Photoluminescence characterization of III-V materials epitaxially grown on silicon

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Silicon photonics is widely adopted as a competitive candidate to meet the increasing interconnects demands of ICs. However, the key component – an efficient laser, is still missing due to its indirect bandgap. The photonics group of Gent University is nowadays working with IMEC in developing an epitaxial method to integrate III-Vs on silicon. To characterize the IIIV/Si material quality, a micro-PL setup, which has wide range of pump intensity, is utilized. Measurement results show that different defects (threading dislocations, anti-phase boundaries) do influence the optical property of the material, and the overall material quality shows the potential for device demonstration.

I. INTRODUCTION

Photonics has been witnessed an explosion in lighting, display, communication, medicine and other application fields in last few decades. As a promising platform, silicon photonics keeps drawing more and more attention since one can integrate electronic and photonic devices together to achieve more complicated and versatile functionalities, while keeping the cost low. In particular, silicon photonics is a very competitive candidate for inter- and intra-chip optical interconnects, while the conventional copper based solution starts to hit its physical limit.

As the key component for on-chip optical communication, an integrated laser on silicon has already triggered a furious race. There exist several approaches. Some groups focus on engineering the band structure of group IV material like Si and Ge [1], however large amount of pumping power is needed to achieve reasonable optical gain. Another solution based on III-V heterogeneously bonding technics, in which people bond III-V dies on silicon or SOI wafer by using BCB (BenzoCycloButene) [2] or molecular force [3], obtains significant achievements in the last decade, but it still confronts problems like low yielding and insufficient heat dissipation.

As the optimal solution, epitaxial growth of III-Vs on silicon has been proposed since 1980's [4]. However, the major problem remains unresolved, in particular, the threading dislocation due to 8.1% lattice mismatch and the cracks arising from 76.9% thermal expansion coefficient mismatch can act as nonradiative centers, which hinder the carriers from radiative recombination. In this work, a new approach, which utilizes high aspect ratio trenches to confine defects [5], has been carried out. PL characterization shows that reasonable good material quality has been achieved for device demonstration.

II. EXPERIMENTS

Epitaxial growth of InP pillar on silicon

Fig. 1 shows a typical transmission electron microscopy (TEM) photo of an InP pillar grown on silicon. The epitaxial growth was performed in IMEC. In general, the aspect-ratio trapping (ART) effect [6] (see the trapping of TDs in Fig. 1) is used to confine the threading dislocations in the bottom part of the pillar, while keeping the top part unaffected. Furthermore, germanium is used as an intermediary material between InP and Silicon, which is well engineered to minimize the formation of anti-phase-boundary due to the polar-nonpolar interface between silicon and InP.

Two different patterns were used for epitaxial growth, and the sketches can be found in the inserts of Fig. 2. Insert a shows a matrix of square shaped trenches while insert b shows a matrix of rectangle shaped trenches. InP is selectively grown in these trenches, a typical scanning electron microscopy (SEM) photo (top view) of is shown in Fig.2. InP grains with different sizes and shapes are formed on top of pillars by lateral overgrowth of InP on the mask surface.

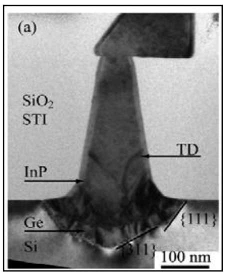

Fig. 1 TEM photo of a typical InP pillar on silicon. Threading dislocations (TD) are terminated by the high aspect ratio SiO_2 trench.

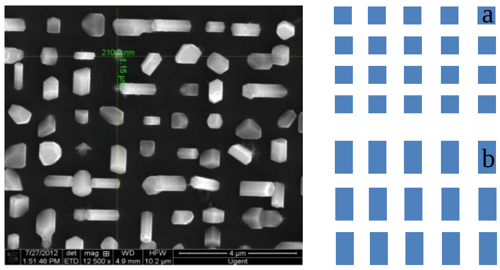

Fig. 2 A SEM top view of the sample with InP grown on silicon. Inserts: two trench patterns used for growth a) square matrix, b) rectangular matrix.

Photoluminescence setup

Fig. 3 shows the configuration of the PL setup used for characterization. After beam expansion, the pumping light is focused by a high magnification objective onto the sample. Pumping area can be adjusted by changing the size of the iris. PL is collected by the same objective and then imaged on the slit of monochomator. PL emission can also be monitored by a camera (see Fig. 3).

Two different pump lasers are used alternatively in the measurement. One is CW laser, which has 1W output power at 445nm. The other one is a Nd:YAG pulse laser, whose pulse energy is 0.9J at 532 nm, and the pulse duration is 10ns. In the following measurement 800Hz repetition rate was chosen for the pulse laser. We could control the pumping intensity by using different neutral density (ND) filters, while the combination of a half-wave plate and polarizer also allow us to adjust the intensity continuously. A Thermo-electric(TE) cooled silicon detector is used for light detection. A lock-in amplifier is routinely used to improve the signal-to-noise ratio.

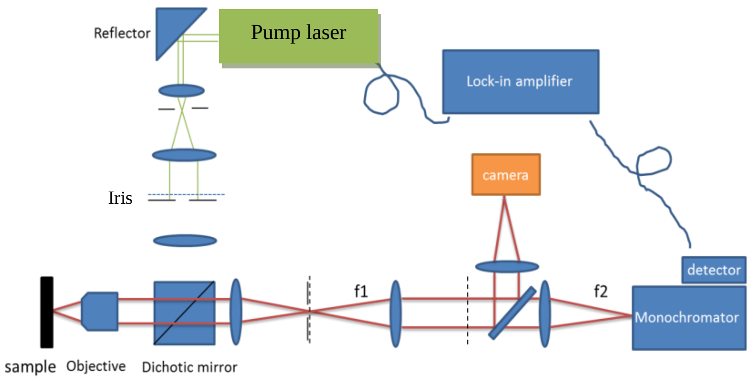

Fig. 3 A schematic diagram of the micro-PL setup

III. RESULTS AND DISCUSSION

Photoluminescence spectrums have been measured at room temperature. Since the pumping area is around 40~50 micrometres in diameter, the luminescence collected mainly contains contributions from emission of large number of InP pillars.

CW pump laser results

Fig.4 shows the typical photoluminescence spectrums recorded by using blue CW pump laser. PL spectrum measured from a reference pure InP sample is also displayed. To be noticed here that the intensity of the PL results from pillars have been multiplied by 10 to compensate the low filling factor (the area covered by InP divided by the whole sample area).

From the figure one can find that there are two individual peaks in the PL (see the black dotted curves), one locates round 910nm while the other can be found around 930nm. Peak around 930nm is similar to the reference in terms of peak position, therefore we assume that this peak is mainly contributed by the bulky band-band transition. Regarding the other peak around 910nm, two possible origins can be provided. One is due to the strain induced by the thermal expansion mismatch between InP and SiO_2 during the cooling down of the sample after epitaxy. Similar blue-shift has also been identified by other groups [7]. The other possibility is the quantum effects induced by the close package of two crystalline phases (zincblende and wurtzite) in the twins (see insert of Fig.4). Similar results have also been obrained in PL characterizations of nanowires [8].

For the growth on b type pattern, since larger trench width will degrade the dislocation trapping effect, one can expect worse material quality. Figure 5 shows the results, and one can find similar curves with two different peaks. However, in this case the peak around 910nm becomes comparable to the peak around 930nm, in terms of magnitude, which tells that the bulky band-band transition is reduced due to the worse material quality.

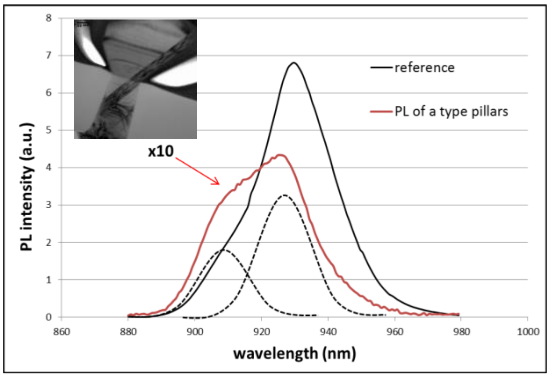

Fig. 4 PL spectrums of InP pillars gown on pattern a (see insert of Fig. 2) under CW pumping. Black dot curves are plotted to approximately indicate the locations of two emission peaks. Insert: TEM photo of one InP pillar.

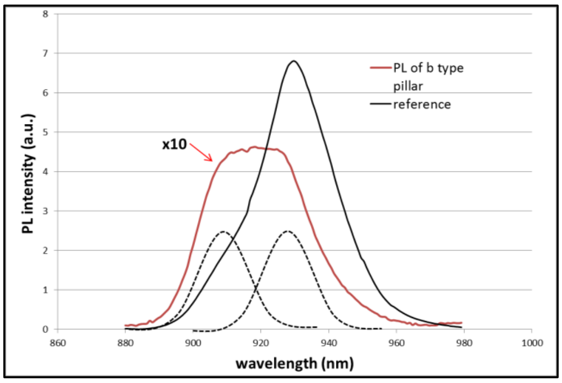

Fig. 5 PL spectrums of InP pillars gown on pattern b (see insert of Fig. 2) under CW pumping. Black dot curves are plotted to approximately indicate the locations of two emission peaks.

Pulse pump laser results

Due to the very short pulse duration, the peak pump intensity of the pulse laser can be orders of magnitude higher than the CW laser. Fig. 6 shows the photoluminescence spectra obtained by pulsed laser pumping. One could expect a similar spectrum as the previous results but with narrower PL peaks, since the non-radiative recombination centres induced by defects or surface states would be saturated by the high pumping intensity. However the results are very different. Several sharp peaks appear in the spectrum, whose locations vary across the whole sample region. One can conclude that some resonance mechanisms have been formed, either inside individual InP grains or between adjacent InP pillars. The high pump intensity provides enough grain to overcome the loss, which makes the resonance more significant. Furthermore, one can hardly find similar peaks from PL of InP grown on pattern b (see Fig. 7), which is mainly due to the less effective aspect-ratio trapping (ART) of the defects.

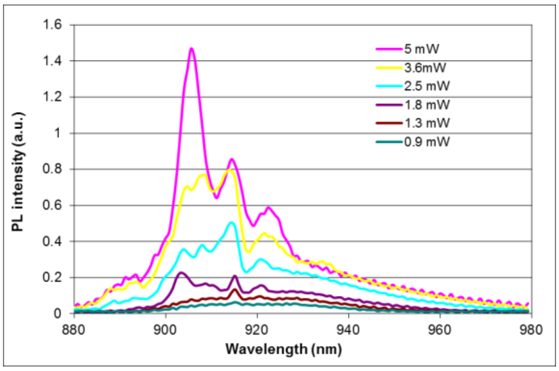

Fig. 6. PL spectrums of InP pillars gown on pattern a of Fig. 2 under pulsed pumping. Sharp peaks start to build up when pumping power is increased.

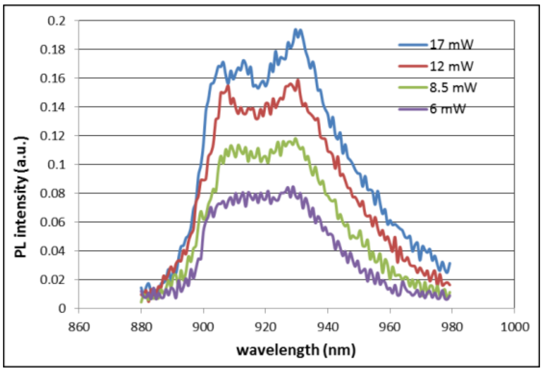

Fig. 7. PL spectrums of InP pillars gown on pattern b of Fig. 2 under pulsed pumping.

IV. CONCLUSION

PL characterization of InP grown on silicon with two different patterns are performed and analyzed. The measured PL spectrums show that the defect trapping effect is more effective by using small trench dimensions. The multi-peaks found in PL spectrum under pulse pumping indicate the formation of cavities and good material quality. More analysis is being carried out to understand the origin of these peaks and seek the possibility of device demonstration.

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Optimized MMI coupler shape for reduced back-reflections

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Spurious back-reflections can be a source of concern in photonic integrated circuits. This is especially true in circuits containing amplifiers, but even in passive circuits, small reflections can already have a strong influence on circuit performance. It is known that strong back-reflections can be present when using a 2×1 MMI as a combiner. We investigate methods for reducing these spurious reflections in a generic integration technology. We present a novel MMI shape which is able to reduce reflections by more than 20 dB.

Introduction

Multimode interference couplers (MMIs) are vital components for splitting and combining light in photonic integrated circuits (PICs). However, these components are known to generate parasitic reflections because they contain abrupt junctions [1]. These reflections may disturb the desired behaviour of the circuit. Parasitic reflections are especially a concern for circuits containing amplifiers, where they can cause gain ripples or even spurious lasing.

When using a 1×2 MMI as a splitter, light is efficiently divided over the two output waveguides. Due to limited imaging resolution, some light will be imaged on the back edge of the MMI. The index step present there causes some light to scatter back to the input. In splitter operation the amount of back-scattered light is very low because almost all the light ends up in the output waveguides. This is not the case when using the same MMI as a combiner. Only when light in the two inputs is coherent, in phase, and of equal magnitude, will it be efficiently coupled to the output waveguide. When only the fundamental mode in one input is present, only half of the light will be coupled to the fundamental mode of the output waveguide for reciprocity reasons. The other half of the light will be scattered and some of it reflected backwards. This back-reflection process can be highly efficient due to the imaging properties of the MMI [2–4].

Previous attempts to reduce the back-scattering level of 2×1 MMI combiners used lossy waveguides [4], or reduced contrast access waveguides [5]. However, in some technologies these approaches may not work. There may not be room for dummy waveguides, or reduced contrast may not be offered by the technology platform. In [6], the corners of the MMI cut to reduce back reflections. Here we take the MMI structure of [6] as a starting point, and add additional structures to reduce back-scattering. The approach we present can be used in any technology that offers designers to freely determine the waveguide shape in the plane.

Design

In our technology, waveguides are defined by surrounding them with deep-etched trenches of width w_t. As a result, most of the chip surface remains unetched, which improves