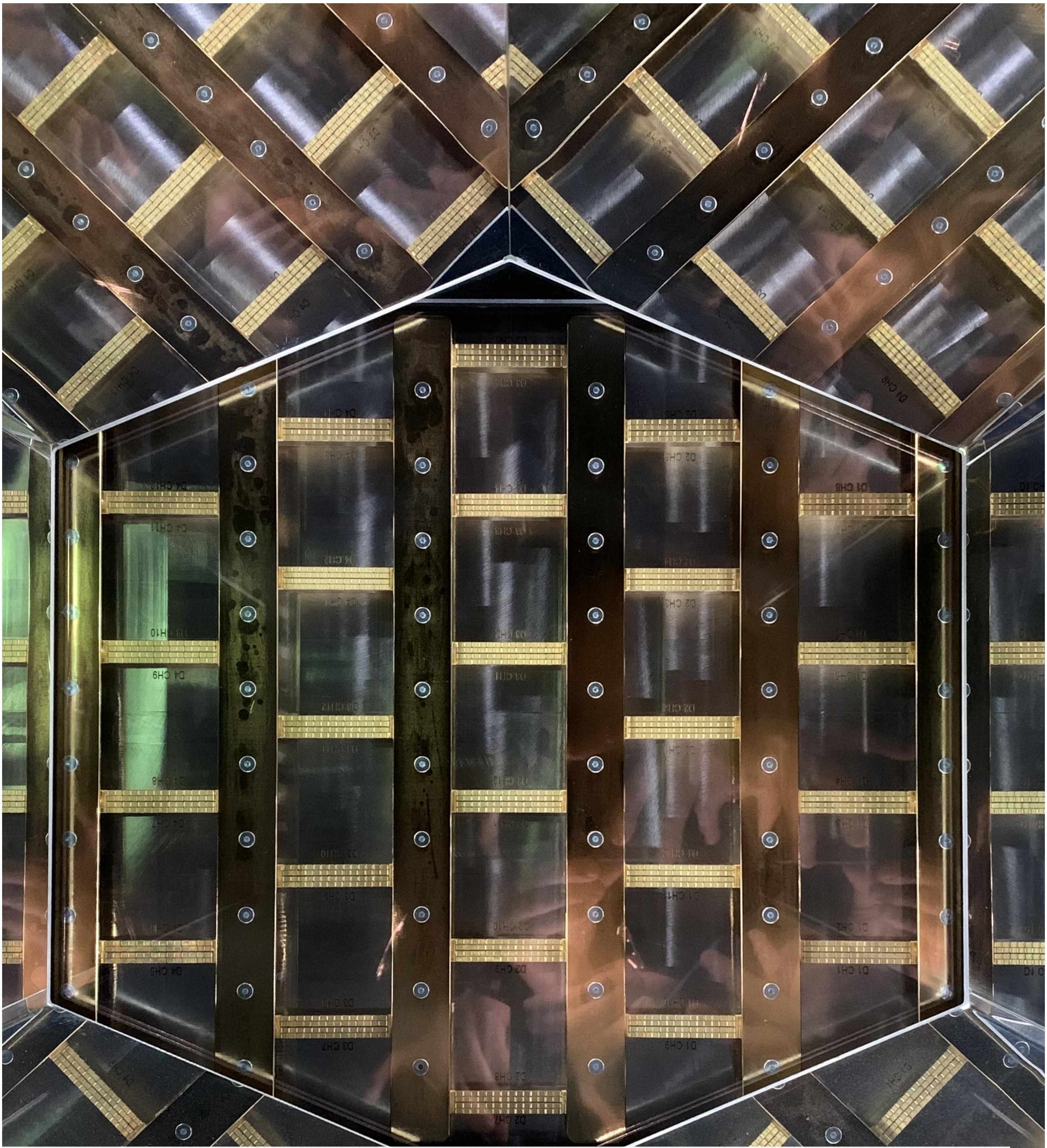

TRUMPF

Whitepaper

Wafer heating with a 9.6 kW system based on VCSEL technology

Contents

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Abstract

This whitepaper shows the possibilities of homogenous large area heating with distributed but densely packed high power VCSEL emitters.
The application example is a Ø 300 mm silicon wafer and a special 9.6 kW VCSEL heating system for large area heat treatment, to discuss the benefits of using VCSEL heating modules for rapid thermal processing (RTP) of Si-wafers. Within the whitepaper, application results are shown and explained. Additionally, optical simulations are highlighted to give an impression of further possibilities and ideas for potential system adaptions to meet customer requirements.

The Challenge of Wafer Heating

The production of semiconductor devices requires many different production steps on wafer level before the wafer is cut into single dies.
Within the processing of the wafer, different temperature levels up to 1000 °C with very good homogeneity, are needed.
Heating the wafer very fast is often mandatory to reach the desired process results.
Furthermore, with VCSEL heating systems, a lot of time during the manufacturing process can be saved and less side effects occur, which leads to a higher yield.

Figure 1: TRUMPF manufactures its VCSEL at their clean room facility in Ulm

Application Setup with VCSEL Heating Systems

At the Connected Technology Center of TRUMPF Photonic Components in Aachen, a compact and laser-safe setup for various application tests is available. The setup is equipped with an IR-camera, optical camera, pyrometers, thermo couples and a fast linear axis.
Flexible mounting possibilities for work pieces and VCSEL heating modules exist, to address different application needs.

Together with customers, feasibility tests can be performed, and customers can experience the high power VCSEL modules on site.
All standard modules from 2.4 to 9.6 kW can be tested; special modules on request.
In the following the application of wafer heating is discussed, for this use case, a special 9.6 kW heating module was set up.

Figure 2: Setup in the Connected Technology Center in Aachen. Laser chamber with cooling unit, driver unit, and control PC

The VCSEL Solution for Wafer Heating

As first step, optical simulations were performed to optimize the distribution of standard VCSEL emitters, in order to achieve homogeneous irradiation of the wafer (see figure 4). The analysis showed, that using e.g. only 24 standard emitter and a mirror tube (see figure 3), perfect homogeneity at the wafer level can be reached. Heating rate and working distance can be controlled by the number of employed emitters, thus allowing for optimization of system performance and cost.
Following these simulation results, in a second step such a system for wafer heating with 9.6 kw (figure 5, module without mirror tube) was built. First tests were performed on bare silicon wafers.
The wafer heater can be scaled up to 75.2 kW, which will result in over 8 times higher heating rates.

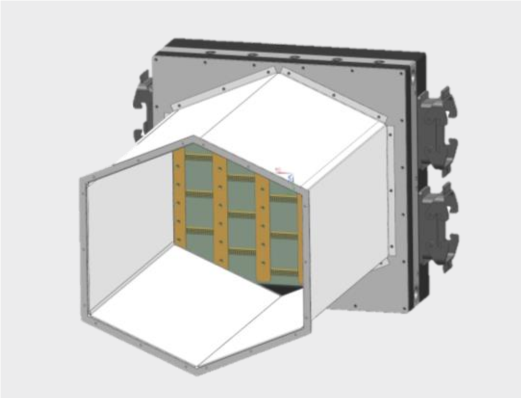


Figure 3: Layout of wafer heater with specifically arranged emitters.

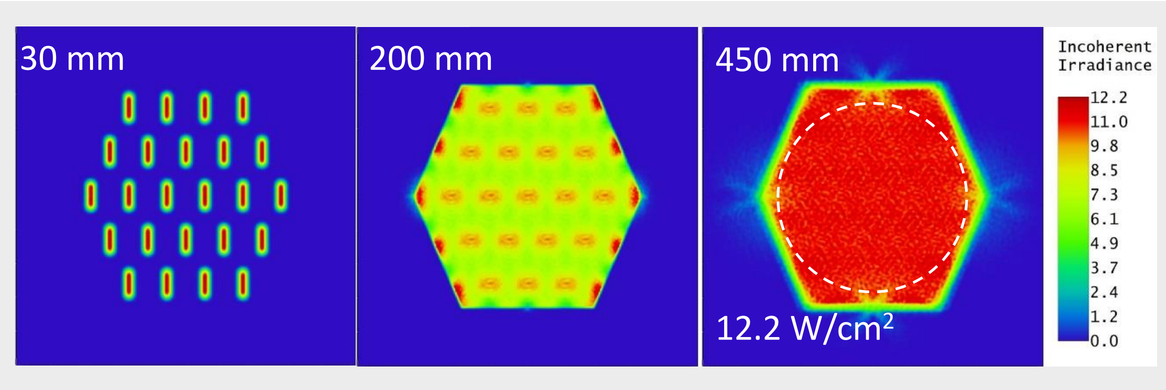


Figure 4: Optical simulations with external mirror at different working distances: 30 / 200 / 450 mm. The dashed circle represent a Ø 300 mm wafer

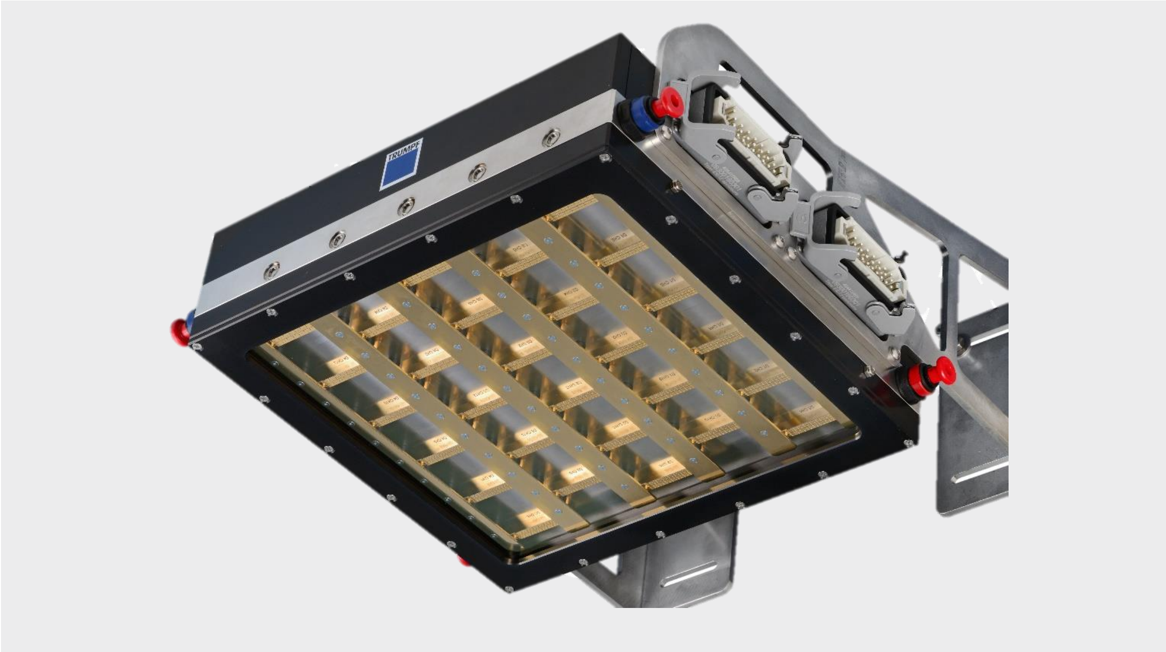


Figure 5: VCSEL heating system of 9.6 kw wafer heater

Experimental Setup for Wafer Heating

At the Connected Technology Center in Aachen, the 9.6 kW wafer heater was set up (see figures 6 and 7).
First tests were run with a Ø 300 mm black coated stainless-steel dummy and with Ø 300 mm bare silicon wafer; the wafers were mounted at three points, using holders with low thermal conductivity.

All experiments were performed at normal atmosphere. During the heating process, temperature and homogeneity were recorded with an IR-camera. The emissivity-setting of the camera was calibrated for bare silicon or for the black steel-coating.

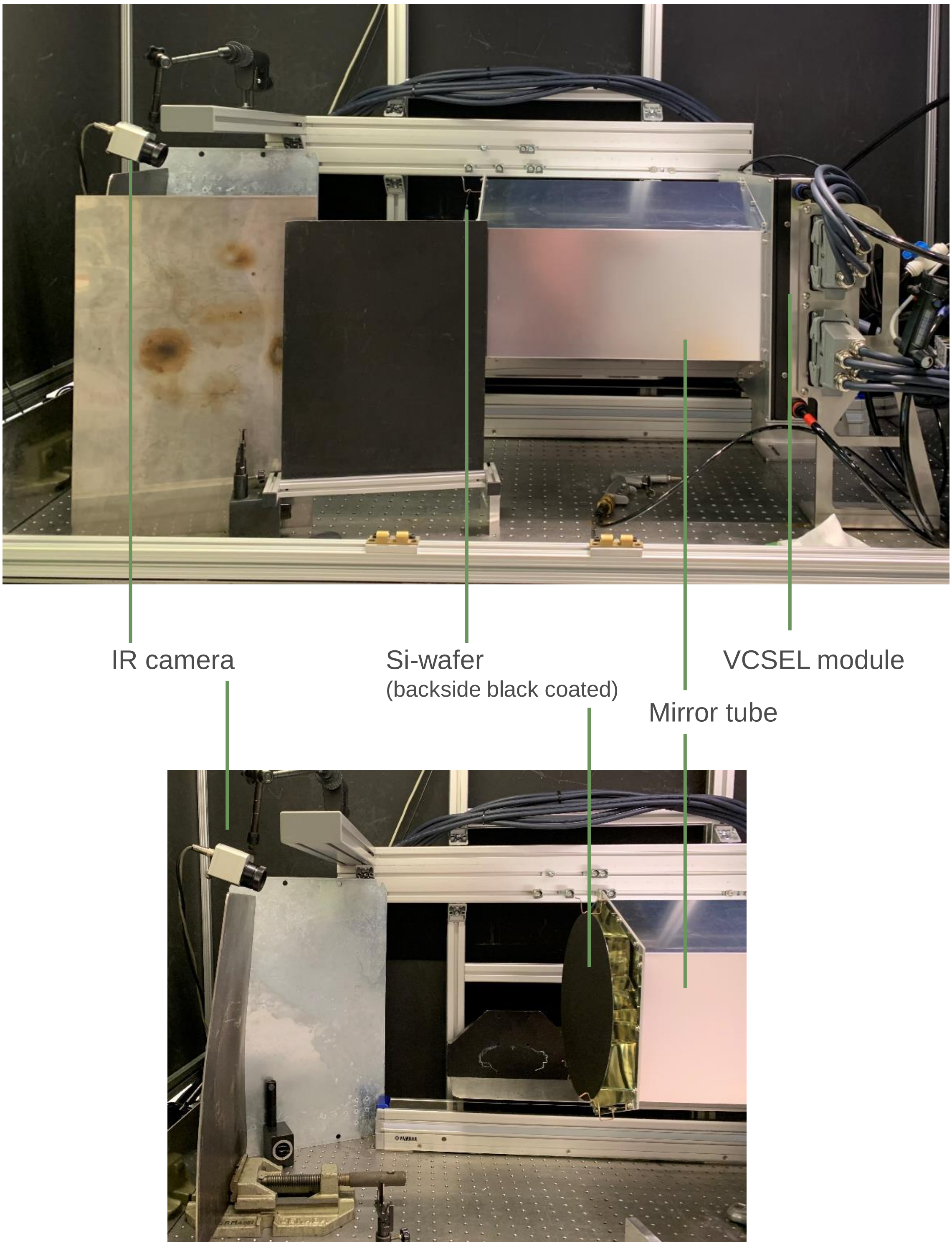


Figure 6: Overview of laser chamber. In front of the VCSEL module,the hexag onal mirror tube with a length of 450 mm can be seen

Figure 7: Setup with Ø 300 mm wafer. The backside of the wafer is coated black, to enable accurate temperature measurements

Heating of Silicon Wafer

Instead of the simulated 9.6 kW, the Si-wafers have been irradiated with an infrared power of 9.12 kW. A slight adaptation of the laser power distribution of the VCSEL heating module led to an improved homogeneity of the Si-wafer temperature. The adaption of the power distribution was necessary to prevent an over heating in the middle and to compensate the convection losses due to hot air flow from the bottom of the wafer to the top.

The heating rate at low temperatures (25 to 230 °C) was 51 K/s; at 625 °C, the heating rate reduced to 16 K/s, due to convection and long-wavelength radiation that was re-emitted by the hot wafer.

The average heating rate in air for a vertically mounted wafer was 32 K/s, with a good homogeneity. It took 20 seconds to reach an average wafer temperature of 640 °C.

The temperature uniformity over the Ø 300 mm vertically mounted wafer reached in air was ± 8 K.

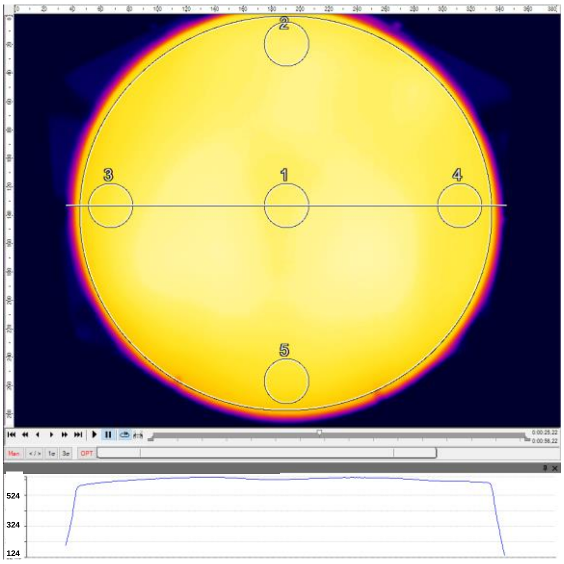


Figure 8: 2D-image and horizontal temperature profile, taken with the IR-camera at peak temperature. The figure also shows the locations of ROIs 1 to 5

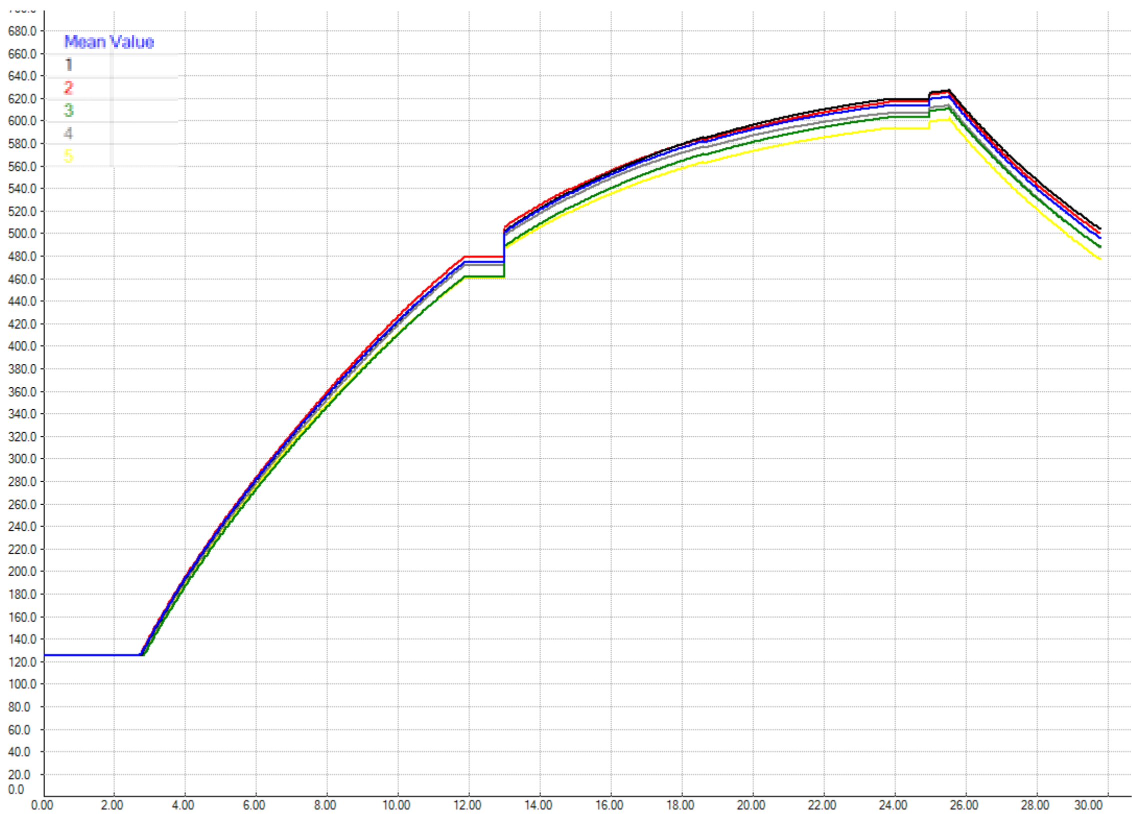


Figure 9: Temperature-time diagram of mean value and ROIs 1 to 5. The IR camera is using a shutter for regular calibration during the measurement, this causes kinks in the temperature curves

Conclusion

A new VCSEL module for heating of large sample areas was proven to yield high heating rates and very good homogeneity.
The system was equipped with 24 carefully distributed VCSEL emitters with a total infrared power of 9.6 kW. Heating rates of up to 51 K/s with a temperature uniformity of ± 8 K in air could be achieved for a Ø 300 mm Si-wafer.

This module concept can be scaled to higher performance by denser packing of emitters.
The maximum number of emitters usable for Ø 300 mm wafer heaters is 188, meaning 75.2 kW of total IR-power. Optical simulation of such a module are shown in figures 10 to 13. The circle in the figures represents a Ø 300 mm wafer.
Figure 10 shows the simulation of the IR-power distribution at 20 mm working distance. Such a configuration could be suitable for applications with rotating wafers.
For a more homogenous irradiation, additional mirrors should be used at the sides and the working distance should be larger. Figure 11 shows a simulation with a working distance of about 250 mm, that is suitable for homogeneous IR irradiation with 70 W/cm². This enables heating rates of Si-wafers up to 260 K/s.
However, a homogeneous illumination does not necessarily lead to a homogeneous temperature profile, e.g., due to application-related cooling effects. One big advantage of the VCSEL heating system is, that the power levels of every single zone of the 188 emitters can be controlled individually. As each emitter has two zones, there are 376 different power settings per module.
Figures 12 and 13 are demonstrating this benefit. A ring of emitters is switched off in these simulations. Figure 12 represents the intensity distribution at 20 mm distance, showing the switched-off emitters And figure 13 highlights the resulting intensity pattern at 250 mm working distance.

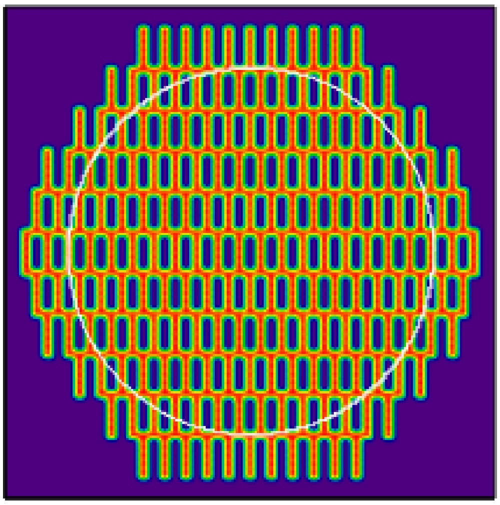


Figure 10: Optical simulation of a VCSEL module for wafer heating with 188 emitters at working distance of 20 mm

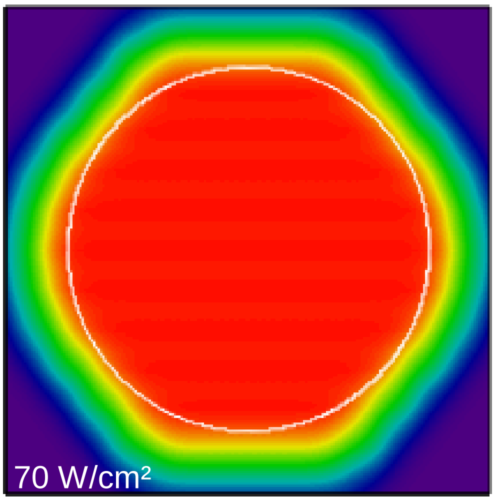
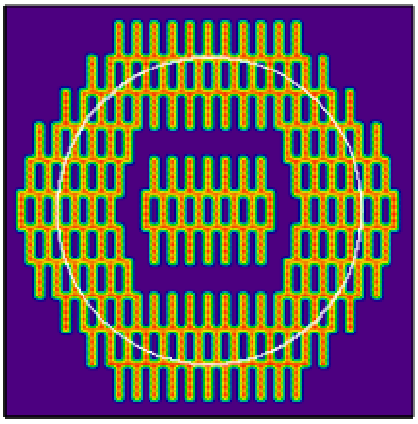


Figure 11: Optical simulation of a VCSEL module for wafer heating with 188 emitters at working distance of 250 mm



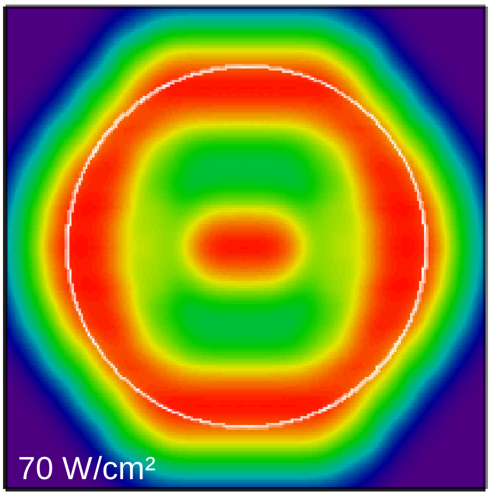


Figure 12 / 13: Optical simulations of a VCSEL module for wafer heating with 188 emitters at working distances of 20 and 250 mm

Conclusion

Depending on the application, a less dense packing of emitters can also offer advantages. Less dense packing creates free space, that can be used to integrate optical metrology, for temperature measurement on the wafer during processing. Thus, the measurement can be done from the same side as the wafer is irradiated by the VCSEL system. This could be from top or bottom side, anyway the VCSELs emit laser radiation only at a specific wavelength (in this application example at 980 nm). Therefore, it is possible to suppress interference with the optical metrology, by proper filtering of the radiation of the VCSELs.
Temperature measuring from the backside of wafer will exclude a negative influence of structure-based inhomogeneities of the emissivity at the front side of the wafer.

Other advantages of wafer heating with VCSEL high power heating systems are:

- Selective heating: the Si-wafer can be heated selectively by the laser radiation as Si has a high absorption at 980 nm
- Extremely long lifetime and high reliability of the VCSEL chips
- Slim design of the laser modules
- Very low service effort
- Easy customization: the total power, and therefore the system costs, can be customized between 9.6 and 75 kW for a 300 mm wafer, just by installation of the optimal number of emitters

With these application tests and simulations for wafer heating, it has been shown that large area heating with high power VCSEL emitters is feasible, scalable, cost effective and reliable. Furthermore, it enables new possibilities for rapid thermal processing (RTP).

For more informtion about the industrial heatings systems visit
www.trumpf.com/s/vcsel-heating-systems

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