U·L·M PHOTONICS

# Single Mode VCSEL

## 850nm,TO46,0.5mW

- Ideal circular gaussian beam
- Built-in ESD protection structure
- High reliability, 10 years @ 85℃

INVISIBLE LASER RADIATION
AVOID BEAM EXPOSURE
CLASS 3B LASER PRODUCT

## ELECTRO-OPTICAL CHARACTERISTICS

T=20℃ unless otherwise stated

| PARAMETER | SYMBOL | UNITS | MIN | TYP | MAX | TEST CONDITIONS |
|---|---|---|---|---|---|---|
| Emission wavelength | $\lambda_R$ | nm | 850 | 855 | 860 | $P_{OP}$=0.50 mW |
| Threshold current | $I_{TH}$ | mA | 0.2 | | 1.0 | |
| Laser current | $I_{OP}$ | mA | 0.7 | | 1.8 | $P_{opt}$=0.50 mW |
| Laser voltage | $U_{OP}$ | V | | | 2.2 | $P_{opt}$=0.50 mW |
| Slope efficiency | $\eta_S$ | W/A | 0.3 | | 0.7 | |
| Output power | $P_{opt}$ | mW | 0.5 | | | |
| Differential series resistance | $R_S$ | Ω | 30 | | 350 | $P_{opt}$=0.50 mW |
| Thermal resistance (VCSEL chip) | $R_{thermal}$ | K/mW | 3 | | 5 | |
| Beam divergence | θ | ° | 10 | | 15 | $P_{opt}$=0.50 mW, FWHM |
| Side mode suppression ratio | SMSR | dB | 10 | | | $P_{opt}$=0.50 mW |

## ABSOLUTE MAXIMUM RATINGS

| | |
|---|---|
| Storage temperature | -40 .. 125℃ |
| Operating temperature | -40 .. 85℃ |
| Electrical power dissipation | 7.5 mW |
| Continous forward laser current | 2 mA |
| Laser reverse voltage | 8V |
| Soldering temperature | 330℃ |

**NOTICE**: Stresses greater than those listed under „Absolute Maximum Ratings“ may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these or any other condition beyond those indicated for extended periods of time may effect device reliability.

**ATTENTION:** Electrostatic Sensitive Devices
Observe Precautions for Handling

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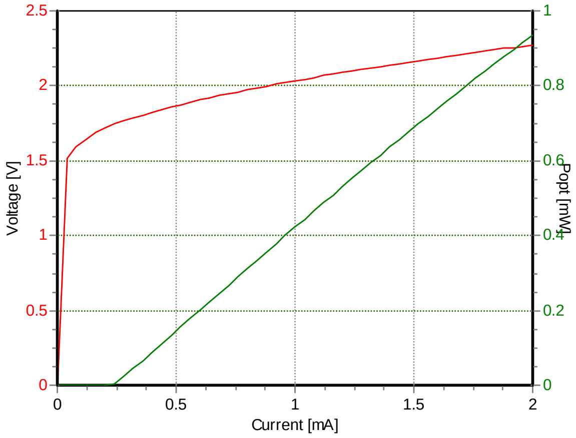
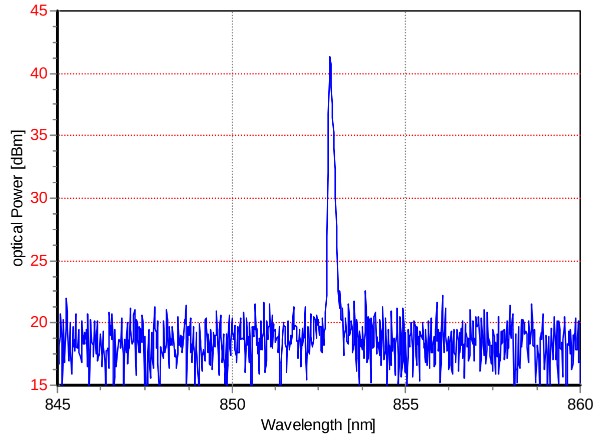
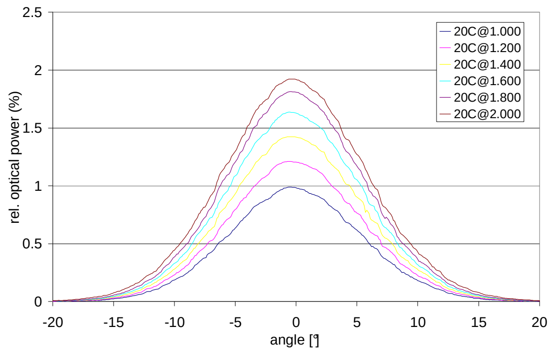
## Electro-optical characteristics




## Spectral Characteristics




## Farfield

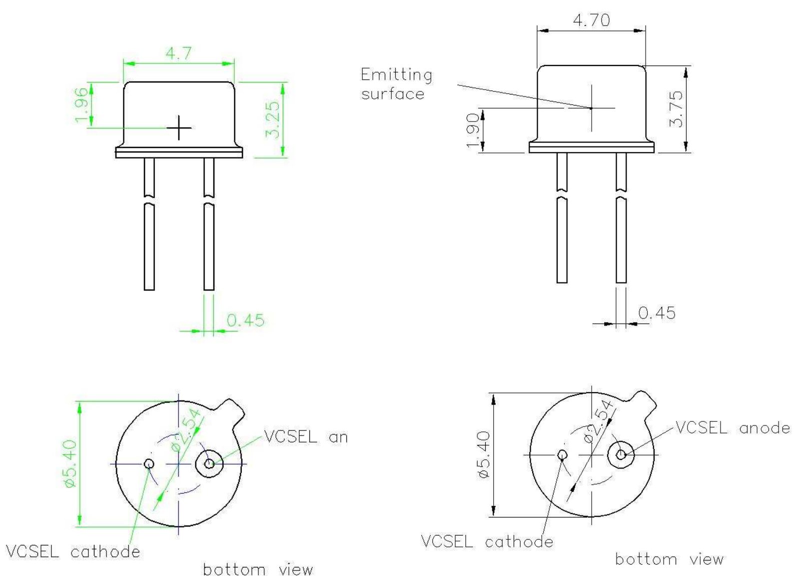



| | |
|---|---|
| ***Typ*** | **ULM850-OM-TN-S46XZP** |
| *Descriptn.* | 850nm SM VCSEL TO46 |
| *Cap* | Cap without glass window |
| ***Typ*** | **ULM850-OM-TN-S46FZP** |
| *Cap* | Flat window cap |

## Package / pin layout

without glass window

flat glass window

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U·L·M PHOTONICS

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# Low cost Single Mode VCSEL

## 850nm,TO46, 1.0mW

- Ideal circular gaussian beam
- Built-in ESD protection structure
- High reliability, 10 years @ 85℃

INVISIBLE LASER RADIATION
AVOID BEAM EXPOSURE
CLASS 3B LASER PRODUCT

## ELECTRO-OPTICAL CHARACTERISTICS

T=20℃ unless otherwise stated

| PARAMETER | SYMBOL | UNITS | MIN | TYP | MAX | TEST CONDITIONS |
|---|---|---|---|---|---|---|
| Emission wavelength | $\lambda_R$ | nm | 845 | 855 | 860 | $P_{OP}$=1.0 mW |
| Threshold current | $I_{TH}$ | mA | 0.2 | | 1.0 | |
| Laser current | $I_{OP}$ | mA | 1.2 | | 2.0 | $P_{opt}$=1.0 mW |
| Laser voltage | $U_{OP}$ | V | | | 2.6 | $P_{opt}$=1.0 mW |
| Slope efficiency | $\eta_S$ | W/A | 0.5 | | 0.9 | |
| Output power | $P_{opt}$ | mW | 1 | | | $I_{OP}$=2.0mA |
| Differential series resistance | $R_S$ | Ω | 30 | | 350 | $P_{opt}$=1.0 mW |
| Thermal resistance (VCSEL chip) | $R_{thermal}$ | K/mW | 3 | | 5 | |
| Beam divergence | θ | ° | 10 | | 20 | $P_{opt}$=1.0 mW, FWHM |
| Side mode suppression ratio | SMSR | dB | 10 | | | $P_{opt}$=1.0 mW |
| ESD damage threshold | | V | 2000 | | | human body model |
| Wavelength tuning over temperature | | nm/K | | 0.06 | | |

## ABSOLUTE MAXIMUM RATINGS

| | |
|---|---|
| Storage temperature | -40 .. 125℃ |
| Operating temperature | -40 .. 85℃ |
| Electrical power dissipation | 7.5 mW |
| Continous forward laser current | 2.5 mA |
| Laser reverse voltage | 8V |
| Soldering temperature | 330℃ |

**NOTICE**: Stresses greater than those listed under „Absolute Maximum Ratings“ may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these or any other condition beyond those indicated for extended periods of time may effect device reliability.

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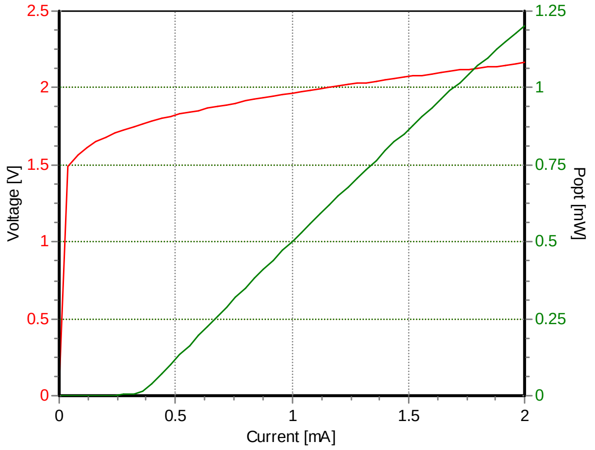
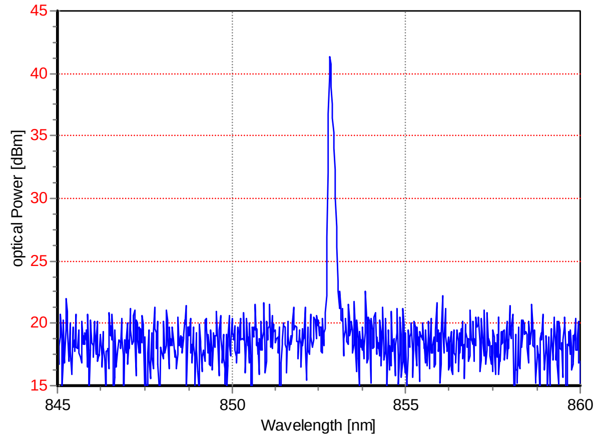
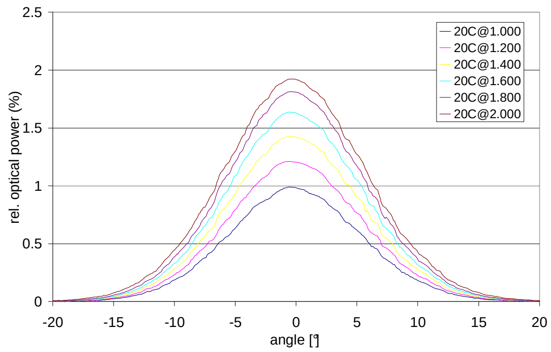
## Electro-optical characteristics




## Spectral Characteristics



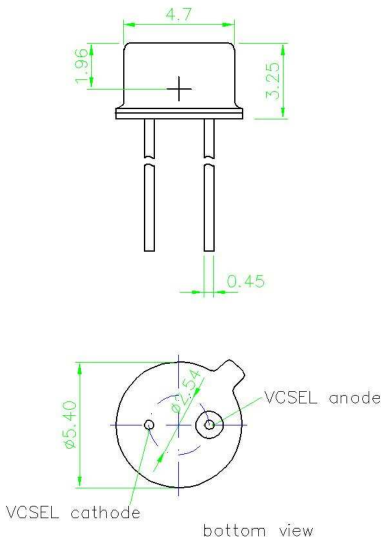

## Farfield



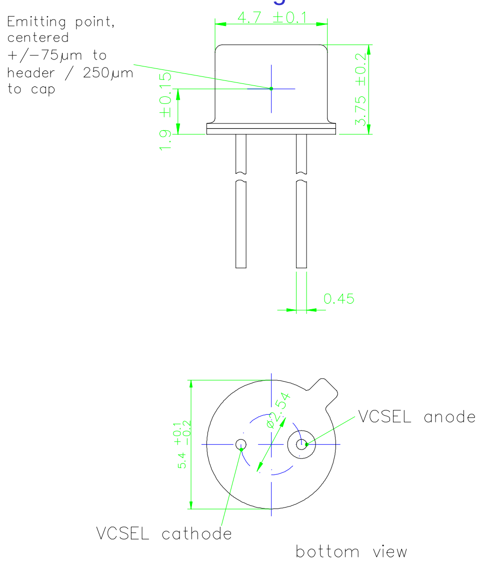

| | |
|---|---|
| *Typ* | **ULM850-PM-TN-S46XZP** |
| *Descriptn.* | 850nm SM VCSEL TO46 |
| *Cap* | Cap without glass window |
| *Typ* | **ULM850-PM-TN-S46FZP** |
| *Cap* | Flat window cap |

## Package / pin layout

without glass window




flat glass window



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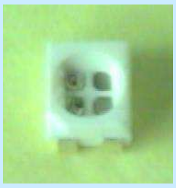
U·L·M PHOTONICS

# Single Mode VCSEL 850nm



- SMD package
- without encapsulation
- ESD protection

INVISIBLE LASER RADIATION
AVOID BEAM EXPOSURE
CLASS 3B LASER PRODUCT

## ELECTRO-OPTICAL CHARACTERISTICS

T=20℃ unless otherwise stated

| PARAMETER | SYMBOL | UNITS | MIN | TYP | MAX | TEST CONDITIONS |
|---|---|---|---|---|---|---|
| Emission wavelength | $\lambda_R$ | nm | 850 | 855 | 860 | $P_{OP}$=0.53 mW |
| Threshold current | $I_{TH}$ | mA | 0.2 | | 1.0 | |
| Laser current | $I_{OP}$ | mA | 1.0 | | 1.8 | $P_{opt}$=0.53 mW |
| Laser voltage | $U_{OP}$ | V | | | 2.2 | $P_{opt}$=0.53 mW |
| Slope efficiency | $\eta_S$ | W/A | 0.3 | | 0.7 | |
| Output power | $P_{opt}$ | µW | 273 | 530 | 780 | |
| Differential series resistance | $R_S$ | Ω | 30 | | 350 | $P_{opt}$=0.53 mW |
| Thermal resistance (VCSEL chip) | $R_{thermal}$ | K/mW | 3 | | 5 | |
| Beam divergence | θ | ° | 10 | | 15 | $P_{opt}$=0.53 mW, FWHM |
| Side mode suppression ratio | SMSR | dB | 10 | | | $P_{opt}$=0.53 mW |
| ESD damage threshold | | V | | 2000 | | human body model |

## Binning table:

**(Laser current for 0.53mW output power)**

| | |
|---|---|
| bin1 | 1.1 mA |
| bin2 | 1.3 mA |
| bin3 | 1.48 mA |
| bin4 | 1.65 mA |

according to 5% driver current tolerance and 68% AEL (530µW)

## ABSOLUTE MAXIMUM RATINGS

| | |
|---|---|
| Storage temperature | -40 .. 125℃ |
| Operating temperature | -40 .. 85℃ |
| Electrical power dissipation | 7.5 mW |
| Continous forward laser current | 3 mA |
| Laser reverse voltage | 8V |
| Soldering temperature | 260℃ |

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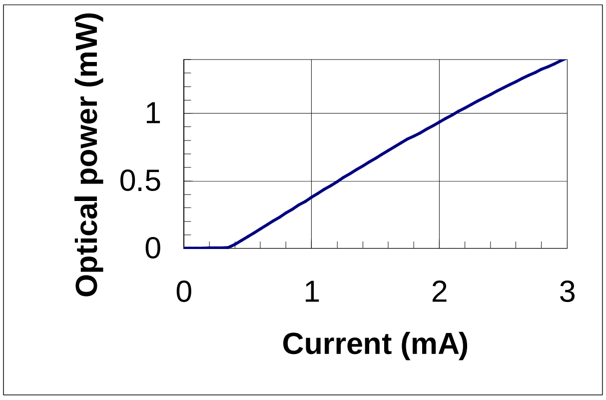
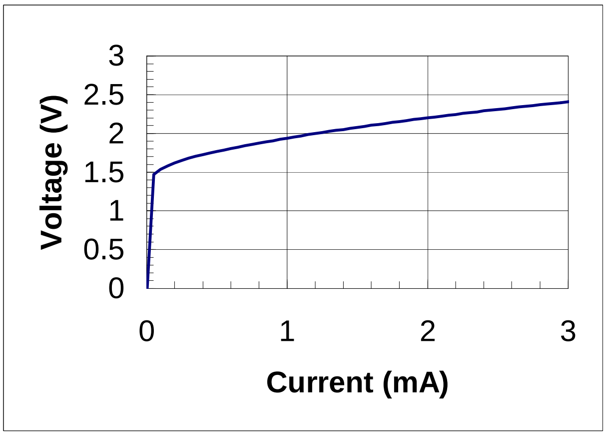
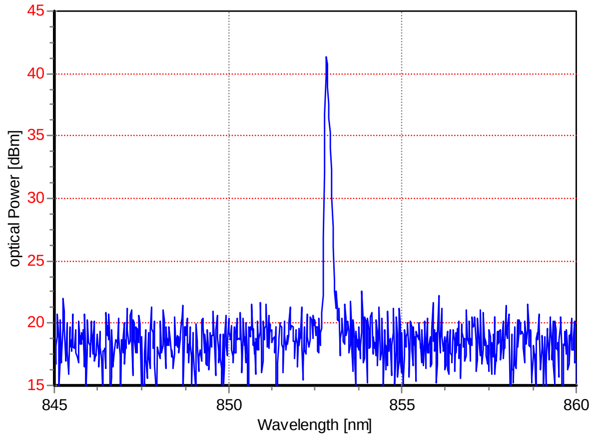
## Electro-optical characteristics

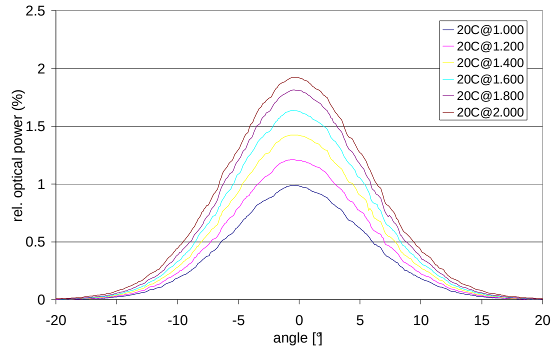


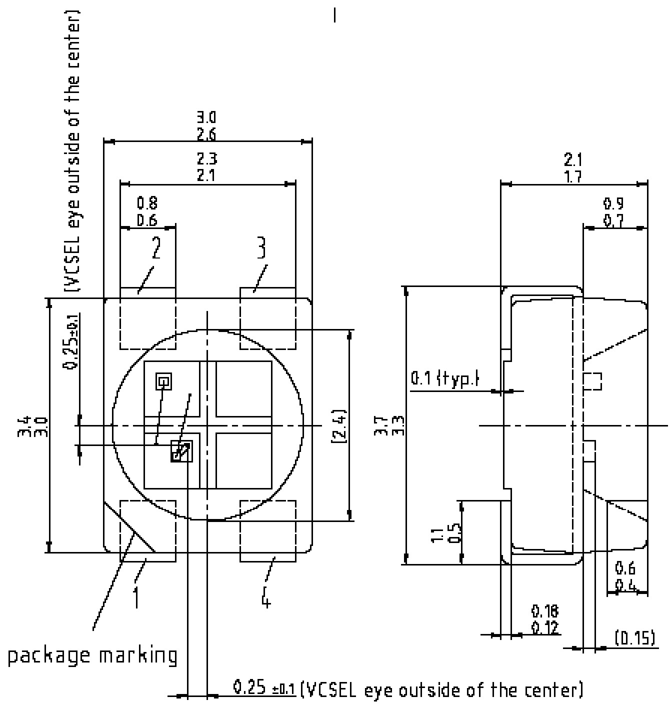

## Spectral Characteristics




## Farfield




| | |
|---|---|
| *Typ* | ULM855-G2-TN-SSMDTL |
| *Descriptn.* | **855nm SM VCSEL** |
| | SMD package |




## Package / pin layout:

PIN 1: VCSEL cathode
PIN 2: VCSEL anode
(all units in mm)

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PRELIMINARY
Specifications are subject to change without notice

# Single Mode VCSEL

## 850nm,TO46, 0.3mW
## single-mode single-polarization

- Ideal circular gaussian beam
- Stable Polarization
- Built-in ESD protection structure
- High reliability, >10⁵ h @ 40°C, 0.3 mW

INVISIBLE LASER RADIATION
AVOID BEAM EXPOSURE
CLASS 3B LASER PRODUCT

## ELECTRO-OPTICAL CHARACTERISTICS

| PARAMETER | SYMBOL | UNITS | MIN | TYP | MAX | TEST CONDITIONS |
|---|---|---|---|---|---|---|
| Emission wavelength | $?_R$ | nm | 845 | 855 | 865 | T=20°C, $P_{OP}$=0.3 mW |
| Threshold current | $I_{TH}$ | mA | 0.2 | | 1.1 | T=20°C |
| Laser current | $I_{OP}$ | mA | 0.8 | | 3.0 | $P_{opt}$=0.3 mW, T=20°C |
| Laser voltage | $U_{OP}$ | V | | | 2.8 | $P_{opt}$=0.3 mW, T=20°C |
| Slope efficiency | $?_S$ | W/A | 0.1 | | 1 | T= 20°C |
| Output power | $P_{opt}$ | mW | 0.3 | | 2 | $I_{OP}$=3.0mA, T=20°C |
| Differential series resistance | $R_S$ | Ohm | 100 | | 350 | $P_{opt}$=0.3 mW |
| Thermal resistance (VCSEL chip) | $R_{thermal}$ | K/mW | 3 | | 5 | |
| Beam divergence | ? | ° | 10 | | 20 | $P_{opt}$=0.3 mW, FWHM |
| Side mode suppression ratio | SMSR | dB | 15 | | | $P_{opt}$=0.3 mW |
| ESD damage threshold | | V | 2000 | | | human body model |
| Wavelength tuning over temperature | | nm/K | | 0.06 | | |

NOTE: Polarization control by optical design

## ABSOLUTE MAXIMUM RATINGS

| | |
|---|---|
| Storage temperature | -40 .. 125°C |
| Operating temperature | 0 .. 50°C |
| Electrical power dissipation | 7.5 mW |
| Continous forward laser current | 3.3 mA |
| Laser reverse voltage | 8V |
| Soldering temperature | 330°C |

**NOTICE**: Stresses greater than those listed under „Absolute Maximum Ratings“ may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these or any other condition beyond those indicated for extended periods of time may effect device reliability.

**ATTENTION:** Electrostatic Sensitive Devices
Observe Precautions for Handling

v2

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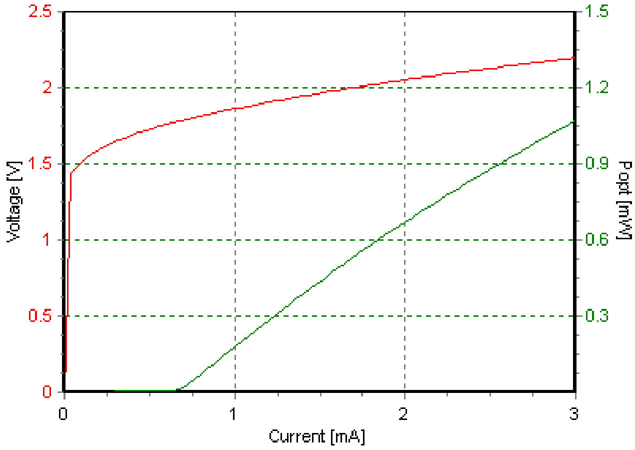
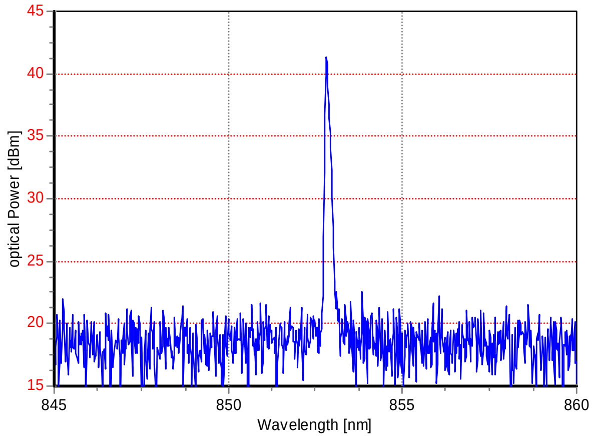
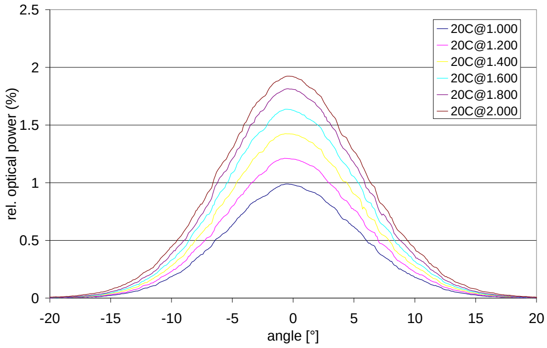
## Electro-optical characteristics




## Spectral Characteristics



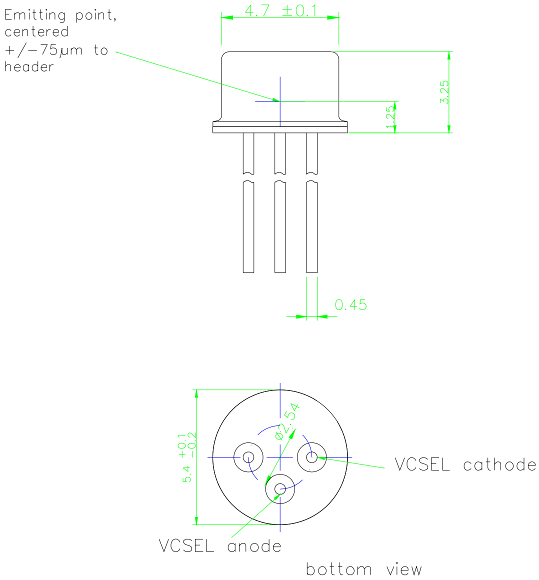

## Farfield




| | |
|---|---|
| *Typ* | **ULM850-VP-PL-S46XOP** |
| *Descriptn.* | 850nm SM VCSEL TO46 |
| *Cap* | Cap without glass window |

## Package / pin layout

without glass window




v2

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LASER COMPONENTS

U·L·M PHOTONICS

# Single mode & polarization VCSEL

## 850nm,TO46, 0.7mW

- Single-mode & single-polarization
- Ideal circular gaussian beam
- Stable Polarization
- Built-in ESD protection structure
- High reliability, 10 years @ 85℃

INVISIBLE LASER RADIATION
AVOID BEAM EXPOSURE
CLASS 3B LASER PRODUCT

**Preliminary**

### ELECTRO-OPTICAL CHARACTERISTICS

T=20℃ unless otherwise stated

| PARAMETER | SYMBOL | UNITS | MIN | TYP | MAX | TEST CONDITIONS |
|---|---|---|---|---|---|---|
| Emission wavelength | $\lambda_R$ | nm | 845 | 855 | 860 | $P_{OP}$=0.7 mW |
| Threshold current | $I_{TH}$ | mA | 0.2 | | 1.0 | |
| Laser current | $I_{OP}$ | mA | 1.2 | | 3.0 | $P_{opt}$=0.7 mW |
| Laser voltage | $U_{OP}$ | V | | | 2.6 | $P_{opt}$=0.7 mW |
| Slope efficiency | $\eta_S$ | W/A | 0.4 | | 0.9 | |
| Output power | $P_{opt}$ | mW | 0.7 | | | $I_{OP}$=3.0mA |
| Differential series resistance | $R_S$ | Ω | 150 | | 350 | $P_{opt}$=0.7 mW |
| Thermal resistance (VCSEL chip) | $R_{thermal}$ | K/mW | 3 | | 5 | |
| Beam divergence | θ | ° | 10 | | 20 | $P_{opt}$=0.7 mW, FWHM |
| Side mode suppression ratio | SMSR | dB | 10 | | | $P_{opt}$=0.7 mW |
| ESD damage threshold | | V | 2000 | | | human body model |
| Wavelength tuning over temperature | | nm/K | | 0.06 | | |

NOTE: Polarization control by optical design

### ABSOLUTE MAXIMUM RATINGS

| | |
|---|---|
| Storage temperature | -40 .. 125℃ |
| Operating temperature | -40 .. 85℃ |
| Electrical power dissipation | 7.5 mW |
| Continous forward laser current | 3.1 mA |
| Laser reverse voltage | 8V |
| Soldering temperature | 330℃ |

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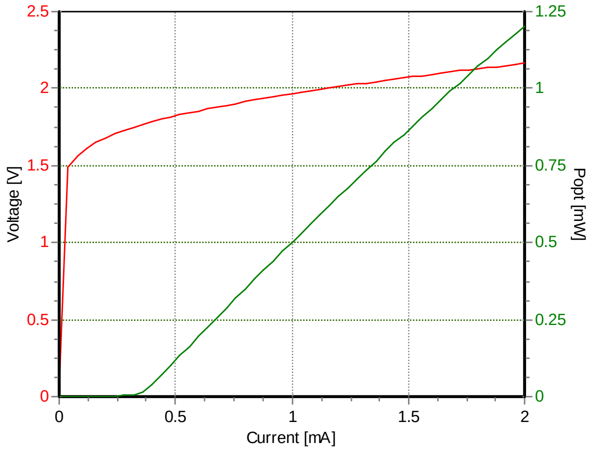
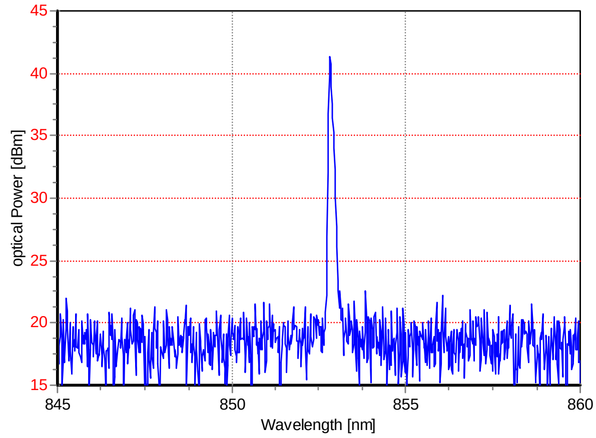
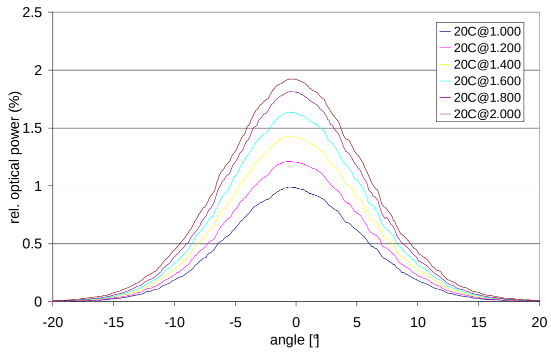
# Electro-optical characteristics




# Spectral Characteristics



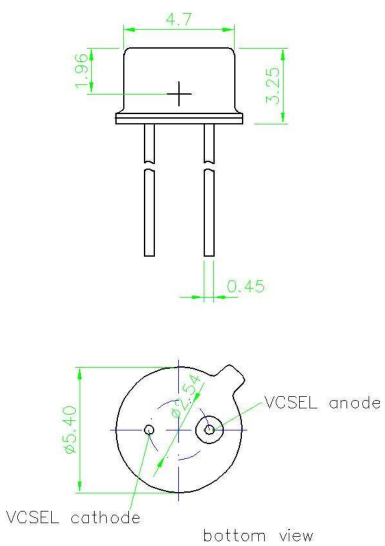

# Farfield



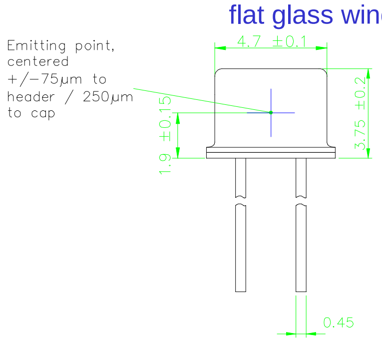

| | |
|---|---|
| ***Typ*** | **ULM850-PM-PL-S46XZP** |
| *Descriptn.* | 850nm SM VCSEL TO46 |
| *Cap* | Cap without glass window |
| ***Typ*** | **ULM850-PM-PL-S46FZP** |
| *Cap* | Flat window cap |

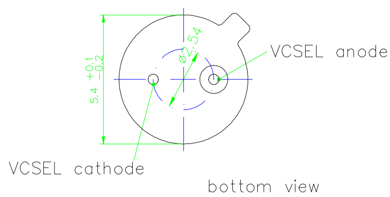
# Package / pin layout

without glass window




flat glass window





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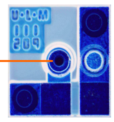
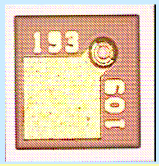


# Single mode & polarization VCSEL

## 850nm

- Single-mode & stable linear polarization
- Ultra low current requirement and power consumption
- Ideally for wireless laser mouse and trackball application in mobile phone



INVISIBLE LASER RADIATION
AVOID BEAM EXPOSURE
CLASS 3B LASER PRODUCT

**Preliminary**

### ELECTRO-OPTICAL CHARACTERISTICS

T=25℃ unless otherwise stated

| PARAMETER | SYMBOL | UNITS | MIN | TYP | MAX | TEST CONDITIONS |
|---|---|---|---|---|---|---|
| Emission wavelength | $\lambda_R$ | nm | 840 | | 860 | |
| Threshold current | $I_{TH}$ | mA | | 0.6 | 1.5 | |
| Laser current | $I_{op}$ | mA | | 1.4 | 2.0 | Output power = 0.45mW |
| Laser voltage | $U_{OP}$ | V | | | 2.6 | |
| Slope efficiency | $\eta_S$ | W/A | | 0.6 | | |
| Differential series resistance | $R_S$ | Ω | | 200 | | |
| Beam divergence | θ | ° | 15 | | 22 | 1/e^2; Output power = 0.45mW |
| Side mode suppression ratio | SMSR | dB | 6 | 20 | | Output power = 0.45mW |
| ESD damage threshold | | V | 50 | 70 | | human body model |
| Dynamic polarization flips | | | | | 0 | |

### ABSOLUTE MAXIMUM RATINGS

| | |
|---|---|
| Storage temperature | -40 .. 70℃ |
| Operating temperature | 5 .. 45℃ |
| Output power | 3 mW |
| Continous forward laser current | 3.3 mA |
| Laser reverse voltage | 8V |
| Soldering temperature | 300℃ |

**NOTICE**: Stresses greater than those listed under „Absolute Maximum Ratings“ may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these or any other condition beyond those indicated for extended periods of time may effect device reliability.

**ATTENTION:** Electrostatic Sensitive Devices
Observe Precautions for Handling

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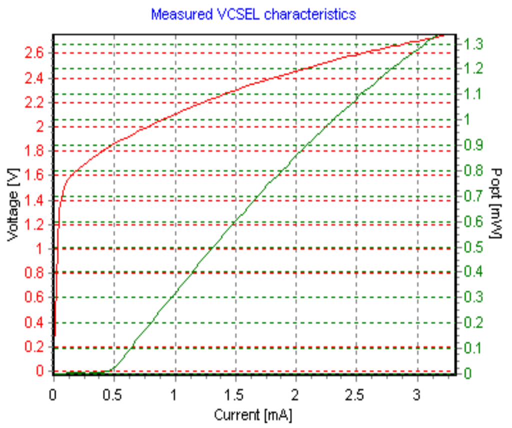
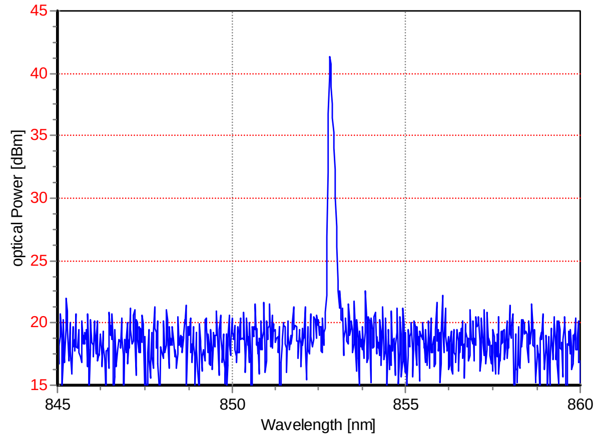
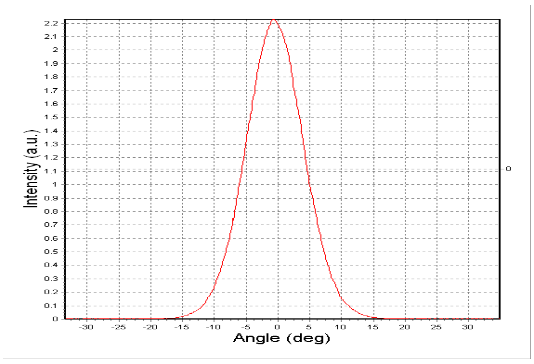
## Electro-optical characteristics



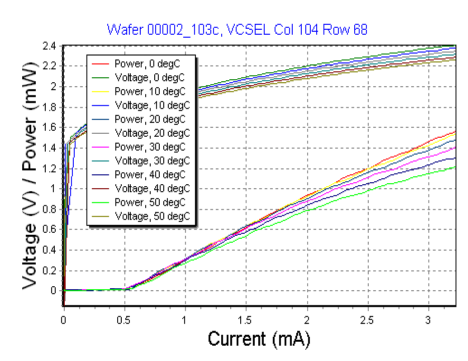

## Spectral Characteristics




## Farfield

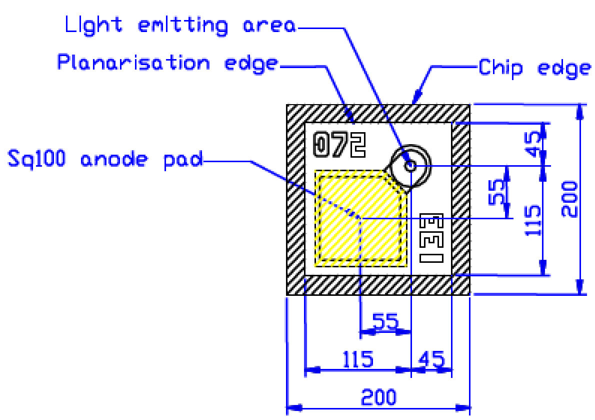



## Properties over temperature




**ULM850-L2-PL-S0101U**

(Single mode with polarization locking, backside cathode contact) Size 200x200x150




unit: µm

## OPTION: TO headers & caps (flat, tilted, ball) or other packages on request

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# Volume production of polarization controlled single-mode VCSELs

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Denise Duckeck, Christian Wimmer
U-L-M photonics GmbH

## ABSTRACT

Over the past 3 years laser based tracking systems for optical PC mice have outnumbered the traditional VCSEL market datacom by far. Whereas VCSEL for datacom in the 850 nm regime emit in multipe transverse modes, all laser based tracking systems demand for single-mode operation which require advanced manufacturing technology. Next generation tracking systems even require single-polarization characteristics in order to avoid unwanted movement of the pointer due to polarization flips. High volume manufacturing and optimized production methods are crucial for achieving the addressed technical and commercial targets of this consumer market. The resulting ideal laser source which emits single-mode and single-polarization at low cost is also a promising platform for further applications like tuneable diode laser absorption spectroscopy (TDLAS) or miniature atomic clocks when adapted to the according wavelengths.

Keywords: VCSEL, single-mode, single-polarization, volume production

## INTRODUCTION

Single-mode VCSELs have been regarded as scientific eccentrics in the early 90ths. Introducing single-mode VCSELs to niche markets like spectroscopy or encoders improved the production techniques significantly. Today, high volume production of single-mode VCSELs in the order of several 10 Mio pcs is reality. The next step in exploiting the uniquenesses of VCSEL technology is the control of the polarization of the fundamental mode. In the past, several techniques have been investigated in order to control the polarization or at least enhance the preferred polarization orientation. The common approach of all investigations has been breaking the high symmetry of the vertical cavity laser system. Among the different approaches are EPI growth on higher order substrates [1,2], highly strained QWs [3], elipically shaped mesa geometries [4,5], and external mechanical stress [6].

We present an approach that makes use of a shallow etched surface grating which offers multiple advantages. No change in the established manufacturing platform for conventional single-mode VCSELs is required and the additional technological steps can easily be implemented into the existing process flow.

The polarization control mechanism is strong enough to guarantee the polarization behavior by design. Statistical data show that thorough process control is sufficient to predict the final laser polarization performance. The influence of the surface grating on the basic laser performance is presented and volume manufacturability is discussed.

## APPLICATIONS

The driving market for single-mode VCSELs is the laser based PC mouse. Two main tracking technologies are using the performance uniquenesses of 850 nm single-mode VCSELs: frame comparison and laser self-mixing [7]. Further PC peripheral devices, especially input devices like pens, or track balls, can be equipped with VCSEL based tracking systems.

Besides those consumer electronic devices, the advanced laser performance is attractive for other systems, e.g. laser absorption spectroscopy (TDLAS) used in oxygen or moisture detection, or miniature atomic clocks. The technology platform needs to be adjusted to the according laser wavelengths of 760 nm for oxygen, 948 nm for moisture, and 780, 795, 852, or 894 nm for miniature atomic clocks [8].

The grating technology which is discussed can be adapted to all mentioned wavelengths that are based on the material system InAlGaAs.

## GRATING DESIGN

The basic effect that is exploited for the polarization control makes us of a surface grating that provides a polarization dependent effective reflectivity. A full vectorial modell [9] supports the design rules used for the device manufacturing.

For a grating pitch below the emission wavelength no higher order diffraction maxima appear in the farfield [10]. The filling factor of the surface grating (etched versus unetched area) is chosen to about 50 %. The nominal etching depth for maximum polarization selective effect is a quarter wavelength which amounts to about 55 nm. The orientation of the grating can be aligned to the main crystal axis. For mass manufacturing a good matching of the design tolerance window and the process tolerance window is crucial due to the high sensitivity of laser performance on process related grating characteristics.

## EPITAXY AND PROCESSING INCL. SURFACE GRATINGS

The epitxial design is identical to standard single-mode VCSELs and consists of a highly reflective n-type DBR, 3 GaAs QWs embedded in a GRINSCH type inner cavity, and a p-type DBR with carbon doping. State of the art mesa etching and wet oxidation is laterally confining the current as well as the optical field. P-contact deposition on top of the mesa and full area cathode on the substrate are used for electrical connection [11]. The emission in the fundamental transverse mode is enforced by the small lateral dimension of the current aperture. In an early phase of the manufacturing process, the surface gratings are etched into the top layer of the wafer. E-beam lithography or imprint technology can be used to create the sub-wavelength grating mask. Whereas E-beam lithography is well known and approved for the relevant geometries, imprint technology is a rather new technology and its use for sub-wavelength surface patterning for VCSELs has only recently be introduced [12]. The grating geometry is transferred to the GaAs by unisotropic RIE etching, where etch rates, etch depths, and homogenieties have to be controlled extremely well in order to hit the small tolerance window for the etching depths of better than +/- 10 nm across the wafer.

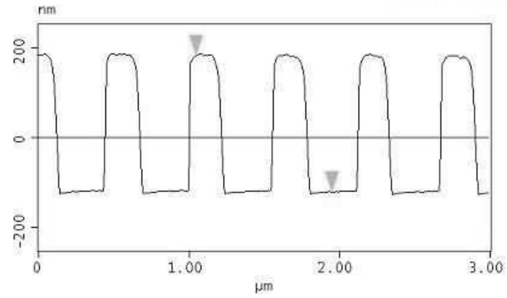



Figure 1: E-Beam resist mask after development for etching of the sub-wavelength grating

In Figure 1 a typical E-Beam resist mask after development is shown, the resist thickness is about 300 nm. The 550 nm pitch, duty cycles around 50 %, and nice sidewall steepness can be seen, which allows for straight forward pattern etching. The measurements are taken by Atomic Force Microsocopy.

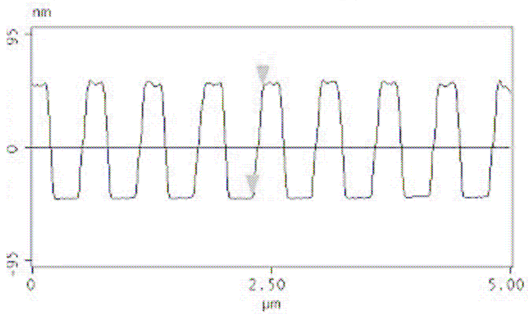



Figure 2: Imprint mask for etching of the sub-wavelength grating

Using imprint technology for the masking results in almost identical mask geometries as can be seen in Figure 2. Again the sidewall quality and the 100 nm thickness of the SiO2 mask is well suited for the subsequent RIE etching. Figure 3 illustrates the highly accurate features of the imprinted mask on top of the VCSEL mesa.

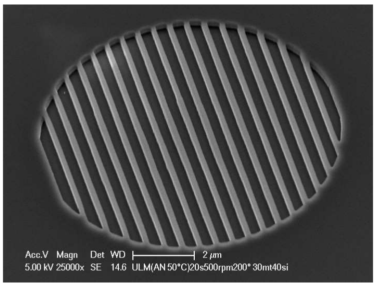


Figure 3: SEM picture of the imprinted area on the emission window.

After RIE etching the grating is transferred to the top layer of the semiconductor stack. Figure 4 shows the resulting grating topographie. The RIE process is optimized to cause minimum crystal defects. The etching needs to be unisotropic and the homogeneity across the 3 inch wafer has to be better than +/- 7 %.

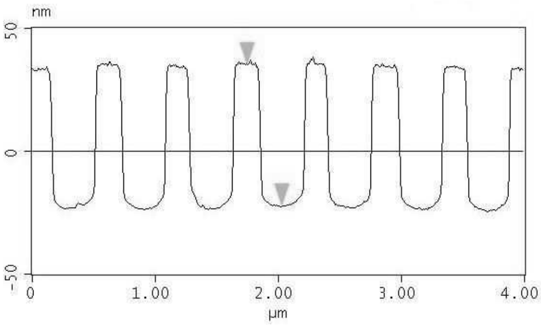



Figure 4: VCSEL surface with sub-wavelength grating etched into GaAs

The fully processed mesa including the surface grating and the p-type contact is presented in Figure 5. The grating which can be seen by an optical microscope is centered in the p-type ring contact with a 10 µm opening.

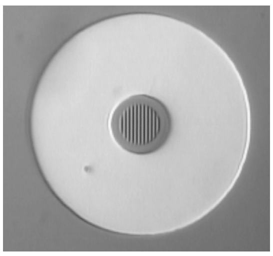


Figure 5: Surface grating in the emission window of a single-mode VCSEL

The grating performance is identical for both masking technologies E-Beam and nano-imprint. There are two main non-technical advantages of nano-imprinting compared to E-beam, which are processing cost per wafer and higher throughput due to short process time. Thus nano-imprint is a good candidate for sub wavelength masking technology in volume production.

## LIV, SPECTRAL, AND POLARIZATION CHARACTERISTICS

For comparison, Figure 6 shows LIV characteristics at room temperature for a reference device without surface grating. Threshold current is 0.45 mA, slope efficiency is 0.65 W/A, and the operation current for 1 mW of output power amounts to 1.8 mA.

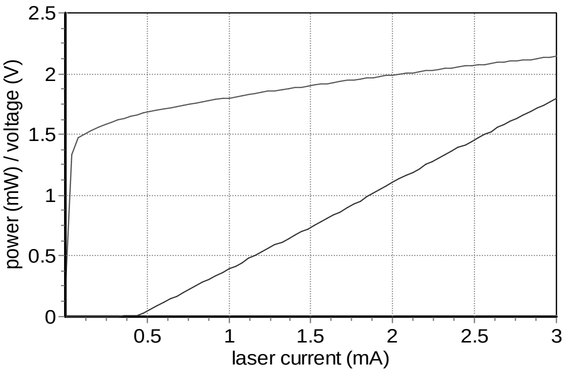



Figure 6: LIV characteristics of the reference device.

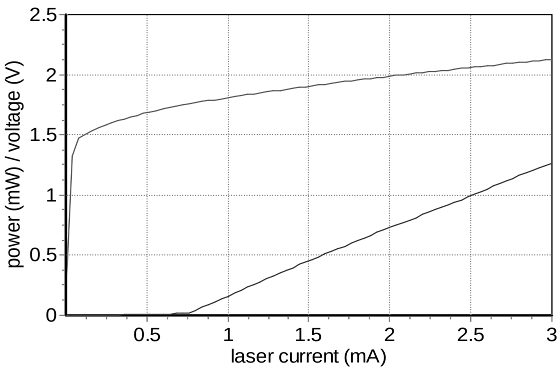
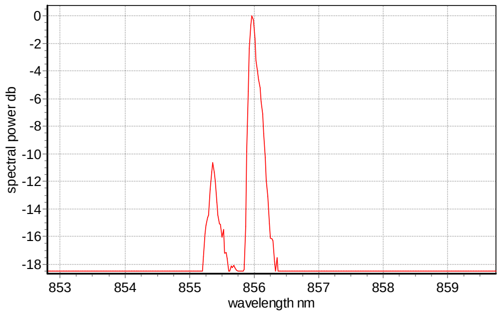



Figure 7: LIV characteristics of the standard polarization controlled device.

Applying the strongest effect to the polarization locking surface grating, the LIV characteristics are significantly affected by the incorporated optical losses. Figure 7 presents the according LIV graphs of a polarization controlled device produced on the identical wafer, where an increase of threshold current to 0.75 mA and an accompaning reduction of slope efficiency to 0.55 W/A are seen. The drawbacks are mostly due to diffraction losses. Consequently the operation current for 1 mW of output power is increased to 2.5 mA. As can be expected, the current-voltage characteristics are not affected by the surface grating.



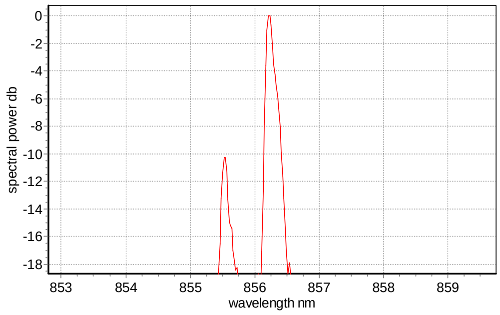




Figure 8: Optical spectra at 1mW for a standard single-mode VCSEL (left) and a polarization stabilized VCSEL (right).

In Figure 8 both optical spectra for the standard and the polarization controlled single-mode VCSEL are depicted. As you can see, no performance drop in terms of spectral purity can be seen at the operating conditions of 1 mW optical output as both spectra show a SMSR of more than 10 dB.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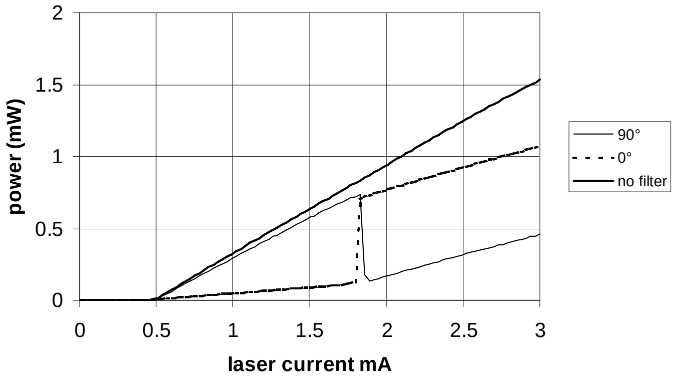


Figure 9: Typical polarization flip behavior of a standard single-mode VCSEL. The output power for the dashed and light line is measured through a polarizer at 0° and 90° rspectively, thus the sudden power drop, respectively power increase, indicates a polarization flip.

A typical polarization flip is shown in Figure 9 for a reference device. The laser starts emitting in 90° polarization orientation and flips it's orientation at 1.8 mA laser current to the perpendicular orientation. For a fixed temperature, the laser current at which the device flips its polarization orientation is reproducible. Polarization flips accur for only few % of devices and only at a specific set of laser currents and ambient temperatures. Statistical investigation on polarization flips is therefore quite difficult. Even if no polarization flips are observed at certain operation conditions, flips might occur in the application due to changes in temperature or laser currents. Applying long pulses in the kHz frequency range and thus changing the cavity temperature and current density in short time is a good way to initiate potential polarization flips. The graph in Figure 10 depicts the optical output of a device operated at 1 kHz repetition rate with a 70 % duty cycle. The output power Popt is filtered by a polarizer. The first 5 pulses do not show any polarization flips, but during pulses 6, 8, and 9 the polarization orientation is flipping after few 100 µs, identified by the sudden power drop.

Using a polarization filter when measuring the optical power in such a pulsed operation leads to identifying suspicious lasers. All wafers without polarization control show at least a small percentage of flipping devices.

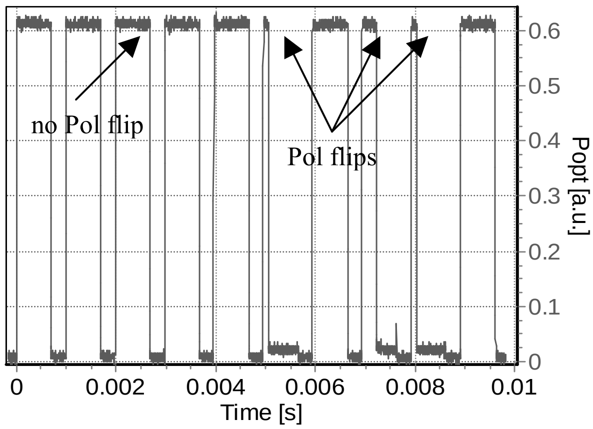


Figure 10: Polarization flip in dynamic operation. Pulse repetition rate is 1 kHz. Optical power is detected through a polarizer. A polarization flip is observed by the sudden power drop within the pulse when measuring the peak power through a polarizer.

For polarization controlled VCSELs we do not detect any flips in polarization when having a minimum of 1000 devices per wafer under test.

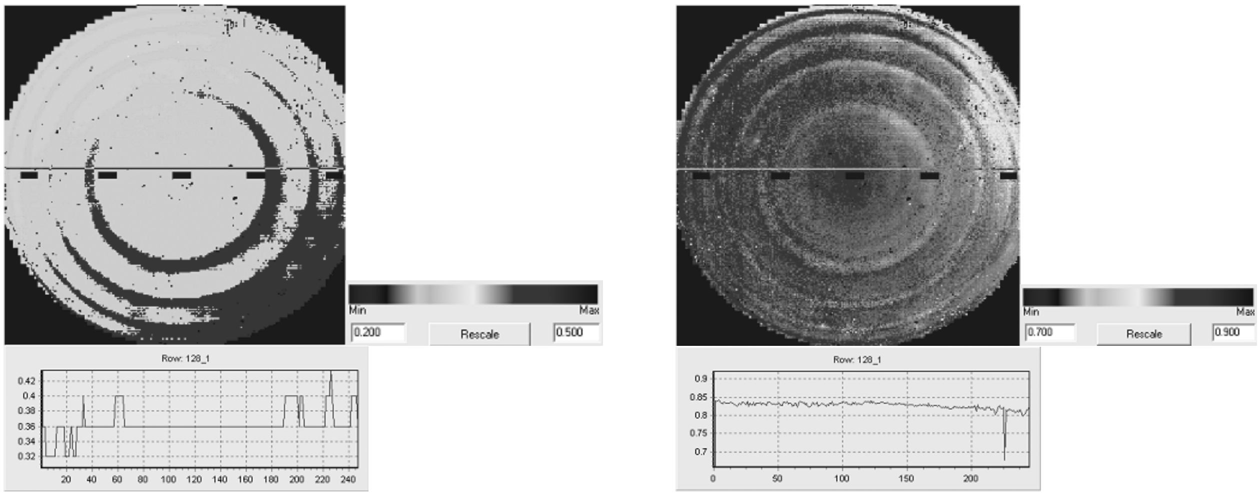


Figure 11: Threshold current (left) and slope efficiency (right) distribution across a 3 inch standard single-mode VCSEL wafer. The values are in mA and W/A, respectively.

In Figure 11 a wafer map for standard single-mode VCSELs is shown, both threshold current and slope efficiency distribution is presented. The threshold current variation is 0.32 to 0.40 mA (+/- 6 %) along 250 devices across the 3 inch wafer, the slope efficiency varies from 0.80 W/A to 0.84 W/A (+/- 2.5 %)
In comparison, Figure 12 depicts the same laser parameters for a polarization controlled single-mode VCSEL wafer. The according on wafer variations are +/- 9 % for the threshold current and +/- 5 % for the slope efficiency, respectively.

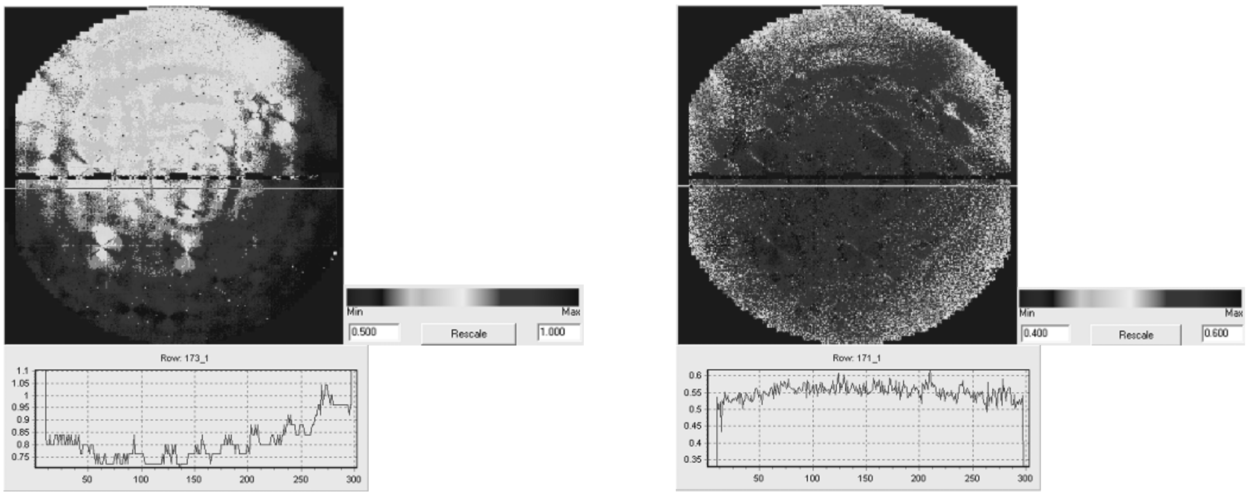


Figure 12: Threshold current (left) and slope efficiency (right) distribution across a 3 inch polarization controlled single-mode VCSEL wafer. The values are in mA and W/A, respectively.

The already discussed impact on increased threshold current and reduced slope efficiency is also seen in the wafer maps above. For the standard and the polarization controlled devices the average values for the threshold currents are 0.4 and 0.8 mA, respectively, and the average slope efficiencies amount to 0.83 nd 0.55 W/A, respectively.
For the surface grating devices, more variation of laser performance parameters are seen, which is due to small variations in the gratings for each device. Although the absolute electro-optical laser characteristics suffer from the polarization control and in addition the laser-to-laser homogeneity is a bit worse, the presented technology for polarization control qualifies for volume production.

## RELIABILITY

Etching of surface gratings in the laser facett may cause negative impact on the laser reliability. In order to minimize crystal effects by reactive ion etching, a very soft process is chosen. Analysis of accelerated lifetime tests as well as operation at high humdity and high temperature shows no deviation from reiability data observed for standard single-mode devices. In Figure 13 preliminary TTF data (no failure accured so far) are depicted and in Figure 14 the according data point in the arrhenius plot is presented. The test conditions are 125°C heat sink temperature and 2.5 mA laser current.

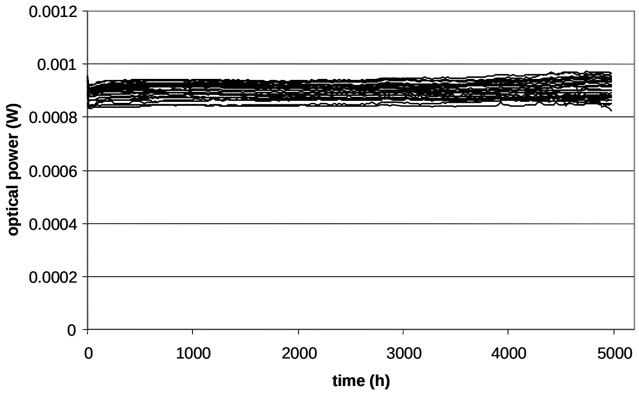


Figure 13: Time to failure data for polarzation stabilized single-mode VCSELs at 125°C heatsink temperature and 2.5 mA laser current. The measurements are taken at room temperature.

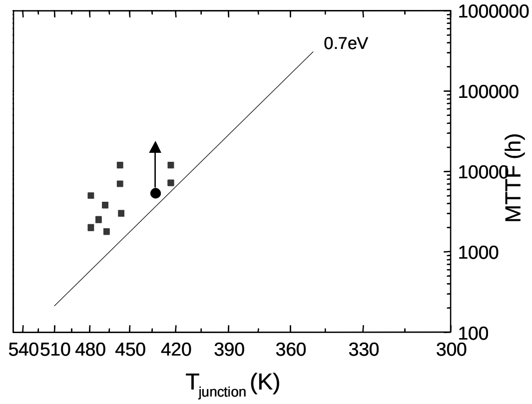


Figure 14: Arrhenius plot of MTTF values versus junction temperature for 850 nm single-mode VCSELs. The rectangular dots represent standard single-mode VCSEL wafers, the circular dot indicates the ongoing ALT test for the surface grating VCSEL wafer.

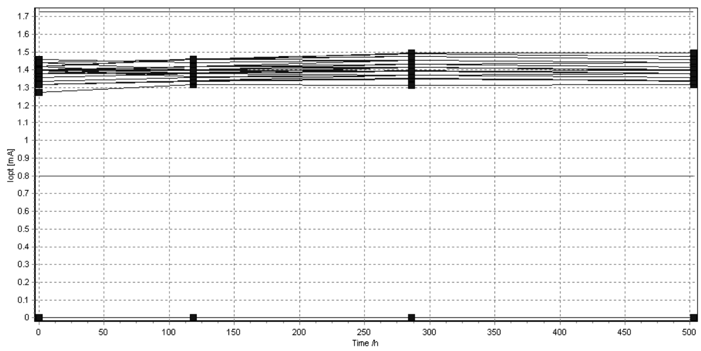

Figure 15: 85/85 test results of polarization controlled single-mode VCSELs over 500 h.

The additional etching step in the top layer does not harm the lifetime of the device. The expected MTTF at maximum operation conditions is still exceeding 100.000 hours.

Surface damages often initiate reliability issues in highly humid ambient. Test results of the devices operated at 85°C and 85 % relative humidity given in Figure 15 show, that no power drop after 500 hours of operation is seen which is in line with the standard wafer qualification procedures.

## SUMMARY

The presented grating technology strongly controls the polarization characteristics of standard small aperture single-mode VCSELs. Two manufacturing techniques have been discussed, whereas for the masking of the grating etch priocess imprinting is the more promising technology compared to E-beam lithography with respect to low cost high volume production.

The drawback of the grating technology is identified in the threshold and output power performance of the lasers. Significantly increased threshold current and reduced slope efficiency for the strongest polarization locking effect results in a 30 % increase of the operation current. Although there is room for further optimization of the desing parameters, additional diffraction losses have to be considered in general.

In terms of reliability, no negative impact is given by the surface grating technology. Preliminary accelerated lifetime testing results as well as operation in high humidity/high temperature do not indicate reduced lifetime expectation.

## ACKNOWLEDGEMENT

Continous support and input from Johannes Michael Ostermann and Pierluigi Debernardi (IEIIT - CNR, Politecnico di Torino) is gratefully acknowledged.

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# Basic Product Code ULM Photonics

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
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- 1–3: supplier
- 4–6: CWL
- 8–9: CWL-Tolerance or Design Type
- 11–12: TN= Top -> Anode Substrate -> Cathode or Polarization Lock
- 14: S= Single mode
- 15–16: 46= TO46, 05= TO05
- 17: F= Flat Window, B= Ball lens, O= w/o cap, X= No Window
- 18: O= No ESD Diode, Z= ESD Diode
- 19: P= P configuration Isolated pin -> Anode, Case= Cathode); U= Chip; T= Thermoelectric cooler and Thermistor

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