Heat-Sink Modules: Performance Enhancement for VCSEL Chips

Anna Bergmann and Rudolf Rösch

We present the layout development for a heat-sink module tailored for small-dimension laser chips. By means of improved heat dissipation, the laser characteristics are expected to be enhanced, which is important for example for a sufficient trapping performance when used as a laser source for optical traps. We show the requirements for the module parts as well as their assembly.

1. Introduction

We are using vertical-cavity surface-emitting laser (VCSEL) sources in optical traps [1]. Advantages are the vertical emission, a suitable emission wavelength of about 850 nm and the rather inexpensive fabrication of these lasers. Additionally, VCSELs can be arranged with very small pitch in almost arbitrary shaped arrays.

In recent studies, we have shown a particle sorting application where tilted linear VCSEL arrays are integrated underneath a microfluidic chip with a channel thickness of several tens of micrometers [2]. These VCSEL arrays are manufactured with a self-aligned surface relief process employing dry etching for steep vertical side walls [3].

After processing, the semiconductor material is cleaved into comparatively small pieces of 1.2 mm by 1.4 mm. These laser chips contain the important sorting cell as well as two neighboring cells to enable an easier handling of the chip and thus a protection of the lasers. However, due to the small dimensions of the laser chip, there was poor heat dissipation and consequently elevated temperatures in the semiconductor material. This led to limited output powers and an earlier thermal rollover. The trapping performance of the laser source is thus drastically degraded by these factors. For those reasons, it seemed necessary to incorporate a heat sink into the setup.

2. Future Setup With Microfluidic Chip and Heat Sink

The former concept for the integrated optical trap can be seen in Fig. 1. One cleaved laser chip is soldered to the polydimethylsiloxane (PDMS) microfluidic chip by indium bumps. Thin glass with back side fanout tracks seals the microfluidic channel. These fanout tracks enable addressing of the laser arrays.

However, operating the lasers in the described setup, we observed output powers between one fifth and almost one half of the output power measured on-wafer. This effect and also the earlier thermal rollover are shown in Fig. 2 for comparison. Because of the strong degradation of the device performance due to poor heat dissipation, we decided to implement a heat sink.

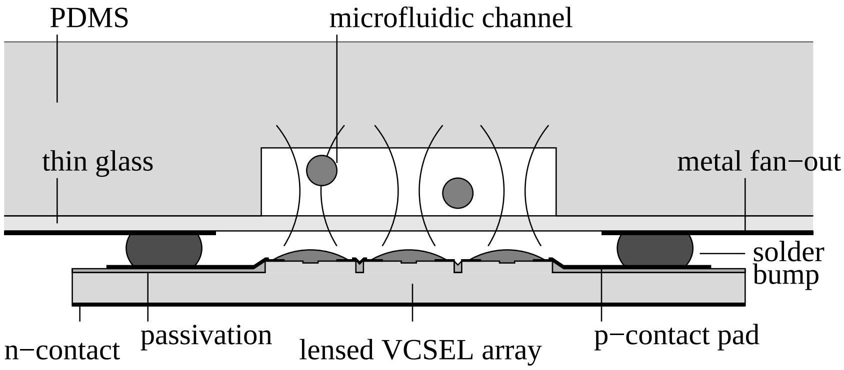

Fig. 1: Former concept of the integrated optical trap. The laser chip with on-facet microlenses is soldered by indium to the microfluidic chip which is sealed by thin glass. Contacting is achieved via lithographically structured metallization on the back side of the glass [1].

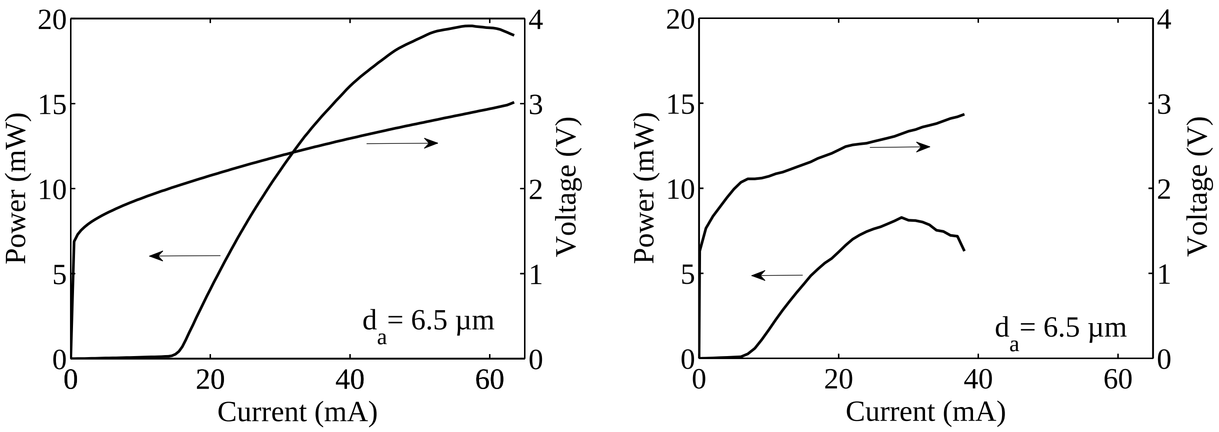

Fig. 2: Operation characteristics of an array with six lasers before (left) and after cleaving and integration (right). The active diameter of the devices is 6.5 µm.

Figure 3 shows the new integrated setup. We are planning to solder-bond the laser chip onto a copper heat sink. The laser chip is surrounded by a glass sheet with an opening and a thickness similar to that of the chip. Fanout metallization is structured on the glass surface. This module is then attached to the microfluidic chip by an adhesive which cures when exposed to ultraviolet light. By mixing this adhesive with micrometer-sized spheres of different diameters, we can easily adjust the distance between heat sink and microfluidic chip and thereby prevent the microlenses on the laser facets from being impaired at the glass surface.

In the following we will introduce the different parts necessary for the proposed setup and finally the assembly.

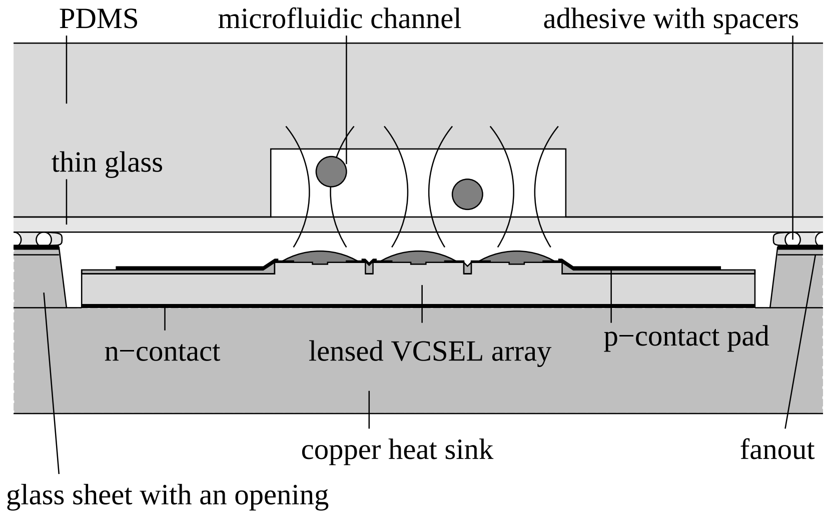

Fig. 3: Proposed concept of the integrated optical trap with the VCSEL array on a heat sink.

3. Heat-Sink Module: Components and Integration

3.1 Challenge: contacting of the embedded laser chip

The main difficulty when applying a heat sink as illustrated above is the contacting step. In the given approach, only very small distances between laser and microfluidic channel can be tolerated because we are dealing with small optical powers and an only weak focusing of the light in comparison to other trapping setups. To keep up with miniaturization, we use glass with a thickness of only 30 µm. Additionally we discarded to contact the lasers by wire bonding. Those wires would have a minimum diameter of 25 µm, resulting in a too large distance between lasers and microfluidic channel. Consequentially we chose the thinner contacting solution, namely lithographically structured fanout tracks on top of the planarized surface.

3.2 Heat-sink module: requirements on the copper part

Our present approach for the module design uses copper as a heat spreader. A rectangular piece of glass with an opening serves as the electrical insulation between copper and fanout metallization.

During high-temperature processing steps, the glass is subjected to mechanical stress caused by the mismatch of the thermal expansion coefficients. If the glass is mounted on a smaller area instead of the whole surface, this tension build-up is suppressed. Therefore we decided to elevate the glass bonding area in comparison to the rest of the heat sink surface. This area contains grooves for a facilitated glass bonding process, resulting from an improved outflow of the glue. Additionally, the heat sink contains an elevated frame for stronger mechanical support.

For some applications it is required to shift the laser chip from the center to the edge of the heat sink, particularly to enable a denser packing of various parts. For this reason, the copper part contains a mounting area both in the center and at one of the edges. With this feature, the heat sink is usable in standard setups as well as in specialized ones.

The whole copper material is able to serve as the back side contact for the laser arrays. This contact is realized by a hole for a wire in conjunction with a thread for a fixing screw.

Figure 4 shows a drawing of the designed copper heat sink, satisfying all of the requirements mentioned above. One advantage is the usability for VCSEL array chips as well as for VCSEL chips with an extended cavity (called VECSEL chips here). Their semiconductor thicknesses are almost the same and their dimensions are rather similar.

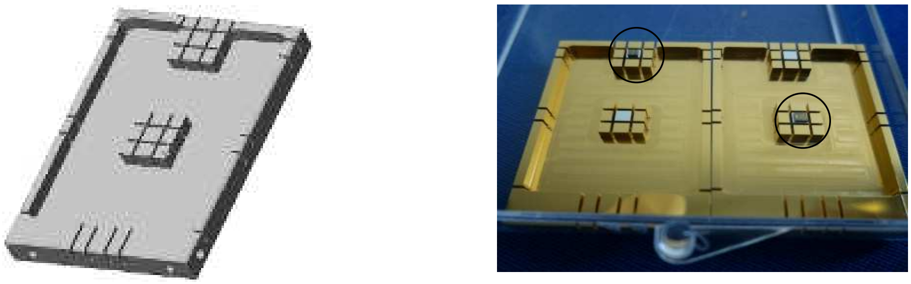

Fig. 4: Left: Drawing of the designed copper heat spreader. Approximate dimensions are $18 \times 25\,\mathrm{mm}^2$. Right: Images of the fabricated heat sinks with soldered laser chips.

Due to the bonding area at the edge, the copper heat spreader is not symmetric and the center of gravity is slightly off-center. This could have the shortcoming that spin-coating of photoresist is dangerous due to unbalanced centripetal forces.

3.3 Heat-sink module: requirements on the glass part

Glass is supposed to be the insulating material between copper and fanout metallization. By using glass, we are able to observe the glue distribution while conjoining copper with glass. Another advantage is the inexpensive and easy fabrication.

The very first requirement is a rectangular opening with dimensions in the same range as the laser chip. At two edges of this rectangle are additionally circular holes with 400 µm diameter. They enable an easier application of the glue into the gap between laser chip and glass, because it is slightly bigger than the outer diameter of the used cannulas. The glass slide thickness is similar to the semiconductor thickness. Again, the glass opening is suitable for both the VCSEL array and VECSEL chips.

Because it carries the electrical contacts, the glass sheet has to be long enough to be accessible even after attaching the microfluidic chip on top. The dimensions of the glass part will be around 4 cm length and 2.6 cm width.

3.4 Heat-sink module: fanout tracks

Using large glass plates is not enough. The fanout tracks must be long enough as well. That means new mask layouts have to be made, taking both centered and displaced setups into account. In the centered setup, the laser chip will be mounted in the center with symmetric fanout tracks (Fig. 5), whereas in the displaced setup, the laser chip is shifted to the edge. The glass opening is also shifted, and the fanout tracks start from this point at the edge (Fig. 6).

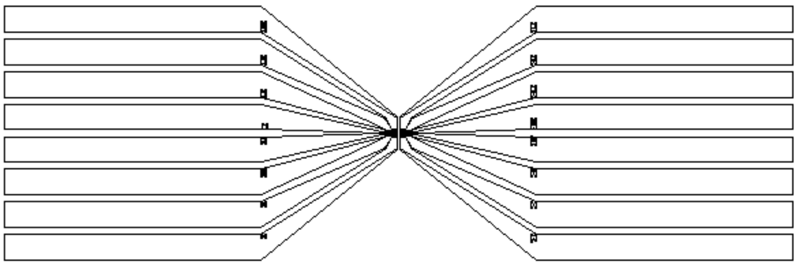

Fig. 5: Mask layout for common applications with the laser chip in the center of the heat-sink module. All fanout tracks start in the middle and have a length of approx. 3 cm.

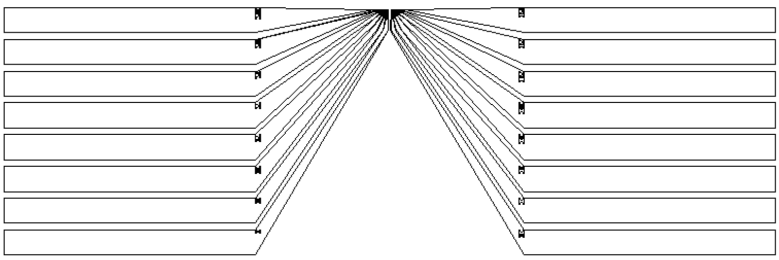

Fig. 6: Mask layout for specialized applications with the laser chip at the edge of the heat sink. All fanout tracks are accumulated at one side of the laser chip. Their length is about 3 cm.

3.5 Heat-sink module: assembly

The first step in the assembly process of the heat-sink module is the evaporation of indium onto the copper surface where the laser chip is supposed to be soldered. After soldering, the glass substrate is bonded to the copper carrying the soldered laser chip. In the next step, the gap between laser chip and glass is filled with a two-part adhesive through a cannula via compressed air.

For an improved adhesion of photoresist and metal we structure a polyimide layer above the filled gap. Polyimide needs a one-hour hard-bake step at 300 °C. This high temperature is one of the reasons for the stepped glass bonding area.

Afterwards we fabricate fanout tracks bridging the gap and reaching over the glass surface. For beam shaping, we apply integrated microlenses on top of the laser facets by reflow of cylindrical photoresist islands. Since the reflow is done at 250 °C, lens fabrication cannot be done prior to the polyimide curing.

The last assembly step consists of bonding the heat sink with lasers to the microfluidic chip, by a UV-curing adhesive mixed with spacers. Figure 7 shows a schematic of the complete assembly with microfluidic chip, long glass plate with fanout, and copper with soldered laser chip.

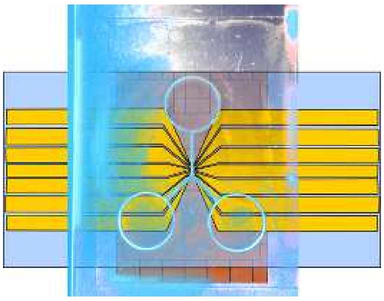

Fig. 7: Schematic of the complete heat-sink assembly. Clearly visible are the copper heat spreader with stepped areas and the long glass with fanout tracks. Attached on top is the microfluidic chip with channels in a Y-junction configuration.

4. Conclusion

Implementing copper as a heat spreader for the laser chip, the trapping performance is expected to improve considerably. The described heat-sink module can be applied in the integrated optical trap or similar integrated setups with small laser chip dimensions.

We have shown the layouts of the needed parts as well as the assembly of the complete module. All parts are designed in a way that they are suitable for both common and specialized applications, and also for similar types of laser chips.

References

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