High Power VCSEL Systems For Thermal Processing

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1. June 2016
“Digital Heating”: Get the Heat Where Needed

• Many industrial processes require heating, but are wasting energy
  - Not spatially selective ➔ Directed power on target only
  - Broad spectral distribution ➔ Single wavelength
  - Slow switching, poor control ➔ Precise & fast control

VCSEL Systems are the smart laser solution for large-area thermal processing!
VCSEL: Vertical Cavity Surface Emitting Laser-Diode

- On-wafer testing and chip selection
- LED-like assembly
- Robust against back reflection
- Standard wavelength 980 nm

VCSEL arrays: thousands of micro-lasers on a chip
Philips Photonics: Leader in VCSEL Technology

Core Value: VCSEL components

VCSEL production facility Ulm
Currently shipping 10M VCSELs per month, expecting doubling in 2016

Business segment

Components for Data communication & sensing

Sensors and illumination modules

High power systems for heating

Location

Ulm
Eindhoven
Aachen
Optical Interconnects - 10x Bandwidth, 10x Less Power

Exponential Growth of Data Traffic

- Active optical cables
  - Electrical interface
  - Transmitter / receiver in plug

- Direct silicon-to-optics interconnect: soon 5 Tb/s

12x14 VCSEL array

Google data center

Laser diodes

Photo diodes

4x 25Gbps

http://compass-eos.com
VCSEL Sensing Everywhere Soon

5-10 VCSEL in every Smart Phone

Illumination for Cameras

Multiple Watts of VCSEL in every car

Gesture Control

Body function

Environmental sensors

Night vision camera

Proximity sensing

High speed display connect

HDMI interconnect

Auto focus camera

high precision industrial sensors

www.st.com
High Power Lasers from Simple Building Blocks

**Single VCSELs**
- 30 µm
- 1-10 mW/VCSEL

**VCSEL array**
- 200 µm
- 1-2 W/mm²

**Assembled chip**
- 2 mm
- 2200 VCSELs/chip

**Chips in series**
- 2 mm
- 7 W/chip

**VCSEL Emitter**
- 400 W/emitter
- 20 mm

**High power modules**
- 2 – 50 kW/module

Presented at LASYS Lasers in Action Forum
Scalable Module Design

• Direct treatment of large areas
• 100 W/cm² power density at emission aperture
• Standard wavelengths 980 or 808 nm
• Compact
• Easy to integrate

4.8 kW module  emission area 104 x 40 mm²

9.6 kW module  emission area 209 x 40 mm²
VCSEL Heating Patterns

Simulated intensity distribution as a function of emitter – target distance

Large Systems:

5 x 19 kW (400 mm)

WD = 200mm

280mm

image size 500 x 500 mm²
Large Area Processing: Simulations for 12“ Wafer

Linear configuration of Standard modules: 168 Emitters – 67.2 kW – 52 W/cm²

Potential „Brick“ configuration: 112 Emitters – 44.8 kW – 42 W/cm²
Unique Feature: Flexible Control of Laser Zones

- Narrow laser zones controlled independently:
  - Flexible control of the heating profile
  - Fast switching & setting of heating power (milliseconds)
  - Closed-loop control possible

Heating zones enabling control of thermal profile

Structured thermal processing:
Flexible Control of Heating Profile

• Example measurements of intensity distribution with 9.6 kW VCSEL-System

Emission area: 209 x 40 mm²

• Measurement of intensity pattern
  – Heating of a thin plate
  – Initial temperature rise (< 1s)
    is a good measure of incident power density
  – Thermal map representing incident IR distribution

VCSEL module thin screen IR camera
Structured Heating Example

- IR camera image with VCSEL module at top
- Moving plastic sheet heated by structured laser treatment
- Variation of heating pattern in time

- Below: temperature profile
Layout of a Typical VCSEL Heating System

VCSEL heating module

Water cooling unit

Primary cooling water

Driver unit

Communication interface

Safety interlock

Air knife inlets

Purge gas
VCSEL Advantages for Heat Treatment

• Advantages over conventional heating:
  – High process speed energy density 100 W/cm²
  – Heat only when needed by fast switching
  – Heat only where needed by directed beam and tailored heating profiles
  – Narrow spectrum stable at all power levels
  – High lifetime 30 khrs expected

• Advantage over conventional diode lasers:
  – Area treatment by design instead of odd-shaped beam no expensive bulky optics or scanner systems
  – Lower cost by factor of 2-5 compared to standard diode laser systems
  – Machine-ready compact, easy to integrate, robust, safe against back reflection
Local Heating of Steel

- VCSELs can heat large target areas simultaneously
  - 10 s to reach 900°C at 1.50 mm steel thickness with 100 W/cm²
  - 2 s to reach 600°C at 0.25 mm steel thickness with 50 W/cm²

![Graph showing temperature vs. time for different power levels.]

- Selective softening of high-strength steel

![Diagram showing Vickers hardness after VCSEL treatment.]

*Note: Graphs and diagrams illustrate temperature-time behavior and hardness variations.*
Metallization Line Sintering In Solar Cell Production

• Successful VCSEL system integration in a commercial Fast Firing Line of Rehm Thermal Systems

• Test wafers were processed at Rehm and characterized by Fraunhofer ISE

• Experimental results:
  – Ultrafast temperature rise in 4 cm treatment length
  – Benchmark cell efficiency reached
  – New compact machine concepts may become feasible

![Graph showing temperature rise over time with a peak of 1050 K/s and 130 K/s for different conditions.](image)

![Image of a solar cell and a machine labeled as Fast Firing System](image)
Solar Cell Treatment

• Example for heat treatment up to 1000 °C
Plastics Welding

- Test conditions:
  - Standard VCSEL Module with 1.6kW IR power (980nm)
  - Pressurized sample holder
  - Samples: PP and PBT

- Simultaneous welding with 1s treatment time

Large area welding of PBT

Test pattern for microfluidic application
Foam Welding

• Test conditions:
  – Standard VCSEL Module with 1.6kW IR power (980nm)
  – Tests stationary and with linear motion

• Results:
  – very good joining quality possible
  – Black foam without absorber foil
  – Colored or white foam with absorber layer

Welding examples:

black foam without absorber foil
colored foam with absorber foil
Carbon Fiber Placement

- VCSEL modules integrated on the tape-laying head
  - 100W/cm² power density enabling high speed process
  - Controllable spatial heating profile
  - Controllable dynamic heating profile
  - Closed-loop control possible

1.6kW compact VCSEL module integrated into tape-laying equipment
Carbon Fiber Placement

Test setup at Fraunhofer IPT

Consolidation roller

Tape

Substrate

VCSEL module

Ring
Compact Module Concept for Fiber Placement

• Compact triangular form
  – Water cooling connection to module sides
  – Electrical connections adaptable to requirements

Example module 9.6 kW IR
• 24 VCSEL emitters
• emission area 209 x 40 mm²

Potential configurations for fiber placement:
Application Example:

Laser Edging of Furniture Panels

- High-quality solution for joining edge bands to wooden furniture panels
  - Plastics welding process yielding best edge quality
  - Tight seal by laser heating of special edge band

- Requirements:
  - high process speed > 15 m/min
  - direct heating with good uniformity
  - fast reconfiguration to material type and size
  - fast switching, precise power control
  - harsh environmental conditions

- Very limited volume available for laser module ⇒ Redesign of the standard laser housing

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Seamless Laser Edging of Furniture Panels – IMALUX

High power VCSEL system is integrated in professional woodworking machines (IMA Klessmann GmbH)

- Fast development time of the VCSEL module within 3 months
- Uniform direct heating, no optics
- Electronic control of heating zones
- Robust system operated in harsh environment
- Much lower cost than existing laser solutions
Conclusions

High power VCSEL systems are offering attractive solutions for industrial thermal processes

- High power density, enabling fast processing
- Precisely controllable, in time and spatially
- Scalable to any power level
- Compact, robust and easy to integrate
- Lower cost than conventional laser systems

Potential application fields
- Plastics welding & forming
- Composite manufacturing
- Coatings, curing, ...
- Photovoltaics
- Sheet & coil treatment
- ...?