Analysis of loss contributions in InP-based microdisk lasers heterogeneously integrated with SOI

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Microdisk lasers are promising components for VLSI photonic integrated circuits (PIC), because of their small footprint and ease of fabrication. However, until now output powers remain quite low. In this paper we investigate the loss contributions of the top and bottom metal contact in a 2D axisymmetric FEM simulation. The coupling efficiency from the microdisk laser to an underlying waveguide is also investigated with 3D FDTD simulations. Optimum values for the contacts and coupling parameters are found and can be used to improve the design of microdisk lasers.

Introduction

Optical interconnects are believed to be a viable candidate in order to overcome the bottleneck that electrical interconnects might form as a result of the increasing data rates [1]. Silicon photonics is an interesting platform for these optical interconnects because of the CMOS compatibility and the mature technology. However, realizing sources in silicon is not trivial. A heterogeneously integrated InP-based microdisk laser [2] with silicon-on-insulator (SOI) is an interesting solution as optical source. The advantages of III-V and silicon are combined and the microdisk laser has small dimensions and low power consumption. However, the output power of these microdisk lasers is still quite low. To achieve higher output powers losses need to be minimized and the coupling efficiency should be optimized.

In this paper we investigate the losses originating from absorption due to the presence of metal. We also analyse the coupling efficiency and show how it can be optimized.

Design

A schematic representation of the microdisk is given in Fig. 1. An InP thin film is bonded on a SOI sample with passive waveguide structures by means of an adhesive bonding process with benzocyclobutene (BCB). The microdisks are etched in this thin film and have diameters in the range of 7.5 to 40 µm. The etch depth is with 480 nm somewhat smaller than the film thickness such that a thin layer of about 100 nm remains for the bottom contact. The active layer consists of three compressively strained InAsP quantum wells and is surrounded by an n-doped layer on the bottom and a p-doped layer on top to form the diode structure. A tunnel junction is implemented on the p-side such that an n-type contact layer can be used instead of a highly absorbing p-type contact layer. Because a microdisk supports optical modes of the whispering gallery type which propagate at the edge of the disk, it is possible to place a top metal contact in the center without affecting the fundamental optical mode. The generated light in the microdisk is coupled to an underlying waveguide by means of evanescent coupling. The microdisk is passivated by spin coating a BCB layer which at the same time also planarizes the structure for the electrical contacts.

In a microdisk cavity the loss can be described in terms of the quality factor Q. The total Q factor can be broken down in individual Q factors for different loss contributions. In this paper we focus on the Q factors following from the metal and coupling losses.

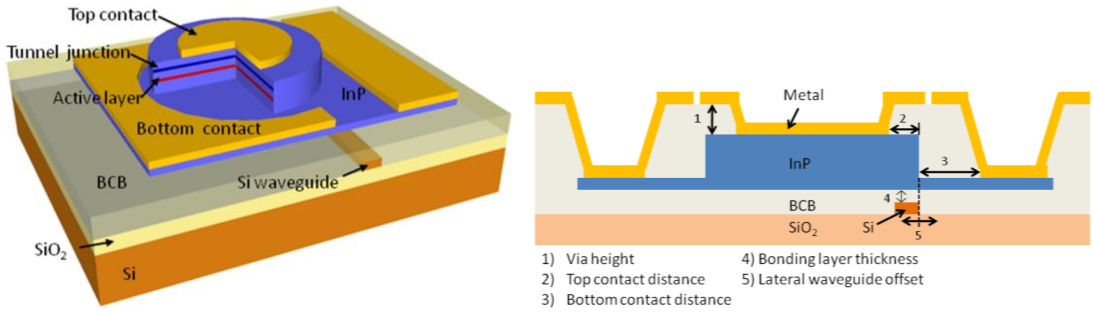

Figure 1:(a) 3D impression of the microdisk laser structure. (b) Cross-section of the microdisk laser with the relevant design parameters.

Results

For efficient current injection it is important to place the metal contacts as close as possible to the area where the light is propagating. On the other hand they should be sufficiently far away from the optical mode or it will result in excessive optical absorption. The amount of absorption also depends on which metal is used. Conventional alloyed metal contacts like AuGe/Ni/Au cannot be used in thin film structures because the Au/InP intermixing is very violent and gold spikes might short-circuit the pn-junction. Therefore, we use non-alloyed Ti/Pt/Au contacts instead, where the platinum acts as diffusion barrier to gold. To simulate the losses induced by the metal we used a 2D axi-symmetric finite element model. In this paper we focus on disk diameters of 7.5 µm, but the simulation can easily be adjusted to any diameter. The simulations were performed for both titanium and gold contacts. The complex refractive index of platinum is very similar to titanium and the effect of platinum can therefore be very well approximated by titanium. Besides the fact that the top contact serves as an interface to inject current into the microdisk laser, it can also be used to suppress higher order whispering gallery modes. The top contact size should thus be chosen in such a way that the fundamental mode is not influenced and the higher order modes are absorbed as much as possible. Fig. 2 shows the evolution of the Q factor as function of the top contact distance for the fundamental (square markers) and first order mode (round markers). The solid blue lines represent gold based contacts and the dashed black curves represent the titanium based contacts. It can be seen that at a top contact distance of about 1 µm the Q factor of the fundamental mode is still in the order of hundreds of thousands, while the first order mode has a Q factor of only several thousands for both titanium and gold based contacts. If the top contact distance is decreased further the fundamental mode will also be strongly absorbed and therefore we can conclude that the top contact distance should be around 1 µm.

From a processing point of view it is desirable to keep the via height small. The relation between Q factor and via height is shown in Fig. 3. A via height of 300 nm is sufficient to reach a Q factor of 100,000 in case of a gold based contact, while for titanium the distance should then be at least 450 nm.

In order to keep the electrical resistance induced by the thin bottom slab low, the bottom metal contact should be placed as close as possible to disk. Again an optimum needs to be found because a too small distance will result in excessive absorption. The Q factor versus bottom contact distance is shown in Fig. 4. The solid blue line with round markers designate a 500 nm thick layer of gold, which represents a situation where the contacts are gold plated. Q factors higher than 100,000 can be achieved for both titanium and gold by making the bottom contact distance larger than 700 nm. It can be seen that the thick gold layer results in only a slight increase of absorption.

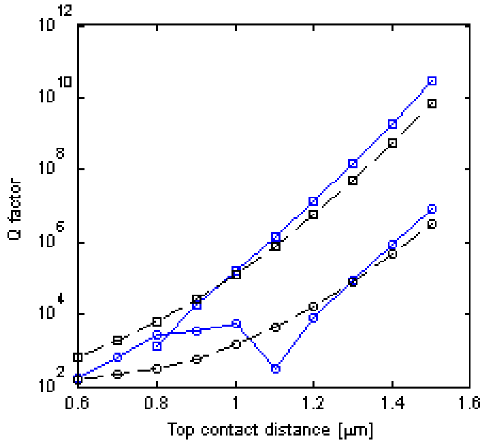

Figure 3: Q factor versus the top contact distance. Au is blue solid line, Ti is black dashed line. Square markers for the fundamental mode and round markers for the first order mode.

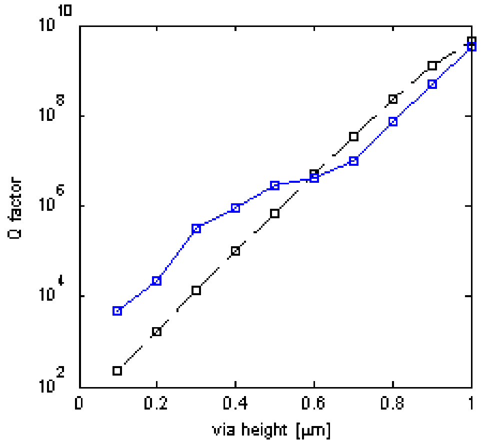

Figure 2: Q factor versus the height of the via. Au is blue solid line, Ti is black dashed line

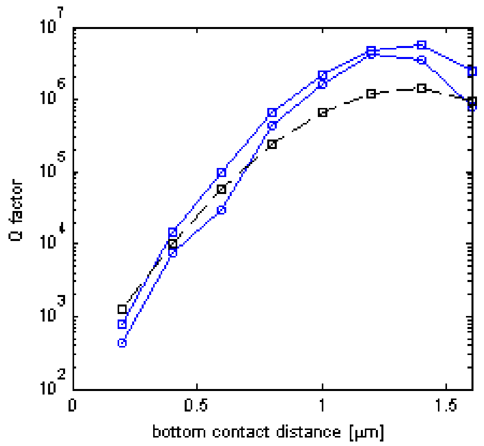

Figure 4: Q factor versus bottom contact distance. Au is blue solid line, Ti is black dashed line. Square marker is 50 nm Au. Round markers is 500 nm Au.

The coupling loss to the underlying waveguide should be optimized in such a way that the laser has a high output power and a reasonable threshold current. In order to simulate the coupling loss a 3D simulation is required because the coupling is in the vertical direction between a bent and a straight structure. We used the Meep 3D FDTD software to study the coupling. The position of the waveguide was varied both in the lateral and the vertical direction. In case of lateral offset we refer to zero offset if the outer edge of the waveguide is aligned with the edge of the disk as indicated in Fig. 1(b). The diameter of the microdisk was again 7.5 μm and the waveguide had a width and height of 500 and 220 nm respectively. The fundamental modes in the disk and the waveguide have a good phase match for these dimensions. First we investigated the coupling as function of the bonding layer thickness because the coupling is expected to have an exponential dependence on the distance between the disk and the waveguide.

Fig. 5 shows the Q factor as a function of bonding layer thickness. The lateral offset is 0 for these simulations. As expected the coupling increases exponentially with decreasing bonding layer thickness. Controlling of the bonding layer thickness should therefore get special attention during processing. The optimal position depends on the achievable gain and all other loss parameters. A Q factor of about 5000 will result in a loss α of about 30 cm^{-1}.
The effect of a lateral offset of the waveguide with respect to the disk is shown in Fig. 6. A bonding layer thickness of 100 nm was used for this simulation. The lowest Q factor, and thus the highest output coupling, is obtained for a positive lateral offset of 100 nm. In this case the maxima of the fundamental mode fields of both the disk and the waveguide will overlap. If the waveguide is moved further outwards the overlap decreases so that the coupling to the waveguide becomes less efficient and the Q factor increases again. On the other hand if the waveguide is moved inwards the Q factor starts to increase until a maximum is reached at -300 nm offset after which it decreases again to a second minimum around -600 nm offset. This is due the fact that coupling between the waveguide and disk will now occur at two points instead of one single point. This results in constructive or destructive interference depending on the distance between the two points and explains the oscillation in Q factor as function of the lateral offset. The coupling at -600 nm is slightly less efficient compared to the single point coupling situation most likely due to dispersion effects.

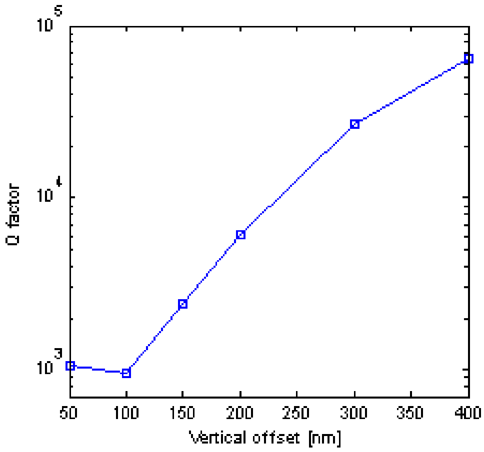

Figure 6: Q factor versus bondinglayer thickness. Offset is 0 nm.

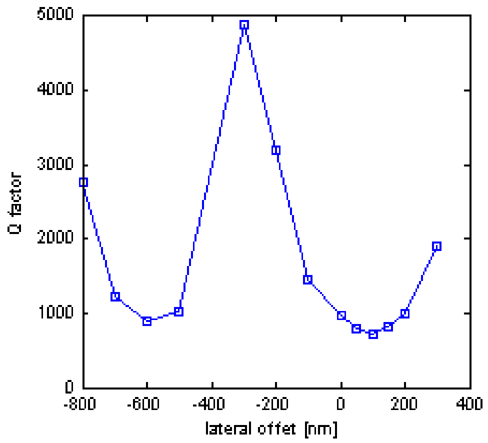

Figure 5: Q factor versus lateral offset of the waveguide. Bonding layer thickness is 100 nm.

Conclusion

We simulated the influence of the different metal contacts with a 2D axisymmetric FEM simulation and we found optimum values for a 7.5 µm microdisk. The coupling efficiency was analyzed with a 3D FDTD simulation and from the obtained results we can, depending on the total loss factors, select the optimum position of the waveguide.

References

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