Si_3N_4 / SiO_2 Passivation Layer on InP for Optimization of the 1.55 μm MQW FP laser Performance

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Abstract—**The importance of the passivation in semiconductor surfaces as chemical passivation, electrical passivation and leakage current blockage is studied. Simulation of the multiple quantum well Fabry-Perot laser diode with passivation layer is done by making the assumption that the passivation interface has an ideal surface condition. The simulation model included the heat flow condition in the passivation interface. The simulation results are in good agreement with experiment. Threshold current as low as 21mA is achieved with 1.8um Si_3N_4 passivation layer. It is found that Si_3N_4 passivation layer improve the laser diode performance compare to SiO_2 passivation. Thicker passivation help in prevention of the leakage current.**

I. INTRODUCTION

Passivation layer on semiconductor devices has become one of the important issues in semiconductors device fabrication. Passivation of the semiconductor surfaces in a device is often used to prevent the surface (surface states) from adversely affecting the device performance and to eliminate interfacial states from the bandgap and prevent their formation (Electrical passivation) [1]. In high speed semiconductor laser such as high electron mobility tansistor (HEMT), field effect transistor (FET) and semiconductor laser, passivation layer is used for electrical passivating and prevent leakage current by forming an adequate barrier. 2 methods can be applied on passivation of III–V semiconductor surfaces. The 1st method is deposition of relatively thick ~thickness ranging from several tens of nanometers to several microns insulator layers. In this process, a semiconductor–insulator heterojunction, where the properties depend largely on the density of states at the interface, which in turn depends on the method used to produce this heterojunction and to prepare the semiconductor surface, is formed [2–3]. The second method is modification of the atomic structure of the surface by foreign atoms which changes the electronic structure of the semiconductor surface. The modification of the atomic structure passivation found not just act as a passivation but also improvement of optical and electrical properties of compound semiconductors by chemical treatments [4]. Although many publications on the fabrication of the passivation were done but the simulation semiconductor laser included the passivation effect is difficult to obtain. This is due to the nonlinearity effect of the surface recombination between the dielectric and material. It is difficult to model the surface recombination and carrier diffusion which is highly dependent on fabrication condition. In this paper, simulation of passivation on 1.5 μm multi-quantum well (MQW) Fabry-Perot (FP) laser structure with silicon nitride (Si_3N_4) and also silicon oxide (SiO_2) with a different thickness is presented. The passivation layer is act as an electrical passivation, prevention of leakage current and enhancement of the optical properties. The simulation results are well agreed with the experiment data. The results show that Si_3N_4 with a thick thickness is most suitable to use as a passivation layer compared to SiO_2 .

II. STRUCTURE DESIGN

The laser structure consist of n-InP substrate followed by a 100 nm u-InGaAsP layer, seven periods of strain-compensated InGaAsP/InGaAsP multiple quantum wells (MQWs), a 100 nm u-InGaAsP layer, and a 100 nm p-InP spacer layer were grown as shown in fig 1. The width of the single ridge waveguide laser is 2 μm and the length of the laser is 600 μm. SiO_2 or Si_3N_4 were used as an isolation layer for current injection to provide enough leakage current blocking. In this simulation different thickness of SiO_2 or Si_3N_4 is studied.

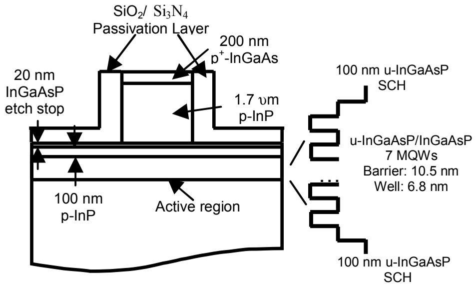

Fig 1. Passivated 1.55 μm MQW FP laser structures used in simulation.

III. SIMULATION MODEL

The theoretical model of laser diode in PICS3D has included varies model of optical, electrical and thermal properties. The detail theoretical models such as temperatures effect, spatial hole burning and optical confinement are also considered by simple analytical formulations. [5]. Carrier transport is simulated using the drift-diffusion model [5]. The heat flux equation is included to address self-heating effects. Poole-Frenkel effect is incorporate in the simulation where the effect describes the field dependent thermionic emission from traps in the bulk insulator [5] is taken into account. This included the heating effect on between the contact and passivation layer [6].

The enhanced effective index method is employed for optical simulation including temperature effects on layer thickness, absorption, and refractive index. In the heating effect simulation model, an artificial layer of lightly doped of the dielectric is needed in the passivation layer for simulation to converge. The heat conductivity value of Si_3N_4 is set to be lower compare to SiO_2.

IV. RESULTS AND DISCUSSION

Figure 2 shows the typical simulation and fabrication LI characteristic of laser diode using 2 different thickness of SiO_2 or Si_3N_4. The results show that the simulation data have a good agreement with the experiment data. Si_3N_4 passivation (21mA, 24mA) has lower threshold current compared to SiO_2 passivation (27mA, 29mA) for passivation thickness of 0.3 μm and 1.8 μm respectively .

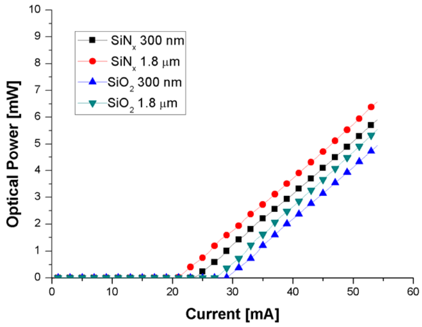

Fig 2a. Simulation result of passivated 1.55 μm MQW FP laser structures.

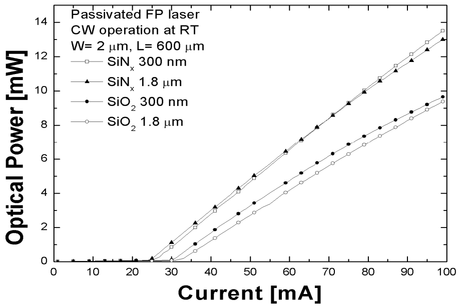

Fig 2b. Experimental result of passivated 1.55 μm MQW FP laser structures.

There are 2 effects that contribute to the deduction of the threshold current in the Si_3N_4 passivation. First it is the due to the increase of the dielectric potential barrier potential layer where the leakage current is minimized. The current flow at the passivation interface can be express in the following equation [5,9]:

$$J_n = u_n\left\{-n\nabla\left[\psi + X + \gamma_n\right] + \frac{2}{3}\nabla(n\omega) - n\omega\nabla\ln(m_n)\right\} \qquad (1)$$

where X , u_n , m_n , γ_n ,and ψ are defined as electron affinities of the semiconductor, electron mobility, electron mass, simulation constant for the Fermi direct statistics and potential dielectric barrier respectively. The electron energy is defined as ω . Si_3N_4 have a higher ψ then SiO_2 due to the higher refractive index and lower heat conductivity [7,9] where increase the potential barrier and prevent leakage current. The effect of the dielectric potential barrier which prevents leakage current is presented in Fig 3. Second effect that contributes lower threshold current is due to the higher optical dielectric index of the Si_3N_4 which produce a better optical confinement [8]. The result also shows that the thicker the passivation layer the lower the threshold current. This is due to the thick passivation is proportional to dielectric constant that provided higher potential barrier which prevents leakage current. This characteristic is well explained in the published paper [2-4]. Even, the effect of passivation region has successfully modelled in to the MQW FP laser but there are some limitations. The assumption of having an ideal surface condition where explain to the different in threshold current of the simulation data compare to the experimental data.

V. CONCLUSIONS

The model of 1.55um MQW FP laser with a passivation layer is successfully simulated and it shows a well agreement with the experimental data. The model is assumed having a ideal passivation interface. The results show that a better performance FP laser can be achieved by using Si_3N_4 compared to SiO_2. Thicker passivation layer also help improvement the performance. Threshold current as low as 21mA was obtained with 1.8 μm Si_3N_4 passivation layer.

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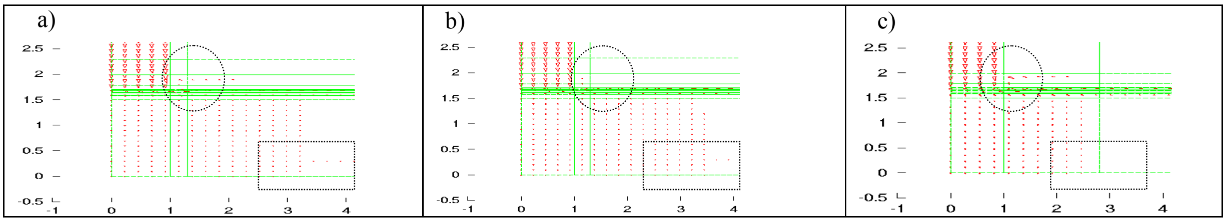

Figure 3.Leakage Current Prevention of MQW FP laser with different passivation layer a)$SiO_2$0.3 μm b) Si_3N_4 0.3 μm c) $SiO_2$1.8 μm.