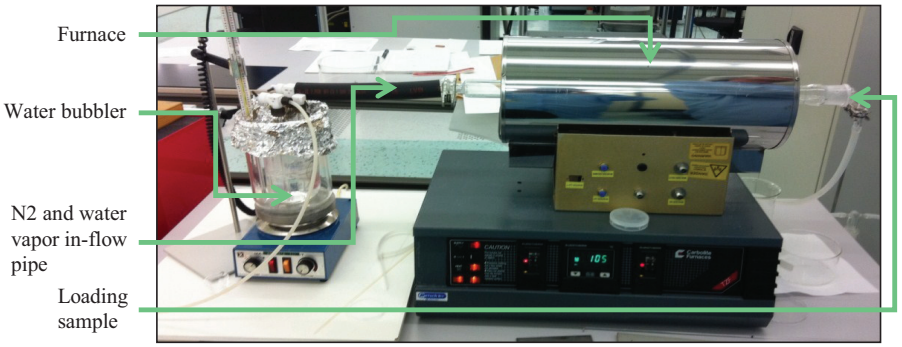

Fig.2: Experimental setup for oxidation process.

Calibration and testing

Based on temperature calibration measurements of the furnace the region with the lowest temperature gradient is determined. This region is chosen for placing the sample during oxidation. To find the time dependence of oxidation depth, prepared samples with etched mesas are placed in the furnace for various time periods. Afterwards, by cleaving through the mesas, the depth of oxidation is measured in the SEM. A cross-section image can be seen in Fig.3. To check for uniformity over the sample, SEM inspection is performed at multiple positions of the cleaved sample. For uniformity inspection over a single mesa, high voltage SEM images are made from the top. Finally, to check for reproducibility of the process, it is repeated on different samples.

Results and discussion

A plot of the oxidation depth with time at T=500°C is shown in Fig.4. As can be seen, the time dependence is linear and has a rate ~ 50 nm/min. A possible reason for such linear dependence is discussed below.

The variation in the oxidation depth of the sample is measured at various positions for T=500°C, time = 33 min and is shown in Fig.5. The oxidation depth has a mean value of 1.52 µm with a standard deviation of 61 nm. As can be seen in Fig.6, an image from the top of a mesa shows that the interface between the oxide (dark periphery) and the semiconductor (bright centre) is smooth along the length and symmetric on both sides of the mesa.

From literature the dependence of the lateral oxidation depth on the time is expected to follow a square-root law [5], as is the case in a diffusion-limited process. However, the observation of a linear dependence indicates that the reaction occurs in the kinetic

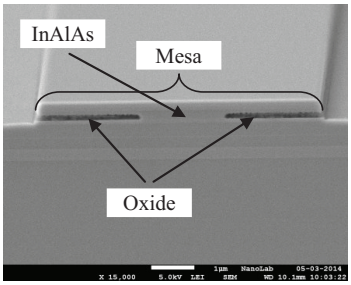

Fig.3: Cross-section image of a partially oxidized lateral mesa

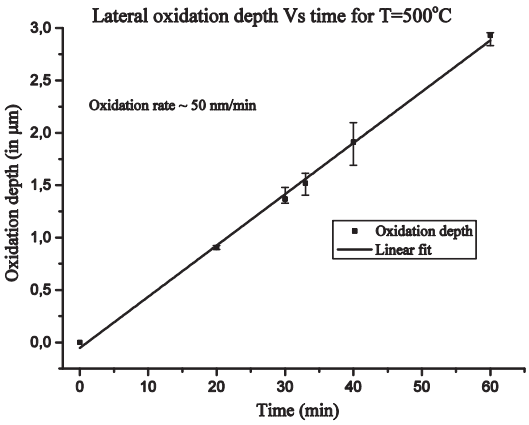

Fig.4: Plot of oxidation depth with time for a furnace temperature of 500°C.

regime. This can be explained as follows. It can be found in literature that the interface between the oxide and the semiconductor is weak due to high stress load that is developed during oxidation [6]. This leads to the formation of micro-pores in the oxide. These pores, in turn, allow the reactants to easily flow to the oxidation front, bypassing the need for the reactants to diffuse through the already formed oxide. Hence the oxidation rate is limited by the reaction rate.

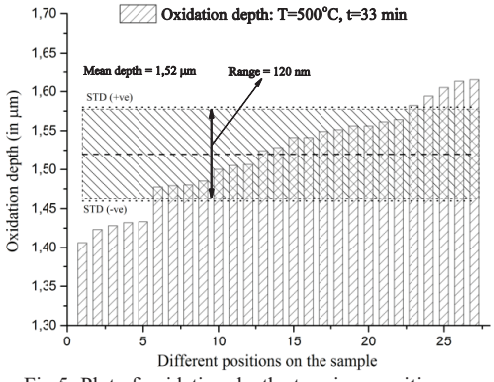

Fig.5: Plot of oxidation depth at various positions on the sample.

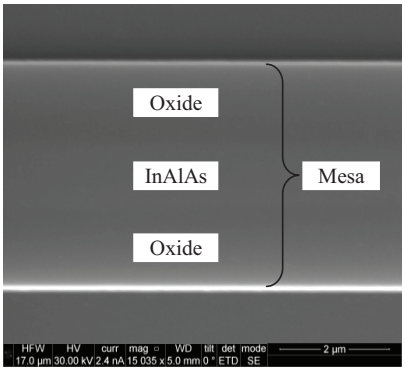

Fig.6: High voltage SEM image from top of a mesa showing uniform oxidation.

Conclusions

An oxidation setup is calibrated and optimized for lateral oxidation of InAlAs. The oxidation rate for the process is determined to be ~ 50 nm/min. A maximum variation of less than 200 nm for a given run with a standard deviation ~ 60 nm over the entire sample is observed. Uniform oxidation depth over the entire sample in a single run and reproducibility over different runs is achieved. The interface between the oxide and the semiconductor appears smooth along the length and symmetric on both sides of the mesa.

Acknowledgements

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