Sub-micrometer active-passive integration for InP-based membranes on silicon

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The high vertical index contrast and the small thickness of InP-based membrane structures bonded with BCB on Silicon allow the realization of very small devices. Since photonic integrated circuits consist of both passive and active components, a successful active-passive integration with sub-micrometer active regions is an essential step. In this paper we will present our results on active-passive integration with sub-micrometer active areas. The interference of active and passive area shows a good quality in terms of morphology. Moreover we find that in the sub-micrometer size active area, the degradation of the material(InGaAsP QWs) due to clean room processing is limited.

Introduction

The complexity of photonic integrated circuits (PICs)has been raised significantly these last few years, following Moore's law in Photonics[1]. But to satisfy the need for even further complexity, devices and waveguides have to be made smaller and less power consuming. This is especially so for using PIC in combination with Silicon and CMOS chips.

One of the solutions to this is to use membranes, so that the waveguide layer has a high vertical index contrast. Suspended membranes[2] for example, have the highest vertical index contrast, as they are surrounded with air. However this solution is hard to handle for a complete PIC. For quite a few years, work has been reported on bonded membranes, such as Silicon On Insulator (SOI)[3]. Silicon is an ideal candidate for passive devices, but intrinsically and unfortunately, this material has an indirect band gap which means that it is difficult to realize "active functions" such as light emission and amplification on SOI platform. This becomes the major disadvantage of SOI platforms[4].

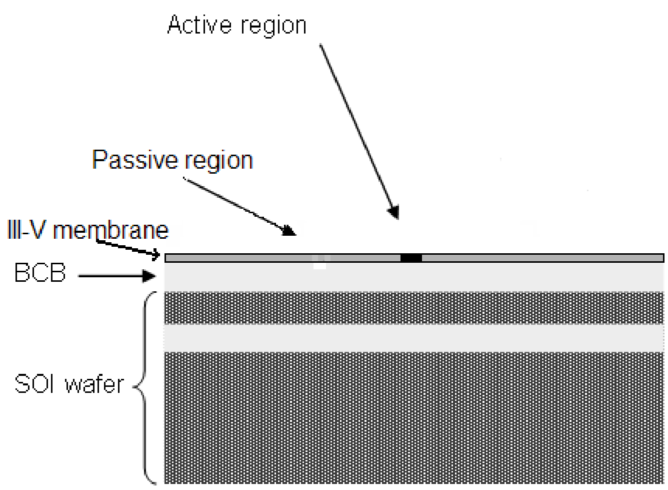


Figure.1 The layer stack of the membrane platform

However, III-V semiconductors have a direct band gap and can handle both passive and active functionalities. Therefore it is natural to think that by combining III-V and SOI platforms and meanwhile introducing membranes, we can have a triple-win solution that leads to the birth of a new PIC platform: InP-based Membranes on Silicon. The advantages of this platform are apparent. First of all, we have the main advantages of a membrane structure which are high vertical refractive index contrast and low power consumption because of the ultra small thickness. Secondly, both passive and active functions can be realised in this platform. Last but not the least, the platform is compatible with SOI and CMOS platforms which make it possible to use the mature and advanced CMOS Fab technology.

In this paper we show below the results of the integration of sub-micron sized active regions (multiple quantum wells) and passive material in a quaternary system(InGaAsP). This is a first step towards PIC on silicon compatible membranes.

Active-passive integration

Fabrication procedure

As it is shown in Figure 2, the starting point is a 200nm quaternary layer with embedded quantum wells, on an InP substrate. The membrane is etched away, except for the places where an active medium is required. Then a regrowth of passive material leads to a passive quaternary layer with local active medium.

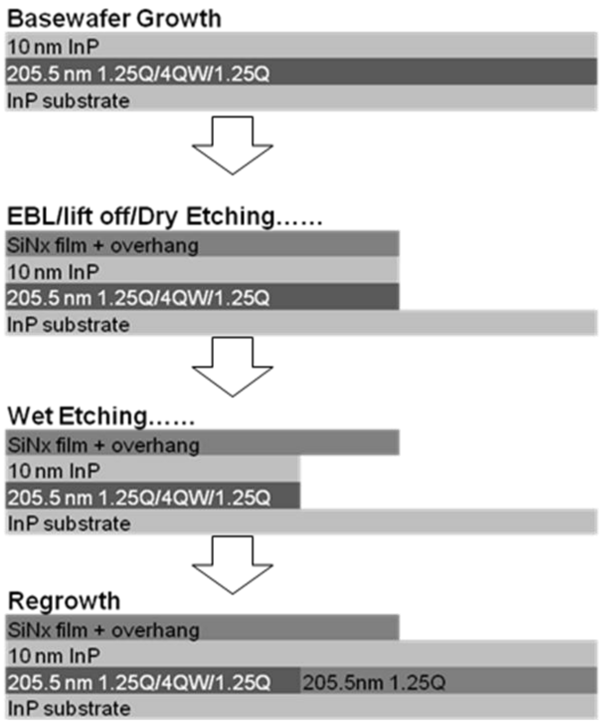
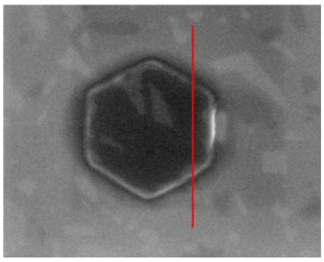


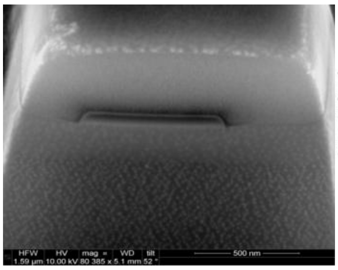
Figure.2 Fabrication process flow

Based on our technology and experience , a successful active passive integration test should satisfy two critical conditions. On one hand, a smooth and flat interface should be realised between the active and passive material. Because a coarse and “bad quality” interface causes both reflection and scattering loss when light is coupled from the active region to the passive region. On the other hand, since the smallest active regions are only around submicron size, it is possible that QWs could be damaged by the processes and are therefore already “dead” optically after all the clean room processing which means that they cannot emit light anymore.

Characterization

Fig.3 shows a top view SEM picture of an achieved structure(hexagon) with a submicron size. The SiNx mask used for the regrowth is left on the sample, in order to make the active areas visible. The line indicates the position where the cross section picture of Fig.5 is made, by the use of Focused Ion Beam etching and SEM. The good quality of the interface and the flatness of the surface are apparent from this picture. Fig.6 shows the photoluminescence of such a structure under CW pumping by a red laser diode at 660 nm. This spectrum corresponds to the quantum wells emission with a peak centred at 1500nm.





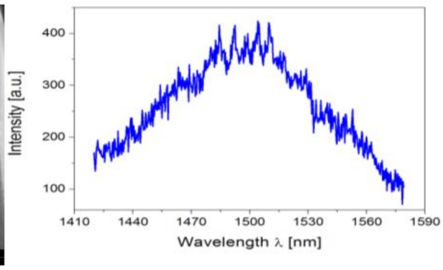


Fig.3: Hexagon SEM picture (250 nm side) Fig.4: Cross section Fig. 5: PL spectrum of the small structure

For the active-passive integration test the morphology and the PL spectrum give strong evidence that submicron active area is usable. We observed blue shift when the size of the active region decreases as one can see clearly from Figure 7. From the top curve(fully active quantum well) to the lowest curve(submicron size active region) , one can see that the PL peak gradually shifts to shorter wavelengths. We believe that this is due to the quantum intermixing effect.

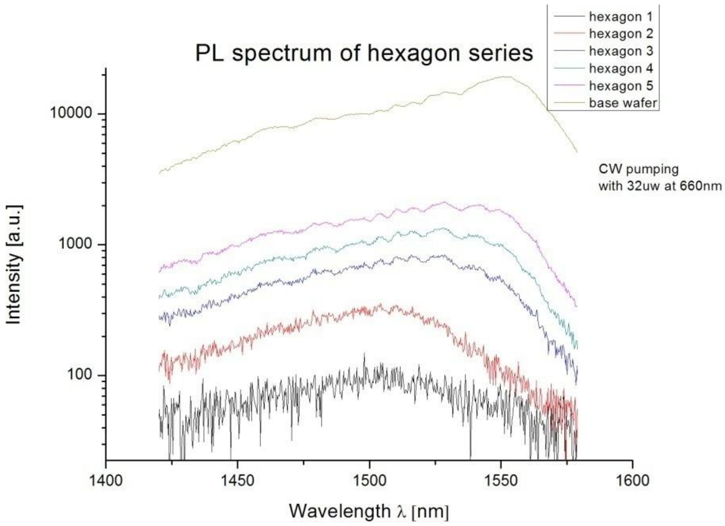


Fig. 6: PL spectrum of the hexagon series (log scale)

QW intermixing involves the interdiffusion of constituent atoms across the well barrier interfaces[5] and is a well known technique to modify the band gap of QWs. However, in our case it happens unintentionally. During the fabrication process, Reactive Ion Etching is used to etch the structure and it is known that defects will be formed on the side walls during this fast dry etching process. During the regrowth process, which is going on under very high temperature(500-600 C^{o}). These defects will diffuse into the QWs and cause intermixing of QWs. The smaller the structure, the easier for the defects to diffuse all over the QWs region, and thus cause a consequently larger blue shift in the spectrum.

Since defects are the cause of the intermixing, the quality of the QWs material reduces, which is detrimental for use in PICs. Therefore in the second cycle, the mission is to optimise the process so that the blue shift can be fixed or at least reduced.

Conclusions

We explored active-passive integration in the submicron scale on a quaternary material system. The quality of interface is good in terms of morphology. On the other hand, PL measurement results shows that the QWs, especially the submicron size one, are ”alive optically.” However, we encounter the problem of blue shift when the size of the active region decreases, and we are trying to studying the problem to reduce this effect.

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