Two-step transfer printed single mode DFB laser on LN

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The integration of lasers on-chip is an important requirement for a fully integrated photonic platform. To achieve this for indirect bandgap material platforms, hybrid or heterogeneous integration of gain materials is needed. In our group the micro-transfer printing technique is used as a flexible heterogeneous integration technique. With this technique we have fabricated on chip-lasers on different material platform such as LN , Si and SiN, by printing III-V amplifiers on a resonator circuit .

For heterogeneous integration an important constraint is the matching of the refractive indexes of the host and source material. This constraint can be overcome with an intermediate index material layer to bridge the gap in refractive indexes.

In this work we print an Si coupon as intermediate layer but we already pattern a quarter wave shifted grating in this layer. After first printing this patterned Si coupon and then printing the amplifier on top, we have effectively printed a compact DFB laser. This removes the requirement to create a good cavity in the underlying circuit as the cavity is created in the intermediate layer. We demonstrate a single mode laser printed on a LN circuit with this two-step process. This process can be readily extended to a host of low-index platforms..

Introduction

Integrated lasers are an important missing component for photonic platforms based on indirect bandgap materials. This lack can be ameliorated by adding direct-bandgap materials through heterogeneous (on-chip) [3][4] or hybrid (chip to chip) integration [1] [2] . An important consideration is the integration method 's scalability. In this regard heterogeneous integration wins out because an array of lasers can be added in parallel with this technique [5][6]. However the extensive post-processing needed in most heterogeneous integration processes, e.g. wafer bonding, is a big disadvantage. Also because the materials are added on-chip, there are often a lot of requirements on the material properties of the target substrate.

Transfer printing is a heterogeneous integration technique that combines the flexibility of hybrid integration with the high throughput of heterogeneous integration . This is possible because a lot of the processing of the print material can be done before printing. This reduces the post-processing on chip to a minimum. It has been used by our group for the heterogeneous integration of III-V amplifiers on Si, SiN and LN. This technique can be used to integrate lasers on a wide range of material platforms although it is still required to have a suitable cavity circuit on the target chip to achieve lasing operation . This places strong constraints on the target material as e.g. the losses should be low enough to ensure round trip gain.

The micro transfer printing technique works by patterning a device or small circuit (the coupon) on a seperate chip called the source chip, underetching it and then picking it up and placing it on a different chip called the target chip [7][8]. The advantages of this technique are that the coupon can be preprocessed heavily on the source chip and that multiple coupons can be transferred at once using arrayed stamps [9].

Transfer printing was first used in our group by Haq et al. [10][11] to print III-V amplifiers on the Silicon on insulator (SOI) platform. Pre-patterned tapers in the III-V were used to ensure good coupling to the Si layer. Then Op de Beeck et al. used the same III-V coupons to print amplifiers on SiN [12]. The large index mismatch between SiN and the III-V material made it impossible however to fabricate a narrow enough taper to ensure good coupling between these layers. This problem was solved by introducing an intermediate layer of silicon (Si) to bridge the index gap. The Si was first transfer printed as a block and then a taper and waveguide were patterned in the Si to enable coupling between the SiN and Si. Finally the III-V amplifier coupon was printed with the taper to enable coupling between the Si and III-V . This two-step coupling process resulted in efficient coupling.

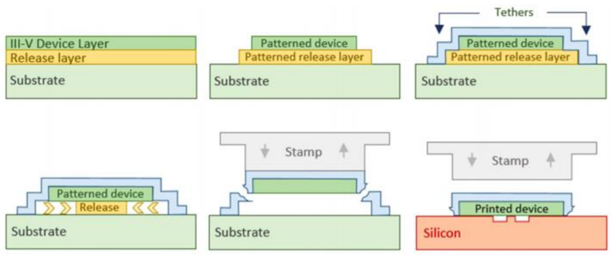

Figure 1: Cross sectional view of the transfer printing of III-V coupons on a silicon substrate

The use of an intermediate layer makes the laser integration design very flexible since it can be used to couple III-V coupons to all low-index materials. However to make a laser the amplifier still needs to be printed on top of a good cavity. This implies that the target material should have low loss to ensure roundtrip gain and that the patterning of reflectors in the target material should be reliable. In this work we expand on this laser integration technique to further improve its flexibility.

Design

In our design we relax the restrictions on the target platform by creating a lasing cavity inside the intermediate layer. We pattern a quarter wave shifted DFB grating on the Si coupons before printing. These gratings can be patterned very reliably because mature SOI processes can be used and post-selection is possible.

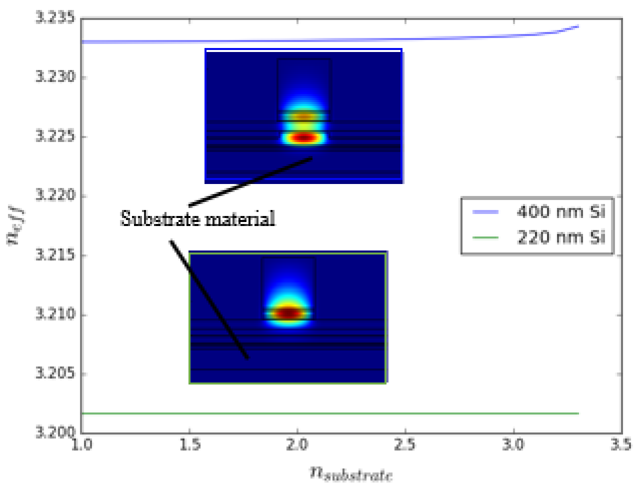

Figure 2: Effective index of the etched and unetched parts of the DFB grating that forms the laser cavity as a function of the substrate index.

Also, for sufficiently low index materials, the effective index in the laser cavity will be affected only very weakly by the substrate index (see Fig. 2). In our design there is no significant change in effective index even when changing the substrate index from 1 to 3. This implies that the pre-processed DFB grating can be optimized and fabricated once for a certain lasing wavelength and can then be used for all low-index materials. A compact DFB laser can thus be printed on any low-index platform using our process.

Two important caveats are the difference in thermal conductivity between platforms and the tapers which need to be reoptimized for different platforms. The thermal conductivity matters because the amplifiers gain spectrum is dependent on temperature. For a fixed pump current this temperature in turn depends on the thermal conductivity of the surrounding materials.

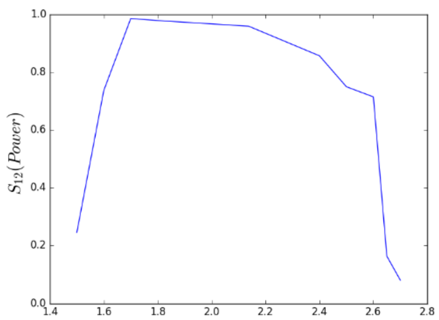

Figure 3: power coupling of the taper we designed for different substrate indexes

The tapers between the Si and the target material are of course dependent on the target material's refractive index. Since this taper is outside the laser cavity some loss can be accepted though. The drop in power coupling is also modest if the index change is small. In Fig. 3 we can see that the taper we designed has >80% coupling for an index range of 1.7-2.3 . The loss of coupling at lower indexes is because of the increasing index mismatch with the silicon. At higher indexes the coupling drops because as the index gets closer and closer to Si , the width of the Si taper should become very close to the full waveguide width of the substrate material, this is not the case in the taper we designed. If the loss is unacceptable the taper can be reoptimized with a relatively simple simulation.

Measurement results

We have demonstrated the experimental implementation of the two-step transfer printed DFB laser on a Lithium Niobate(LN) platform. We measure these lasers at different temperatures and apply pump currents of up to 120 mA. The laser shows single mode lasing at 1534 nm in a narrow pump current range , 86-92 mA.

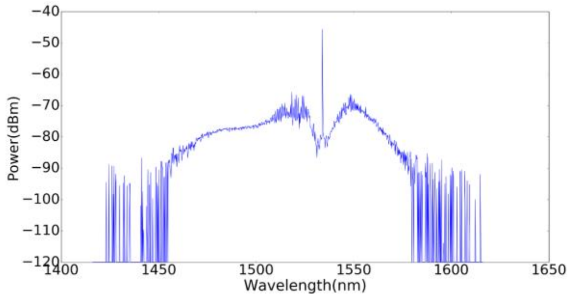

Figure 4: spectrum of the two-step transfer printed DFB laser on a LN platform with 90 mA pump current

The multimode behavior at other currents is caused by broadband reflections due to badly fabricated tapers. These broadband reflections in combination with a mismatch between the center wavelength of the DFB stopband and the maximum gain wavelength can lead to unstable lasing close to the gain maximum but outside of the DFB stopband.

Fabrication

The lasers were fabricated by separately fabricating an LN circuit, the intermediate Si coupon with DFB gratings and the amplifier coupons.

First the 600 nm LNOI platform provided by NANOLN is patterned by our collaborators at Harvard. The circuit consists of a pedestal for transfer printing and a tapered coupling section which is connected to grating couplers. An oxide cladding of 800 nm is then deposited on top. To ensure good coupling to the circuit we first etch a recess above the pedestal leaving only 100 nm of oxide on top. We also deposit a thin layer ~70 nm of BCB to smooth over any roughness before printing. A protective layer of 30 nm AlOx is then deposited. The Si coupons are prepared on a 400 nm SOI chip by first shallow etching (180 nm deep) the waveguide and DFB grating and then deep etching (>400 nm deep) the coupon so it can be released later. The DFB grating section is 650 um long, and the grating has a pitch of 248 nm. The amplifier coupons are the same used by Haq [10] [11] and Op De Beeck [12]. They are approx. 700 um long with tapers on each side to couple to and from the intermediate Si layer.

The Si coupons are then transfer printed on the LN pedestal. To couple from the LN to the Si we then do a full etch to define the Si tapers, relying on the AlOx layer to protect the LN underneath.

After this we again deposit a thin layer of BCB ~70nm before printing the amplifier coupons. Then finally we deposit a thick layer of BCB , etch vias and deposit the final metal to contact the laser.

Conclusion

We have shown a proof of concept device for a highly flexible integrated laser design. The transfer printing of both the amplifier and the resonator makes the preprocessing of both possible. The high indexes of both the intermediate layer as well as the III-V coupon ensure the design is very generic for low index platforms.

In this work our design is shown to work experimentally on a single platform and it is shown to be generic through simulation. In future work we want to show this experimentally, starting with the implementation on the SiN platform. Also most of the post-processing could happen before the printing of the coupons. Both the etching of the tapers in the Si and the contacting of the amplifiers could happen on the source chips. This would simplify the processing on-chip to just the two transfer printing steps. Advances on this front will be implemented in next generation devices.

The performance of the laser itself will also be improved with the etching tests we did on this chip for the tapers, as well as the gratings. This will lead to less broadband reflection and higher power after the tapers.These improvements should result in a generic printable single mode DFB laser, with an on-chip power of around 1 mW.

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