FP6-2005-IST-5 – 2.5.1 Photonic Components (STREP)

NEMIS

New **M**id-**I**nfrared Sources for Photonic **S**ensors

031845

Publishable Final Activity Report

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Project coordinator organisation name: Walter Schottky Institut
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1 Project execution

1.1 Summary of Project Objectives

The objectives of the NEMIS project were the development and realisation of compact and packaged vertical-cavity surface-emitting semiconductor laser diodes (VCSEL) for the 2-3.5µm wavelength range and the demonstration of a pilot photonic sensing system for trace gas analysis using these new sources. The availability of electrically pumped VCSELs with their low-cost potential, low power consumption, small beam divergency and compactness in this wavelength range that operate continuously at or at least near room-temperature and emit in a single transverse and longitudinal mode (i. e. single-frequency lasers) has been considered a basic breakthrough for laser-based optical sensing applications.

These devices need also be mode-hop-free tuneable over a couple of nanometers via the laser current or the heatsink temperature. They are therefore ideal and unmatched sources for the spectroscopic and trace analysis of gases and the detection of many important and/or toxic gases. It has been the purpose of the project to develop the underlying semiconductor technology based on Gallium Antimonide, the VCSELs as well as pilot applications in sensing systems to demonstrate the potential and performance of these novel lasers.

1.2 Contractors Involved

The contractors involved in the NEMIS project were:

Contr. no.	Contractor name	Contractor short name	Country
1	Technische Universität München	WSI	Germany
2	Université Montpellier 2	UM2	France
3	Institute of Physics of the Academy of Sciences of the Czech Republic	IOP	Czech Republic
4	Chalmers Tekniska Högskola AB	Chalm	Sweden
5	VERTILAS GmbH	VERT	Germany
6	Omnisens SA	Omni	Switzerland
7	Siemens AG	SAG	Germany

1.3 Work Performed

In order to achieve the project goals as efficiently as possible and get optimum collaboration among partners, the project had been structured thus that the specifications and design of the devices, the materials preparation (epitaxy), the chip technology, materials and device characterisations, and the pilot applications are in separate workpackages. The workplan has been therefore divided into five technical workpackages each of which was managed by a partner, plus a management workpackage WP6:

WP1: Specifications, design and analysis

WP2: Epitaxy of VCSELs structures

WP3: VCSEL technology

WP4: Characterisation of laser structures and devices

WP5: Applications

WP6: Management

The first workpackage established the target specifications of devices and applications at a very early stage using the inputs from all partners and supports the technology activities by repetitively providing design rules and parameter extractions from measurements. The basic technology work was done in the large workpackages 2 (epitaxy) by WSI and UM2 and 3 (VCSEL technology) by WSI, UM2 and VERT. These two workpackages are of roughly equal importance. To manage the high risks of the project and to achieve the objectives, two different device approaches, insulator-confined and buried-tunnel-junction (BTJ) structures, as well as two pumping schemes, optical and electrical, were considered. The insulator-confined devices were developed at UM2 while the BTJ-type devices were developed at WSI.

The epitaxial wafers for both device approaches have basically identical or similar active regions but differ in the upper cladding layers. The risks were further reduced by performing the extensive epitaxial growth processes by the two partners WSI and UM2 that are highly skilled on the molecular beam epitaxy of antimonides and will strongly interact on this task.

All epitaxial and device work was permanently monitored in workpackage 4 by appropriate electrical, optical and thermal analysis and characterisations accomplished by partners IOP, Omni, WSI, VERT and UM2.

Pilot systems for the application of the NEMIS VCSELs have been established in workpackage 5 by partners IOP, Omni and SAG using photoacoustic and wavelength modulation spectroscopy, respectively. Prototypes of electrically pumped devices were delivered to the systems applications relatively early (month 15, deliverable D7) to enable system tests.

1.4 End Results

The main goals of the NEMIS project were the development of an Sb-based technology platform for electrically pumped VCSELs in the 2.0-3.5µm wavelength range, the realisation of application suited and packaged devices at 2.33µm and 2.7µm as well as demonstrator sensing applications using these lasers.

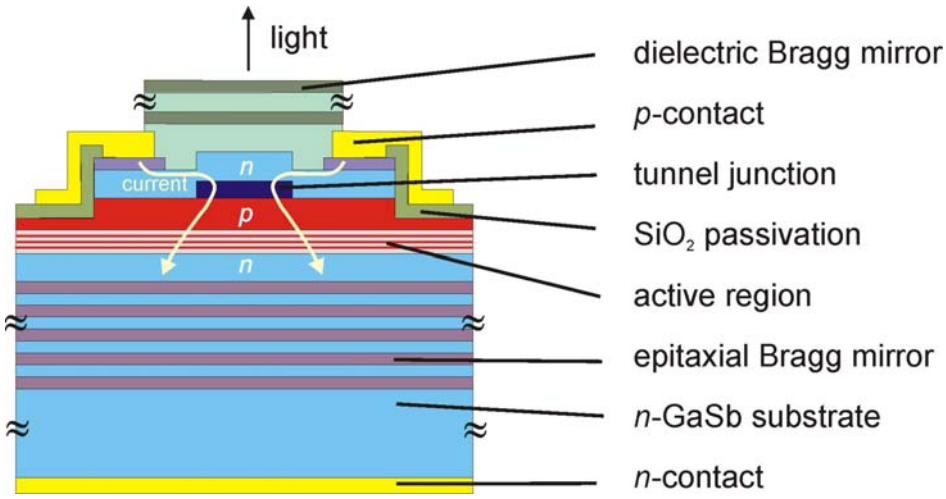


Fig.1: Schematic cross-section of the GaSb-based Buried Tunnel-Junction (BTJ)-VCSEL structure.

Two device concepts for the electrically pumped GaSb-VCSELs were investigated: One is a modified version of the buried-tunnel-junction (BTJ) concept (Fig. 1) that has proven very successful on 1.3-2.3µm InP-based VCSELs and has now been extended to the GaSb-based materials. The second approach is based on mesa-confined VCSEL-structures (Fig. 2).

The consortium first succeeded in realizing GaSb-based 2.3µm VCSELs with both approaches. As shown in Fig. 3 and 4, remarkable experimental results have been achieved. These comprise very low threshold current densities comparable to edge-emitting devices as shown for a 20µm diameter wide mesa-confined VCSEL in Fig. 3. But also excellent cw-performance with the BTJ-structure was obtained. Fig. 4 shows temperature dependent power-current characteristics of a device with an elliptic

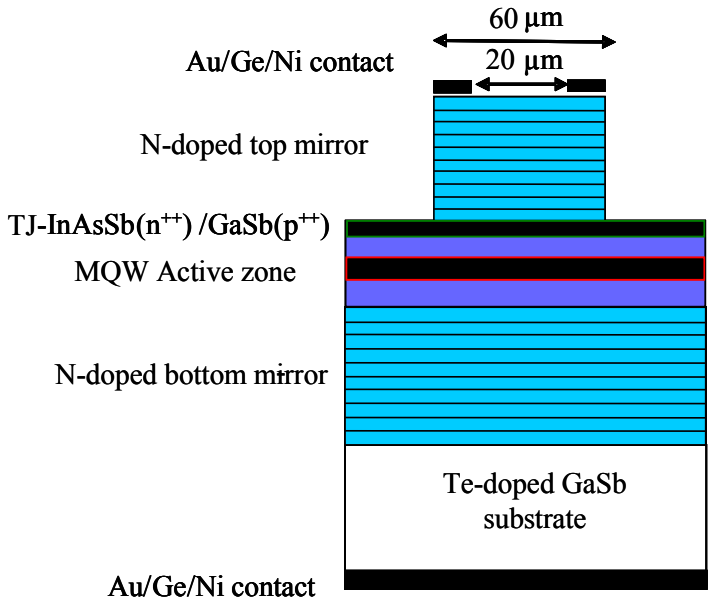


Fig. 2: Schematic cross-section and edge SEM picture of a monolithic mesa-defined VCSEL structure

BTJ of 6.4µm x 5.6µm diameter. As can be seen, the VCSEL operates in cw up to 90°C with small threshold currents of the order 1 - 4 mA. The output power is of the order of several hundred microwatts which well which is sufficient for most sensing applications. Also displayed are the room-temperature emission spectra for different laser currents clearly showing single-mode operation with an SMSR exceeding 25dB (1:300) and an electro-thermal tuning range of about 10 nm.

WMS- and PAS-based sensor systems have been realized (Fig. 5) and first measurements with the GaSb-VCSELs showed promising results for CO detection around 2.33µm.

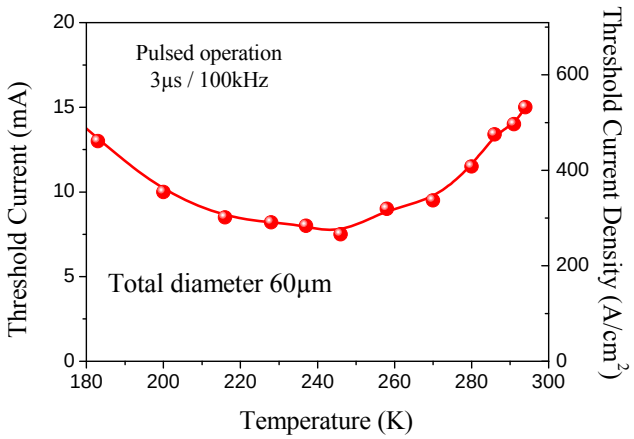


Fig. 3: Threshold current density vs. temperature variation of a 20 µm-internal diameter mesa-confined-VCSEL in quasi-CW operation (1 µs, 10%).

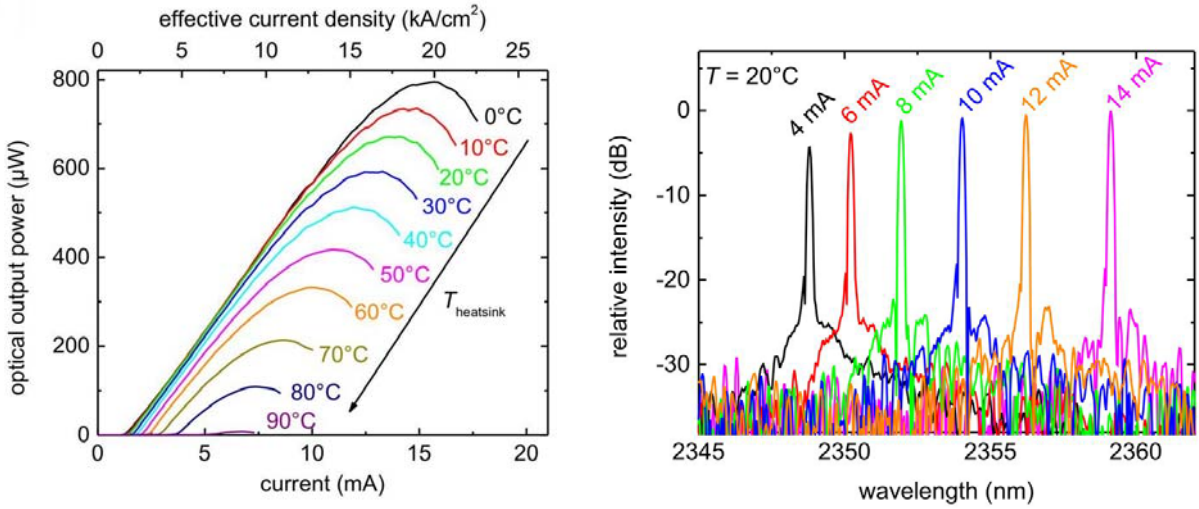


Fig. 4: GaSb-based 2.3 µm BTJ-VCSEL with an elliptic BTJ of 6.4 µm × 5.6 µm diameter: cw voltage-current and light-current characteristics (left) and current-tuned spectra at room-temperature (right).

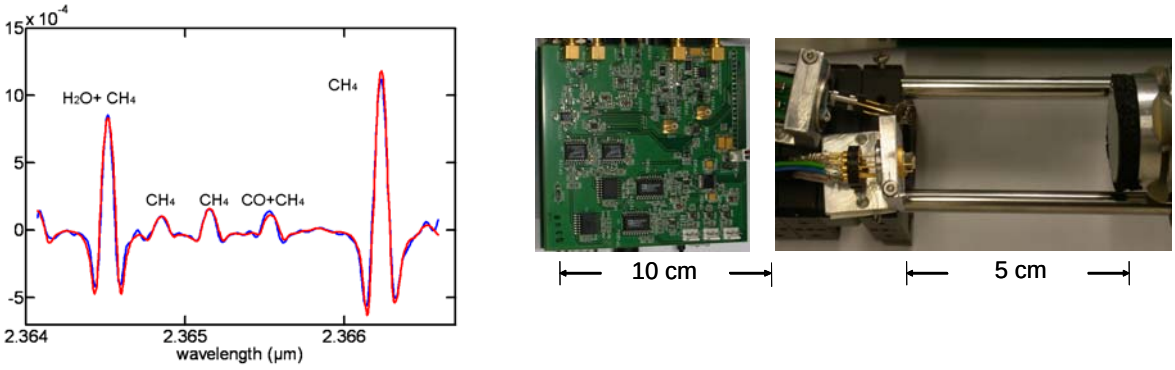


Fig. 5: Second harmonic spectrum of CO, CH_4 and H_2O recorded with WMS demonstrator platform hardware.

Further VCSELs were also developed for the 2.7µm (+/- 100nm) wavelength regime. Considerable progress has been achieved in spite of the extremely challenging technology. Fig. 6 shows an SEM picture of an MBE-wafer for a monolithic 2.65µm VCSEL. As can be seen, excellent layer and crystal quality has been achieved even though the total thickness for this large wavelength is of the order 17 µm!

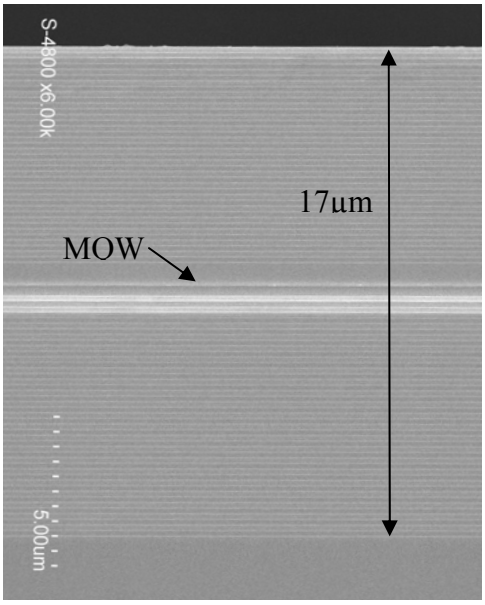


Fig. 6: SEM picture of monolithic VCSEL for emission at 2.65 µm

In addition, complete VCSELs were made and characterized in this wavelength range. Using the BTJ-structure with a top dielectric DBR, cw operation and single-mode emission was reproducibly obtained around room-temperature. As the gain-DBR adjustment was not yet perfect, because of the blue-shift occurring during epitaxial overgrowth, higher threshold currents were obtained than for the 2.3µm counterparts. The achieved performance is illustrated in Figs. 7 and 8, indicating that these devices meet the requirements for corresponding gas sensors, particular with respect to their spectral properties.

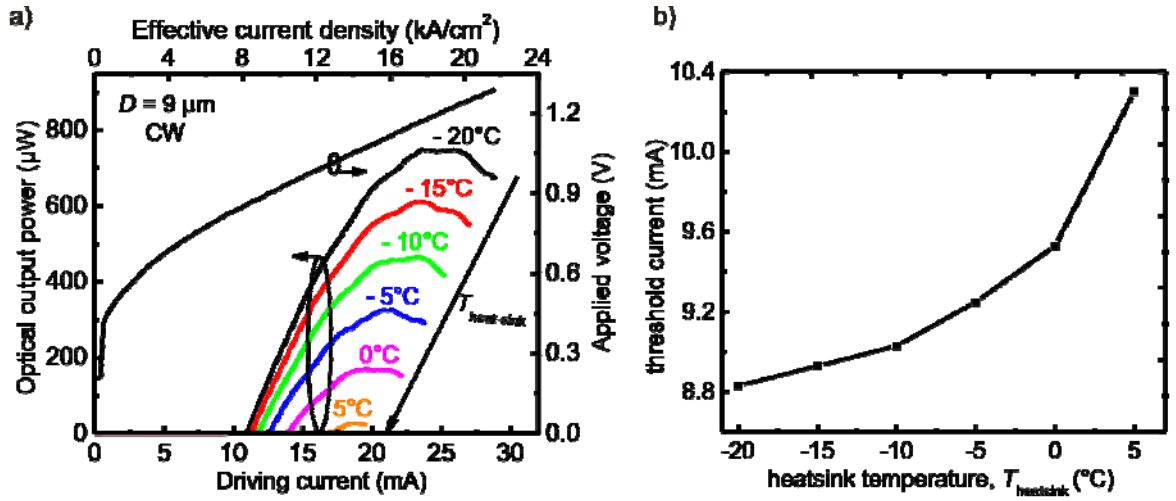


Fig. 7: (a) Temperature dependent *L-I* characteristics of a GaSb-based VCSEL @ 2.62 µm. *I-V* characteristics is shown at -20°C. (b) Threshold current vs. heat sink temperature.

Extensive numerical modelling accompanied the experimental work and helped to understand device performances better and to straightforwardly establish optimized designs. In the frame of the NEMIS project a full "multiphysics" VCSEL model that simultaneously accounts for the detailed optical fields, the complex current transport, and the local heat generation and dissipation was developed. This "multiphysics" VCSEL model was applied to simulate the output characteristics, i.e. output power and wavelength versus current for the buried-tunnel-junction (BTJ) VCSEL, with and without a surface relief. As a particular feature, the diffraction losses occurring in a VCSELs because of the localized transverse waveguiding have been analysed in dependence on the relevant technological parameters.

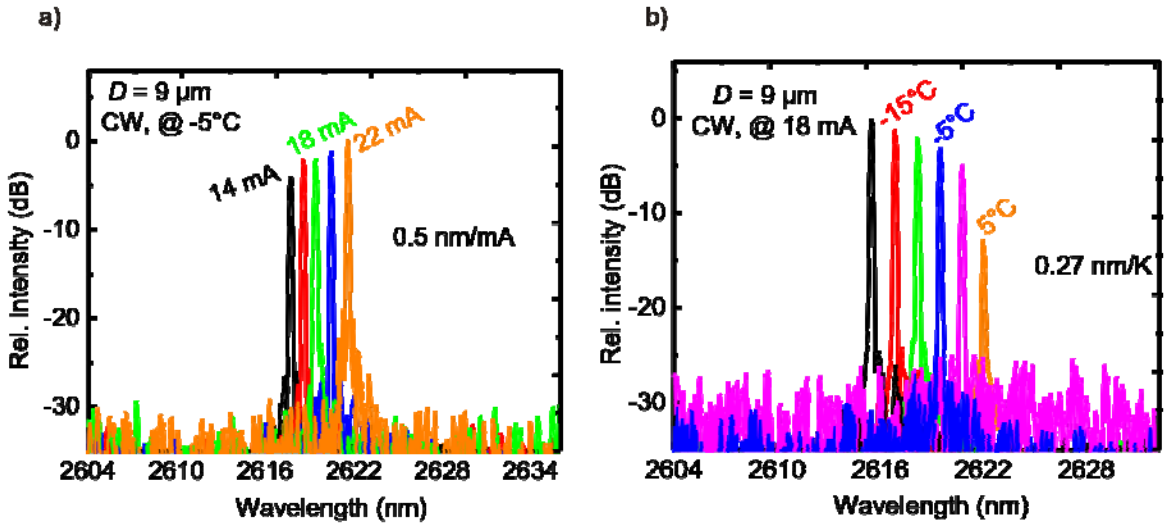


Fig. 8. a) Cw spectra of VCSEL @ 2.62 µm for different driving currents at a heatsink temperature of -5°C. b) Cw Spectra of VCSEL at varying heatsink temperature and constant driving current of 18 mA.

In summary, the main achievements gained in the NEMIS project are:

- worldwide first realisation of electrically pumped single-mode and tuneable GaSb-VCSELs in the 2.3-2.7µm wavelength range that operate at room-temperature and above
- successful demonstration of WMS- and PAS-based pilot gas-sensors for carbon monoxide and ammonia using packaged GaSb-VCSELs
- establishing a technology platform for GaSb-based VCSELs in the GaSb material system enabling the realisation of VCSELs in the entire 2.0-3.5µm wavelength range
- development of a comprehensive opto-electro-thermal modelling suite for design and analysis of the VCSELs
- improving and completing the data base on optical constants of GaSb-based compounds

1.5 Project Logo and Website

NEMIS New Mid-Infrared Sources for Photonic Sensors

http://www.nemis.eu/

2 Dissemination and use

2.1 Section 1 - Exploitable knowledge and its Use

In the third project year GaSb-based VCSEL devices emitting up to 2.62 µm have been achieved. Efforts realizing longer wavelength VCSEL unfortunately have not yet been successful. Device properties for the 2.36 µm VCSEL could be greatly improved (e.g. output power up to 0.8 mW, operating temperature up to 90°C). These are prerequisites for a use of the new VCSELs in commercial competitive gas sensors. Due to the withdrawal of Omnisens unfortunately the PAS related activities were terminated. Siemens continued on the WMS technology finalizing the advanced demonstrator being on a promising way to integrated, versatile, low cost, gas sensor hardware.

The table below identifies the exploitable knowledge obtained from the NEMIS project and its use by the industrial partners. The following chapters then give a detailed description of the technology, dissemination strategies, target groups and impact of the project on the competitiveness of the industrial partners. The targeted applications were already identified and described in the project proposal. By publishing the results to the scientific community the consortiums contacts new possible cooperation partners and application fields. For the industrial partners in the consortium the initial plan for using and exploiting the results from NEMIS is still valid, except for Omnisens which left the consortium before the end of the project.

Exploitable Knowledge	Exploitable product(s) or measure(s)	Sector(s) of application	Timetable for commercial use	Patents or other IPR protection	Owner & other partner(s) involved
MID-IR VCSEL	BTJ-GaSb-based VCSEL chips	Gas sensing, free space or fluoride fiber based optical communication	No decision	The BTJ technology is patented by Vertilas	Vertilas
MID-IR VCSEL	2.3 µm BTJ-InP-based VCSEL chips	Gas sensing, free space or fluoride fiber based optical communication	No decision	The BTJ technology is patented by Vertilas	Vertilas
Wavelength modulation Spectroscopy WMS	Sensor electronics platform	Gas monitoring	only in conjunction with VSCELs available		SAG
	CO-Monitor		2 to 3 years	Patent filed for sensor concept (covers other gases as well)	SAG
	Humidity monitor		3		SAG
	Gas monitors for various gases		4 to 5 years		SAG

2.1.1 TDLAS – Tuneable diode laser absorption spectroscopy

Accessible gases in the NIR[1] and the MIR[2] are presented in fig. 1. The graph shows the relation between wavelength and detection limit for a number of gases in the range from below 1 µm to above 4 µm, as well as the wavelength ranges for different laser technologies, DFB, QCL, VCSEL. With rising wavelength the sensitivity for most gases increases by orders of magnitude.

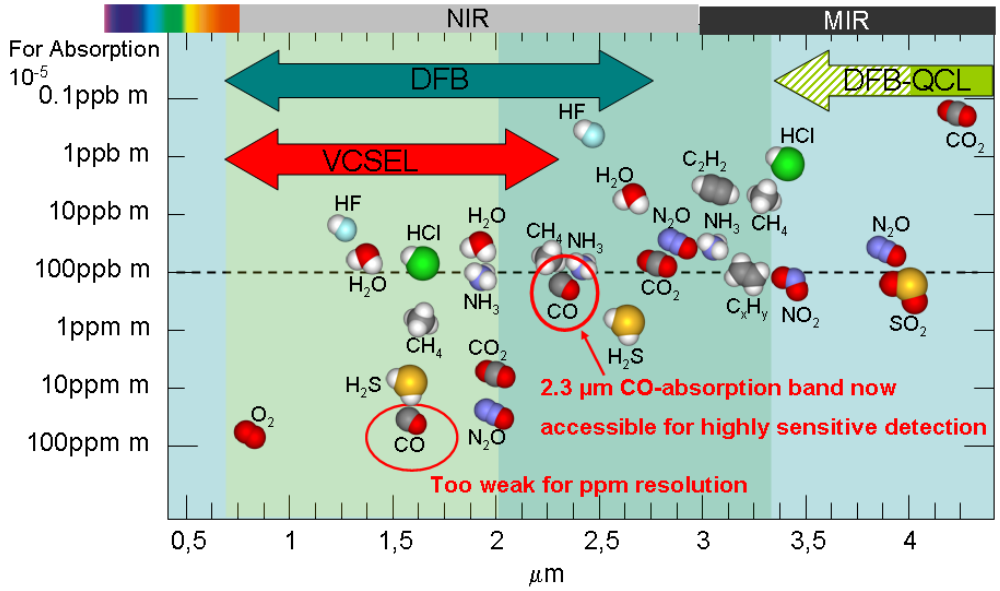


Fig. 1: Detection limit for several gases in the NIR and MIR range and wavelength ranges for the different laser technologies. Note the log-scale for the concentration. The values hold for a minimum detectable absorbance of 10^{-5}.

This corresponds to the transition from the overtone absorption bands to the fundamental bands in the MIR. Also from the existing NIR technology to the wavelength range for the NEMIS VCSEL a considerable increase in sensitivity is observed. This can be exploited in different ways: Building more sensitive equipment or following the path to less complex, low cost sensors.

The market for TDLS gas monitors can be divided into tree segments, as indicated in the table below.

Market segments for Laser based gas monitoring			
Category	1	2	3
	Application specific analytics	Analysers, industrial monitors	Mass applications
System price	≥ 20000	500..5000	< 50
Number of pieces p.a.	<1000 (all applications)	1000..10000 (for each application)	100000 …. 1000000
Turnover [Million €]	2..20	0.5..50	5..50

The first category comprises process gas analysers, mainly for monitoring industrial processes, e.g. monitoring flue gases from power plants. Instruments in this category typically sell for >20000 € per unit. The overall market for these instruments is well below 1000 today,

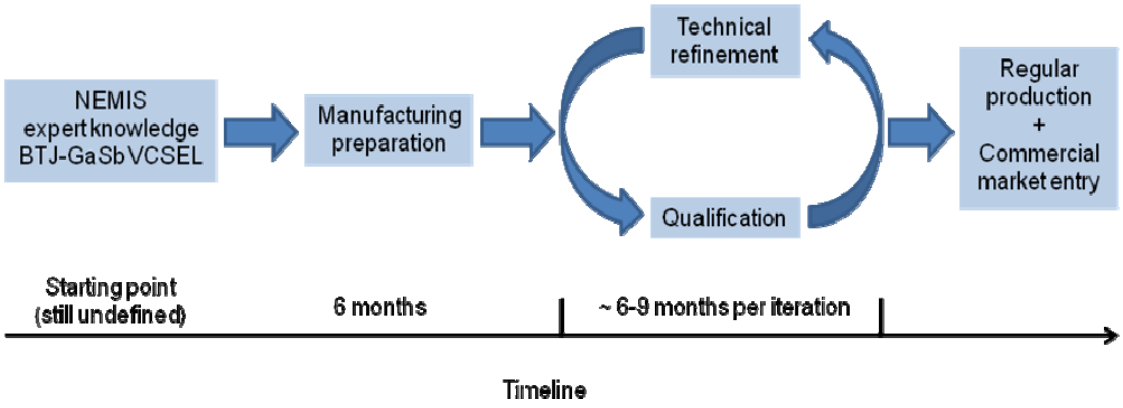
[1] NIR = Near Infrared
[2] MIR = Mid Infrared

however with a growth rate in the order of tens of percent. Numbers for category two are based on the existing sensor technologies. The laser based technology has to meet the given price frame to be competitive. As there are several applications many 10 000 monitors are required in industry per year. Category 2 products are targeted by the industry partners in the NEMIS project in the short and medium time frame (3 to 10 years).
The following section recapitulates the partners plan for exploiting the knowledge (taken from the Description of Work)

2.1.2 VERTILAS: MID-IR VCSEL (2 to 3.5 µm)

The scope of NEMIS is in distinct relationship to the current product portfolio as well as the future research and commercial strategy of VERTILAS. Based on its patented buried tunnel junction (BTJ) technology which was initially developed at the Walter Schottky Institute as one of the main collaboration partners of NEMIS, VERTILAS currently develops, produces and markets BTJ-VCSELs based on the indiumphosphide (InP) rather than antimony material system. The InP-based technology can not access the wavelength range beyond 2.3 µm and the corresponding shorter emission wavelengths do not interfere with the wavelength range of NEMIS.
While sensing applications in the near infrared range up to 2 µm wavelength have become a main pillar, VERTILAS also faces customer interest in wavelengths beyond the emission range of its current products. For example, monitoring the exhaust gases from almost any combustion processes requires precise concentration measurements of CO to achieve proper conditions. This can be best achieved at wavelengths around 2.3 µm. Regarding this interest for laser sources beyond 2 µm wavelength, VERTILAS has been exploring techniques to realize such VCSELs in the extended wavelength range. While the mature InP-based VCSELs have demonstrated first promising results, a distinct limit is set for the InP-based technology regarding stress tolerances in the semiconductor crystals.
Together with its relationships to more than 60 worldwide customers in the field of optical gas sensing, the extension of available wavelengths could significantly increase the company's added value and strengthen its position as a leading supplier of long-wavelength VCSELs. Accordingly, the outcomes of the NEMIS project are of significantly high interest.
In this context, VERTILAS is in close relationship particularly with the partners for device fabrication. As a leading supplier of long-wavelength VCSELs and with its experience in BTJ-VCSEL technology, VERTILAS is the predestined partner to adopt the technology of GaSb-based lasers.
On the other hand, GaSb-based devices could open up a versatile way to substantially increase the product portfolio to even extended wavelengths. Besides the potential decision for a market entry dependent on commercial market considerations, a mandatory precondition is set by the proof of an application compliant device performance. The scientific results of NEMIS clearly indicate the potential of the GaSb-based technology to serve as a platform for these new types of long-wavelength VCSELs. This includes output powers well beyond 0.2 mW, spectral purity with at least 30 dB side mode suppression ratio as well as an adequate reliability which is typically of the order of ten years under continuous operation. While GaSb-VCSELs have shown excellent stationary light-current-temperature characteristics, first promising results have been also achieved during ageing tests. Naturally, ongoing research efforts are needed particularly to demonstrate the long-term reliability of these new VCSELs. In addition, technological improvements such as polarization control still have to be implemented.
Up to the NEMIS project ending, little is known on the cost issues such as yield numbers in an industrial production environment. Optimization of production yields is evidently not part

of the project tasks but would be pursued by the future chip manufacturer. Based on the experience of InP-based devices, a competitive and reasonable production yield should be at least 50% after passing the entire production chain. With this precondition, long-wavelength GaSb-based VCSELs with emission wavelengths from 2-3 µm would compete well against existing DFB lasers or even appear as preferred light source for many applications. In particular, the cost saving is expected to amount a factor of 2-3 when compared to actual pricings for DFB laser diodes.
The principal workflow for transferring GaSb-based VCSELs into market is depicted in the figure below.



In the framework of NEMIS, VERTILAS has not filed any patents so far. The company continuously communicates the results from NEMIS partners during its participations on industrial exhibitions.

2.1.3 Omnisens: PAS monitor for trace gas detection

Omnisens left the NEMIS Consortium as a consequence of the company's decision to sell its gas analyser business. For IP and confidentiality reasons, the NEMIS research and results were not transferred to the new owner. So the results of the PAS developments conducted by Onmisens will not be used commercially. None of the NEMIS cooperation partners intents to use the know-how.

2.1.4 Siemens: WMS monitor platform for hazardous gases

Siemens AG, I IA SC PA (Industry Automation Sensors and Communication Process Analytics) already holds a substantial market share in the business of laser based process gas analysers for industrial applications e.g. for flue gases of power plants. In the short term, therefore the new VCSEL devices will be used in these instruments, as soon as they are commercially available. They will open the door to the detection of new gas species and replace NIR laser diodes (< 2 µm), whenever increased sensitivity is required.
Siemens supplies all kind of equipment for process control and automation and even complete production lines to a wide variety of businesses, e.g. to the chemical industry. There is a growing desire from the customers to get the complete equipment for process control and safety monitoring as well as maintenance from one hand. Siemens is not supplying safety equipment today. The emerging laser technology offers the chance to enter the safety market with an innovative gas detector for monitoring working environments for hazardous, toxic and explosive gas species, and thus fills this gap in the portfolio.
During the NEMIS project it turned out that CO monitoring covers many applications. Since the first VCSEL at 2.3 µm are available and have been tested successfully more and more

applications are identified. Fire detection is the most prominent one. CO-monitors for this application will be first available for professional applications, like in ships and aircrafts. In the medium time frame CO-monitors for the safety of working environments will become available. In the long run it is likely that this technique will enter the domestic application for fire detection, CO from malfunction of heating appliances and natural gas leaks (simultaneous methane detection with on e VCSEL possible). Combustion control for gas- and oil-burners and combustion engines is another field of application for the new CO-monitor. There are ongoing activities qualifying the new technology for the different applications. Provided the new VCSEL will become a stable and reliable product, two to three years after the termination of NEMIS a CO-monitor as a product is envisaged.
Besides safety applications process control instrumentation in the medium to low price segments is also attractive from a commercial viewpoint. The pilot application should be humidity sensing. Humidity sensing covers a wide range of applications from the low cost humidity sensor for air conditioning over medium cost humidity control in a vast variety of production processes to high cost trace humidity detection for processes in semiconductor Fabs. The platform VCSEL gas monitor fits best to humidity control in production processes in terms of performance and initial costs at the time of entry to market. An application under development is dedicated the professional cooking equipment, where exact humidity control is essential for the quality of the food prepared as well as for energy saving reasons. This product is envisaged to be launched three year after the termination of NEMIS. Another project to be launched soon refers to H_2O in Natural Gas.
In the long run, the integrated sensor concept allows in conjunction with decreasing laser prices to successively enter lower cost sensor market segments.
Four to five years after the termination of NEMIS when VCSEL for a sufficiently large number of gases are available multi-gas sensors shall become commercially available. Such combined sensors are attractive for certain process control applications, as well as certain working environments and environmental sensing, where a specific set of gases shall to be monitored. For traffic management systems e.g. the set of or a subset is very interesting. Future traffic management systems will automatically redirect traffic flows from areas with temporarily high air pollution to less polluted areas and thus balance the emission over a larger area. Siemens IS ITS (Industrial Solutions, Intelligent Traffic Systems) is currently developing traffic management systems, which require such sensors to be effective.

Summing up the plan for use and dissemination at the end of the project a few remark shall be discussed. The plan for Siemens is still valid. VCSEL for CO detection have been successfully demonstrated within NEMIS, however from these results to commercially available products a considerable amount of development work is required. This is a decision of the device manufacturer. InP-based 2.3 µm – which also have been pushed within NEMIS - are at the moment closer the commercialisation than GaSb-VCSEL. From the viewpoint of the sensor manufacturer the technique behind the light source is irrelevant. So Siemens welcomes InP- as well as GaSb-based VCSEL. During NEMIS VCSEL >2.63 µm could not be realized for various reasons. This affects of course strongly the plans for the realisation gas monitor based on these VCSEL e.g. for gases like CO_2, NO, H_2S, NO_2. As these gases are of high interest for various applications. A follow up research project is envisaged, which will make these lasers available in the next three to four years, postponing the market entry for these gas monitors by the same period. The plan for H_2O monitoring is not affected as it does not depend on VCSEL developed within NEMIS. This project will, however, benefit from the platform idea of the NEMIS-electronics hardware, which is versatile and not limited to certain laser wavelengths.

2.1.5 Universities and research institutes

Exploitation plans of universities and research institutes (WSI, UM2, IOP, Chalm) are related to the education at the very highest technical level, to the formation of new start-up companies and to the licensing of tools and technologies to other companies. The education occurs mainly in the context of Ph.D. work and provides highly skilled people to the industry. The universities and research institutes are also very active in starting up new spin-off companies.

An active policy will be pursued to find exploitation of the results obtained at the universities and institutes and to trigger interest from industry. It is also believed that, with the current interest in diode laser based sensing systems, good scientific results easily find their way to industrial exploitation.

To establish a new platform for exchange between the European universities with projects concerning VCSEL or VECSEL, the NEMIS management organized together with the coordinator of MOSEL the first VCSEL Day on 21/5/2008 in Copenhagen. App. 20 scientists from the different FP6 and FP7 projects MOSEL, ODIN, NEMIS, NATAL and VERTIGO took part in the workshop, presenting and discussing the results and building up new relationships/collaborations. The informal workshop met the participants' approval and they agreed to continue building up a common exchange platform by regular VCSEL Day workshops. A press release in the Photonics Newsletter was made to invite other VCSEL related EU-projects to join the new network.

The second VCSEL Day was subsequently organized by the NEMIS partner Chalmers University of Technology in Göteborg, Sweden, on 24/4/2009. The one-day event attracted 38 scientists from the European FP6 and FP7 projects HELIOS, MOSEL, NEMIS, SUBTUNE, VERTIGO and VISIT. The meeting was highly appreciated by the participants and it was decided that another VCSEL Day should be held in the spring of 2010 in Torino, Italy (to be organized by Pierluigi Debernardi at Politecnico di Torino).

2.2 Section 2 – Dissemination of knowledge

The NEMIS Website has been created and is updated regularly. For details see Deliverable 1 *Creation of NEMIS website*. The project results (reports, publications, etc) are continuously added.
The dissemination effort addressed a wide spread audience from the scientific community, professionals in industry and the general public.
More than 50 articles and conference contributions were published addressing scientists; a couple of articles were published in non-refereed journals. The following table lists of individual publications with the addressee, the size of the audience and the involved partners

Publications 1st period

Date	Type	Audience	Countries addressed	Size of audience	Partners involved
01.02.2007	Seminar in IAF Fraunhofer Freiburg : Recent developments on antimonide-based VCSELs and other photonic devices by University Montpellier 2. F. Genty (UM2)	Research	Germany	50	UM2
01.03.2007	Conference Contribution: 14th European MBE Workshop 2007, Granada / Spain, Growth and Fabrication of electrically pumped GaSb-VCSELs, Talk by O. Dier, C. Lauer, T. Huesgen, A. Bachmann, M.-C. Amann	Research, Industry (electronics & opto devices)	Europe	n.a.	WSI
01.03.2007	Seminar: E. Hulicius, Semiconductor materials and devices for Midinfrared wavelength region of radiation, J. Heyrovsky Inst. of Phys. Chem., Invited lecture at all Institute seminary, March 9th	General public	Czech republic	30	IOP
27.04.2007	Seminar in IAF Fraunhofer Freiburg: Laser diodes for the mid-infrared, talk by M.-C. Amann	Research	World	50	WSI
14.05.2007	Conference Contribution: 8th Int. Conf. on Mid Infrared Optoelectronics Materials and Devices, Bad Ischl (Austria), Mid-Infrared Vertical-Cavity Surface-Emitting Lasers, Proceedings of MIOMD VIII, p. 60, Bad Ischl / Austria, Contribution by C. Lauer, O. D	Research, Industry (electronics & opto devices)	World	300	WSI
14.05.2007	Conference Contribution: 8th Int. Conf. on Mid Infrared Optoelectronics Materials and Devices, Bad Ischl (Austria) : Poster by Genty (UM2).	Research, Industry (electronics & opto devices)	World	300	UM2
01.06.2007	Conference Contribution: 8th Int. Conf. on Mid Infrared Optoelectronics Materials and Devices, Bad Ischl, Austria, June 3rd 6th, 2007, Proc p. 184-5 E. Hulicius A. Hospodkov, J. Pangrac, K. Melichar, T. Simecek, K.D. Moiseev, E.V. Ivanov, M.P. Mikhailova,	Research, Industry (electronics & opto devices)	World	300	IOP
01.07.2007	Seminar in UM2 : High coherent semiconductor photonic sources: design, fabrication, characterization. A. Garnache/M.Myara (UM2).	Research, students	France	50	UM2
09.07.2007	Seminar in UM2 : 1St year phD results (CST) on development of new GaSb-based EP-VCSELs structures. A. Ducanchez (UM2)	Research, students	France	50	UM2
18.07.2007	Conference Poster: Tunable Diode Laser Spectroscopy Conference 2007, Reims, France, Straightforward modeling of the n-th harmonic signals used in wavelength modulation spectroscopy and their mathematical properties, poster by A.Hangauer, J. Chen, M.-C. Am	Research, Industry (electronics & opto devices)	France	n.a.	SAG, WSI
01.08.2007	Internship: UM2 Master 1 internship: Fabrication and characterization on Sb-based mid IR RC-LEDs devices. Report and oral presentation by U. Erbakan (UM2).	Research, students	France	n.a.	UM2
01.08.2007	Conference contribution: ICCG-15, Negative electroluminescence in type II p-InAs/AlSb/InAsSb/AlSb/ p-GaSb asymmetric heterostructure, E. Hulicius1, J. Pangrác1, A. Hospodková1, K. Melichar1, T. Šimeček1, K.D. Moiseev2, E.V. Ivanov2, M.P. Mikhailova2, Yu.P	Research	World	120	IOP
08.08.2007	Conference: International Nano-Optoelectronic Workshop (iNOW) 2007, Lanzhou, China, Long Wavelength VCSELs for Sensing Applications, invited talk by M.-C. Amann	Research	World	100	WSI

Publications 2nd period

01.09.2007	Project website: www.wsi.tum.de/e26/nemis	All	World	n.a.	WSI/all
01.09.2007	Regular Article: AlAsSb/GaSb doped distributed Bragg reflectors for electrically pumped VCSELs emitting around 2.3 µm, A. Perona, A. Garnache, L. Cerutti, A. Ducanchez, S. Mihindou, P. Grech, G. Boissier and F. Genty, Semicond. Sci. Technol. 22 (2007) 114	Research	World	n.a.	UM2
01.09.2007	Conference Contribution: European Semiconductor Laser Workshop 2007, Berlin, Germany, Realization of a tunnel-junction for electrically-pumped GaSb-based vertical-cavity surface-emitting lasers for sensing applications, talk by A. Bachmann, O. Dier, C. La	Research, Industry (electronics & opto devices)	Europe	n.a.	WSI

01.09.2007	Conference Contribution: Field Laser Applications in Industry and Research (FLAIR), Florence, Italy, Reconstruction of the Transmission from n-th harmonic Spectra, Poster by A.Hangauer, J. Chen, R. Strzoda, M.-C. Amann	Research, Industry (electronics & opto devices)	Europe	n.a.	SAG
01.09.2007	Invited Journal paper: Mode and polarization control in VCSELs using shallow surface structures, J.S. Gustavsson, Å. Haglund, E. Söderberg, J. Vukusic, P. Modh, P. Jedrasik, and A. Larsson, IET Optoelectronics, vol.1, no.5, pp.197-205, 2007.	Research, Industry (electronics & opto devices)	World	n.a.	Chalmers
01.09.2007	Conference Contribution: Field Laser Applications in Industry and Research (FLAIR), Florence, Italy, Recent developments and prospects of long-wavelength VCSELs for TDLS applications, talk by M. Ortsiefer, J. Rosskopf, R. Shau, C. Gréus, and E. Rönneberg	Research, Industry (electronics & opto devices)	Europe	n.a.	VERT
01.09.2007	Project fact sheet: NEMIS - project summary, accessible through the project website	General	World	n.a.	all
01.10.2007	Conference Contribution: Deutscher MBE-Workshop 2006, Hamburg, Germany, Reinigung von GaSb-Oberflächen mittels atomaren Wasserstoffes, Talk by O. Dier, C. Lauer, and M.-C. Amann	Research, Industry (electronics & opto devices)	Germany	n.a.	WSI
13.10.2007	Open day: Nanoday LMU, Munich, Germany, Infrarotlaserdioden für Kommunikation und Gassensorik, Poster by T. Lim, A. Bachmann, O. Dier, K. Kashani-Shirazi, M.-C. Amann	General public	Germany		WSI
01.12.2007	Regular Article: Reduction of hetero-interface resistivity in n-type AlAsSb/GaSb distributed Bragg reflectors, O. Dier, C. Reindl, A. Bachmann, C. Lauer, T. Lim, K. Kashani-Shirazi, and M.-C. Amann, submitted and accepted by Semicond. Sci. Technol.	Research, Industry (electronics & opto devices)	World	n.a.	WSI
01.12.2007	Conference contribution: International Symposium on VCSELs and Integrated Photonics, Tokyo, Japan, Engineering the optical properties of VCSELs using surface structures, talk by A. Larsson	Research, Industry (electronics & opto devices)	World	n.a.	Chalmers
06.12.2007	Conference contribution: MQW laser diode photoacoustic detection of formaldehyde in 2.3 mu m spectral range, talk by Cihelka et al, ICTON Mediterranean winter conference, Sousse, Tunisia	scientific, students	world	100	IOP
01.01.2008	Regular Article: Room-temperature, monolithic, electrically-pumped type-I quantum-well Sb-based VCSELs emitting at 2.3µm, L. Cerutti, A. Ducanchez, P. Grench, A. Garnache, F. Genty, Electronics letters Vol. 44 No. 3, 203-205, 2008	Research, Industry (electronics & opto devices)	World	n.a.	UM2
01.01.2008	Regular Article: Continuous wave operation of electrically pumped GaSb-based vertical-cavity surface-emitting laser at 2.3 µm, A. Bachmann, T. Lim, K. Kashani-Shirazi, O. Dier, C. Lauer and M.-C. Amann, Electronics letters Vol. 44 No. 3	Research, Industry (electronics & opto devices)	World	n.a.	WSI
19.01.2008	Regular Article: Modeling of the n-th harmonic spectra used in wavelength modulation spectroscopy and their properties, A. Hangauer, J. Chen, M.-C. Amann, Appl. Phys. B	Research, Industry (electronics & opto devices)	World		SAG
01.03.2008	Conference contribution: Accurate measurement of the wavelength modulation phase shift of tunable vertical cavity surface-emitting lasers (VCSELs), talk by A.Hangauer, J.Chen, R. Strzoda, and M.-C. Amann, SIOE conference 2008, Cardiff, Wales	Research, Industry (electronics & opto devices)	World	n.a.	SAG
20.03.2008	Regular Article: RT Continuous Wave operation of electrically-injected Sb-based RC-LED emitting near 2.3 µm, A. Ducanchez, L. Cerutti, P. Grech and F. Genty, in Superlattices and Microstructures, 44, 62-69, 2008	Research, Industry (electronics & opto devices)	World	n.a.	UM2

31.03.2008	Conference Contribution: Dynamic Wavelength tuning behavior of Vertical-Cavity Surface-Emitting Lasers, J. Chen, A. Hangauer, R. Strzoda, M.-C. Amann, SIOE conference 2008, Cardiff, Wales	Research, Industry (electronics & opto devices)	World		SAG, TUM
04.04.2008	Open Days at UM2. Application of Sb-based VCSELs, poster by A. Ducanchez	Research, Schools, Students, Public	France	100	UM2
15.04.2008	Magazine Article: GaSb VCSELs execute CW operation, Compound Semiconductor Magazine April 2008 Volume 14 Number 3	Research, Industry (electronics & opto devices)	World	n.a.	WSI
01.05.2008	Conference contribution: Room Temperature, Sb-based Monolithic EP-VCSEL at 2.3 µm including a Tunnel Junction, F. Genty et al., oral presentation, talk on CLEO Conference 2008, San Jose, California	Research, Industry (electronics & opto devices)	World	200	UM2
01.05.2008	Conference contribution: Monolithic, Sb-based electrically-pumped VCSEL emitting at 2.3 µm, A. Ducanchez et al., poster on the IPRM 2008, Versailles, France	Research, Industry (electronics & opto devices)	World	200	UM2
01.05.2008	Conference contribution: Square-Root Law Thermal Response in VCSELs: Experiment and Theoretical Model, talk by A.Hangauer, J. Chen and M.-C. Amann, CLEO Conference 2008, San Jose, California	Research, Industry (electronics & opto devices)	World	200	SAG
01.05.2008	Conference contribution: Electrically Pumped GaSb-based VCSEL with Buried Tunnel Junction, talk by A. Bachmann, T. Lim, K. Kashani-Shirazi, O. Dier, C. Lauer and M.-C. Amann, CLEO Conference 2008, San Jose, California	Research, Industry (electronics & opto devices)	World	200	WSI
01.05.2008	Conference contribution: Single-mode Continuous Wave Operation of Electrically Pumped 2.25 µm GaSb-based VCSEL, talk by A. Bachmann, K. Kashani-Shirazi, T. Lim, O. Dier, C. Lauer and M.-C. Amann, IPRM 2008, Versailles, France	Research, Industry (electronics & opto devices)	World	n.a.	WSI
08.05.2008	Conference contribution: Presentation of the NEMIS project and scientific results, F.Genty, K. Kashani, talk on the VCSEL day, Copenhagen, Denmark	Research, Industry (electronics & opto devices)	Europe	20	All
09.05.2008	Conference contribution: Recent Progress and Prospects on GaSb-based BTJ-VCSELs, talk by A. Bachmann, International Semiconductor Laser Workshop 2008, San Jose	Research	World	30	WSI
01.06.2008	Regular Article: "VCSEL-day offered a common platform for VCSEL and VECSEL-related EU-funded projects", K.Kashani, p. Gilet, Photonics newsletter Volume 2 Issue 2	Photonic related EC-funded projects	EU	n.a.	WSI
01.06.2008	Regular article: "Electrically pumped GaSb-based VCSELs emitting at 2.3 µm", K.Kashani, F. Genty, Photonics newsletter Volume 2 Issue 2	Photonic related EC-funded projects	EU	n.a.	WSI, UM2
09.06.2008	Regular Article: Wavelength modulation spectroscopy with a widely tunable InP-based 2.3 µm vertical-cavity surface-emitting laser, A. Hangauer, J. Chen, R. Strzoda, M. Ortsiefer, M.-C. Amann, Optics Letters	Research, Industry (electronics & opto devices)	World		SAG, VERT, TUM
01.07.2008	Regular Article: Fabrication and characterization of GaSb-based monolithic RC-LED emitting around 2.3 µm and including a Tunnel Junction, A. Ducanchez, L. Cerutti, A. Gassenq, P. Grech and F. Genty, in IEEE J. Select. Topics Quant. Electronics, 14(4),2008	Research, Industry (electronics & opto devices)	World	n.a.	UM2
01.07.2008	Regular Article: Simplified model of the dynamic thermal tuning behavior of Vertical-Cavity Surface-Emitting Lasers", J.Chen, A.Hangauer, M.-C. Amann, IEEE Photonics, 20 (3), 1082-1085, 2008	Research, Industry (electronics & opto devices)	World	n.a.	SAG

10.07.2008	Seminar in UM2: 2nd year PhD results (CST) on development of new GaSb-based EP-VCSELs structures. A. Ducanchez	Research, Students	France	50	UM2
15.07.2008	Magazine Article: VCSELs head farther into the infrared, Compound Semiconductor Magazine, July 2008, Volume 14 Number 6	Research, Industry (electronics & opto devices)	World	n.a.	WSI
01.08.2008	Conference contribution: Long wavelength GaSb-based VCSEL with BTJ technology, poster by K. Kashani, A. Bachmann, M.-C. Amann, BNNi iNow Workshop 2008, Tokyo, Japan	Research, Industry (electronics & opto devices)	World	n.a.	WSI
03.08.2008	Conference contribution: GaSb-based VCSELs emitting in the mid-infrared wavelength range (2-3µm) grown by MBE, L. Cerutti et al., invited talk on the 15th International Conference on MBE 2008, Vanouver, Canada	Research, Industry	World	200	UM2
05.08.2008	Conference contribution: MBE Growth of active regions for electrically-pumped, cw-operating GaSb-based VCSELs, talk by K. Kashani, A. Bachmann, G. Boehm, M.-C. Amann, 15th International Conference on MBE 2008, Vanouver, Canada	Research, Industry	World	n.a.	WSI
27.08.2008	VCSEL extends its reach to detect CO	Semi-scientific audience	World	n.a.	SAG

Publications 3rd period

01.09.2008	Conference contribution: GaSb-based Electrically Pumped VCSEL with Buried Tunnel Junction, A. Bachmann, K. Kashani, M.C. Amann, IEEE/LEOS ISLC 2008, Sorrento, Italy	Research, Industry (electronics & opto devices)	World	n.a.	WSI
01.09.2008	Regular article: MBE Growth of active regions for electrically-pumped, cw-operating GaSb-based VCSELs, K. Kashani, A. Bachmann, G. Boehm, S. Ziegler, M.-C. Amann, Journal of chrystal growth	Research, Industry (electronics & opto devices)	World	n.a.	WSI
01.09.2008	Regular Article: "Room-Temperature Continuous-Wave Operation of 2.3 µm Sb-based Monolithic" by A. Ducanchez, L. Cerutti, P. Grech, and F. Genty, IEEE Photonics Technology Letters, Vol. 20, No. 17-20, pp 1745-1747	research, Industry (electronics & opto devices)	World	n.a.	UM2
02.09.2008	Internship: UM2 Master 2, Internship: Electrical and thermal optimisation on Sb-based VCSELs, report and oral presentation by Henry Nguyen	research, Students	France	n.a.	UM2
02.09.2008	Conference contribution: Laser diode photoacoustic and FTIR laser spectroscopy of formaldehyde in the 2.3 mu m and 3.5 mu m spectral range, talk by Cihelka et al, 20th International Conference on High Resolution Molecular Spectroscopy, Prague, CZ	scientific, students	world	100	IOP
05.09.2008	Presentation at the NUSOD conference, Nottingham, UK: "Trends in cavity designs for vertical cavity lasers and simulation of their consequences", talk by Jörgen Bengtsson	Specialists in numerical modeling of optoelectronic devices	World	100	Chalmers
07.09.2008	Invited talk: GaSb-based VCSELs: NEMIS results, F. Genty, A. Bachmann et al., joint invited talk, MIOMD conference 2008, Freiburg, Germany	Research, Industry (electronics & opto devices)	World	120	UM2, WSI
07.09.2008	Conference contribution: Mid-Infrared Optical Response of Heavily Doped GaSb:Te, J. Humlíček, K. Navrátil, E Hulicius, J. Vyskočil, T. Šimeček, K. Kashani, M. Amann, poster, MIOMD conference 2008, Freiburg, Germany	Research, Industry (electronics & opto devices)	World	120	IOP, WSI
08.09.2008	Conference contribution: Mid-infrared photovoltaic detectors based on a type II p-InAs/AlSb/InAsSb/AlSb/p(n)-GaSb heterostructure with deep quantum wells at the interface D-IX, poster by M.P. Mikhailova et all , MIOMD conference 2008, Freiburg, Germany	scientific, students	world	150	IOP
14.09.2008	Conference contribution: GaSb-based Microcavity EP-VCSEL emitting above 2.2 µm in CW regime at RT, talk by A. Ducanchez, L.Cerutti, P. Grech and F. Genty, ISLC	Research, Industry (Opto devices)	World	200	UM2

	2008, Sorrento, Italy				
20.09.2008	Conference Contribution: CO and CH4 sensing with electrically pumped 2.3 µm GaSb-based VCSELs, talk by J. Chen, A. Hangauer, A. Bachmann, T. Lim, K. Kashani-Shirazi, R. Strzoda and M.-C. Amann, European Semiconductor Laser Workshop. Eindhoven, 2008	Research	World	50	SAG, WSI
01.11.2008	Laser Diode Measures Carbon Monoxide Traces	Non-scientific audience	World	n.a.	SAG
06.11.2008	Regular Article: GaSb-based monolithic EP-VCSEL emitting above 2.5 µm , Ducanchez A, Cerutti L, Grech P, et Genty F, Electronics Letters, Vol 44, No 23, 1457, 2008	Research, Industry (electronics & opto devices)	World	n.a.	UM2
01.12.2008	Diffraction loss in long-wavelength buried tunnel junction VCSELs analyzed with a hybrid coupled-cavity transfer-matrix model, J. Bengtsson, J. Gustavsson, Å. Haglund, A. Larsson, A. Bachmann, K. Kashani-Shirazi, and M.-C. Amann, Opt. Expr. 16, 25, 2008	Research, Industry (Opto devices)	World	n.a.	Chalm, WSI
12.01.2009	Laserdiode misst winzige Spuren Kohlenmonoxid	Non-scientific audience	Germany	n.a.	SAG
13.01.2009	Conference contribution: VCSEL Structures and Applications, talk by M.-C. Amann (invited), TuB2.1, IEEE Winter Topicals 2009, Innsbruck, Austria	Scientific, students	World	100	WSI
17.02.2009	Conference contribution: IR VCSELs for Sensing Applications, talk by M.-C. Amann, 39th Freiburg Infrared Colloquium, Freiburg, Germany	Research, students	World	100	WSI
26.02.2009	Regular article: Mid-infrared GaSb-based EP-VCSEL emitting at 2.63 µm, Ducanchez A, Cerutti L, Grech P, Genty F, and Tournie E, Electronics Letters, Vol. 45, No. 5, pp 265-266, 2009	Research, Industry (electronics & Opto devices)	World	n.a.	UM2
10.03.2009	Conference Contribution: Optimized MBE growth technique for GaSb-based edge emitters at 2.7 µm, talk by K. kashani-Shirazi, A. Bachmann, S. Arafin, K. Vizbaras, M.-C. Amann, Euro MBE 2009, Zacopane	Research, Industry (electronics & opto devices)	World	150	WSI
15.03.2009	Regular Article: GaSb-based VCSELs emitting in the mid-infrared wavelength range (2-3µm) grown by MBE, L.Cerutti et al., Journal of crystal Growth. 311 (2009) 1912	Research, Industry (electronics and opto devices)	World	n.a.	UM2
07.04.2009	Conference Contribution: Low-resistive ohmic contacts to n-InAs0.91Sb0.09 for GaSb-based VCSELs in the mid-infrared range, talk by S. Arafin, A. Bachmann, K. Kashani-Shirazi, S. Priyabadini, M.-C. Amann, SIOE Conf., Cardiff	Research	World	100	WSI
07.04.2009	Conference Contribution: Buried Tunnel junction Mid-infrared GaSb VCSELs investigated using hydrostatic pressure, talk by I. Marko, A. Ikyo, A. Adams S. Sweeney, A. Bachmann, K. Kashani-Shirazi, M.-C. Amann, SIOE Conf. 2009, Cardiff	Research	World	150	WSI
24.04.2009	Regular Article: GaSb-based VCSEL With Buried Tunnel Junction for Emission Around 2.3 µm, A. Bachmann, K. Kashani-Shirazi, S. Arafin, M.-C. Amann, J. Sel. Top. Quantum Electron. 15(3)	Research, Industry (elevctronics & opto devices)	World	n.a.	WSI
24.04.2009	Conference Contribution: Presentation of the Nemis results in UM2 talk by L.Cerutti et al, on the VCSRL day, Göteborg, sweden	Research and Industry (Electronics and opto devices)	Europe	50	UM2
12.05.2009	Award: Kaiser Friedrich Forschungspreis 2009	Research, Industry (electronics & opto devices), non-scientific audience	Germany	70	WSI

17.05.2009	Conference contribution: Sb-based Mid-infrared lasers, Invited talk by E. Tournie et al. Workshop on Compound Semiconductor Devices and integrated Circuits (WOCSDICE) 2009, Malaga, Spain.	Research, Industry (Electronics & opto devices)	World	150	UM2
02.06.2009	Regular Article: Low-Threshold Strained Quantum-Well GaSb-Based Lasers Emitting in the 2.5 To 2.7 µm Wavelength Range, K. Kashani-Shirazi, K. Vizbaras, A. Bachmann, S. Arafin, M.-C. Amann, IEEE Photon. Technol. Lett. 21(16)	Research, Industry (electronics & opto devices)	World	n.a.	WSI
02.06.2009	Conference Contribution: Ultra-low threshold GaSb-based laser diodes at 2.65 µm, talk by K. Kashani-Shirazi, A. Bachmann, S. Arafin, K. Vizbaras, M.-C. Amann, CLEO 2009, Baltimore	Research, Industry (electronics & opto devices)	World	150	WSI
02.06.2009	Conference Contribution: Fire Detection with a Compact, 2.3 µm VCSEL-Based Carbon Monoxide Sensor by A. Hangauer, J. Chen, R. Strzoda, M. Fleischer and M.-C. Amann (CLEO)	World	World	500	WSI SAG
04.06.2009	Conference Contribution: Low-resistive thermally stable metal-semiconductor contacts on n-GaSb using n-InAsSb contact layer, talk by S. Priyabadini, S. Arafin, A. bachmann, K. Kashani-Shirazi, M.-C. Amann, Internat. Conf. on Frontiers of Physics, Kathmand	Research	World	100	WSI
05.06.2009	Conference Contribution: CO and CH4 Sensing with Single Mode 2.3µm GaSb-Based VCSEL by J. Chen, A. Hangauer, A. Bachmann, T. Lim, K. Kashani-Shirazi, R. Strzoda, and M.-C. Amann (CLEO)	World	World	500	WSI SAG
14.06.2009	Conference Contribution: GaSb-based mid-IR electrically-pumped VCSELs covering the wavelength range from 2.3 to 2.7 µm, talk by A.Ducanchez, et al., IEEE Conference on Laser and Electro-Optics 2009 (CLEO europe 2009), Munich, Germany	Research, Industry (electronics & opto devices)	World	200	UM2
02.07.2009	Internship: UM2 Master 2, Improvement of electrical confinement in electrical Sb-based VCSELs, Report and Oral by Dorian Sanchez	Research, Students	France	n.a.	UM2
08.07.2009	Internship: UM2 PhD Thesis, Technological process for concption of MIR sb based electrically VCSELs, talk by A.Ducanchez	Research, Students	France	n.a.	UM2
14.07.2009	Conference Contribution: Long wavelength electrically pumped GaSb-based Buried Tunnel Junction VCSELs, talk by A. Bachmann, S. Arafin, K. Kashani-Shirazi, M.-C. Amann, 14th Internat. Conf. on Narrow Gap Semiconductors and Systems, Sendai	Research	World	100	WSI
06.08.2009	Conference Contribution: Tunable Near- and Mid-Infrared VCSELs for Sensing and Spectroscopy, talk by M.-C. Amann, ThA2, p. 39-40, 2009 International Nano-Optoelectronics Workshop, Stockholm, Sweden and Berlin, Germany	Scientific, Students	World	200	WSI
28.08.2009	Seminar in EPFL Lausanne, GaSb based electrically pumped VCSELs emitting in the mid-infrared wavelength range (2-3.5µm), talk by A. Ducanchez	Research	Europe	50	UM2
08.09.2009	Long-wavelength VCSELs for TDLS applications	Research, Industry	World	150	VERT
08.09.2009	Conference Contribution: Miniaturized Laser Spectroscopic CO Sensor for Industrial and Safety Applications by J. Chen, A. Hangauer, R. Strzoda, M. Fleischer and M.-C. Amann (Eurosensors Lausanne)	World	World	500	SAG WSI
20.10.2009	Conference contribution: W-heterolasers verzus QCL, invited talk by E. Hulicius, p.44, Nanocon 1, Roznov pod Radhostem, Czech Republic	Scientific, students	Czech Republic	50	IOP
17.12.2009	Regular Article: "Single-mode electrically pumped GaSb-based VCSELs emitting continuous-wave at 2.4 and 2.6 µm", New J. Phys. 11 (2009) 125014 (invited).	Research, Industry (electronics & opto devices)	World	n.a.	WSI
19.01.2010	Regular Article: Diagnostic and Characterization of the VCSEL Diode Based on GaSb, I. Matulkova, J. Cihelka, J. Vyskocil, Z. Zelinger, E. Hulicius, T. Simecek and S. Civis, submitted and accepted to Appl. Phys. B	Research	World	n.a.	IOP


Materials
Devices
Sensing Applications
European Semiconductor Laser Workshop 2008
Friday 19 September and Saturday 20 September 2008
Technische Universiteit Eindhoven - The Netherlands
Vancouver Canada
MBE
IPRM
2008
Est. 1989
CLEO
QELS
08
FIELD LASER APPLICATIONS IN INDUSTRY AND RESEARCH
LASER World of PHOTONICS China


Materials
Devices
Sensing Applications
Euro-MBE 2007
Granada, Spain
Deutscher MBE Workshop 2006
Hamburg, Germany
MIOMD-VIII
8th Int. Conf. on Mid Infrared Opto-electronics Materials and Devices
Bad Ischl, Austria
ICCG-15
The 15th International Conference on Crystal Growth, USA
European Semiconductor Laser Workshop 2007
Berlin, Germany
FIELD LASER APPLICATIONS IN INDUSTRY AND RESEARCH
REIMS
6th International Conference
TUNABLE DIODE LASER SPECTROSCOPY
July 9- 13, 2007
Reims, France

Fig. 2: International conferences members of the NEMIS consortium contributed to.

Members of the NEMIS consortium visited a number of international conferences and contributed with invited talks, presentations and posters. Fig. 2 gives an overview of the attended conferences.
The conferences scopes range from material growth and devices development to sensing applications. Thus NEMIS results are made accessible to an audience of roughly 3000 experts worldwide. As the NEMIS project includes the development of the new GaSb material system, the processing and characterisation techniques for VCSEL devices and the implementation of these new devices into the gas sensing applications, the visited conferences and publications are in perfect relation to the NEMIS project and help to communicate the role of the FP6 programme in the scientific research.

The award of the Kaiser-Friedrich-Forschungs-Preis for the development of GaSb-based VCSEL for CO detection and the nomination for the AMA-Sensor Innovation Award for 2.3 µm VCSEL-based CO-monitoring disseminate the results of NEMIS especially with respect to new sensing capabilities to a wider audience first and foremost to industrial professionals, but also to the general public by articles in the general press, radio and TV broadcasts.
The activities of the press in conjunction with the award and six press releases launched by the partners initiated a number of inquiries from industry for new applications of the presented technology, which in the end will result in new products.

The size of the audience addressed by these actions is difficult to judge, however the main goal of the dissemination efforts has been reached. The interested professionals in industry are informed about the gas sensing capabilities of the new MIR-VSCEL.
Beyond the professionals dissemination to the general public was enforced by open days and the participation in exhibitions. At the open days of the Walter Schottky Institute at the 24.Oct 2009 and the Siemens research labs in Erlangen at 24. Sept 2009 the interested public was given an insight into the research of the institutions with the latest results. Siemens participated in the Ideen Expo, Hannover, 5-13 Sept 2009 among others with a TDLS CO2 gas sensor based on the NEMIS platform. The Ideen Expo is an exhibition which especially addresses young people in schools and students, This exhibition showed a wide range of new technological developments and attracted in 2009 250000 young visitors.

2.3 Section 3 - Publishable results

Title	*Laser emission of room-temperature, monolithic, electrically-pumped GaSb-based VCSELs at 2.3µm*
Abstract	An all-epitaxial monolithic vertical cavity surface emitting laser (VCSEL) grown on GaSb substrate was realized. The structure is composed of two n-doped AlAsSb/GaSb distributed Bragg reflectors, a type-I GaInAsSb/AlGaAsSb multi-quantum-well active region and a tunnel junction. Quasi continuous-wave laser operation is demonstrated at 2.3 µm up to room temperature.
Possible market applications	WMS, PAS
Stage of development	prototype
Collaborations sought or offered	-
Collaborator details	-
Intellectual property rights	-
Contact details	Université Montpellier 2, Dr. F. Genty, genty@univ-montp2.fr

Title	*Laser emission of room-temperature, electrically-pumped GaSb-based VCSELs with buried tunnel junction at 2.3 – 2.4 µm*
Abstract	An electrically pumped GaSb-based vertical cavity surface emitting lasers (VCSEL) including a structured buried tunnel junction (BTJ) as current aperture is realized. Continuous-wave, single mode, room temperature operation at 2.3 to 2.4 µm has been achieved. Maximum single-mode output power reached is approx. 800 µW. The device is tunable by the applied current over a range of 8 nm.
Possible market applications	WMS, PAS
Stage of development	prototype
Collaborations sought or offered	-
Collaborator details	-
Intellectual property rights	-
Contact details	Walter Schottky Institut, A. Bachmann, bachmann@wsi.tum.de

Title	*Laser emission of room-temperature, electrically-pumped GaSb-based VCSELs with buried tunnel junction at 2.6 µm*
Abstract	An electrically pumped GaSb-based vertical cavity surface emitting lasers (VCSEL) including a structured buried tunnel junction (BTJ) as current aperture is realized. Continuous-wave, single mode, room temperature operation at around 2.6 µm has been achieved. The device is tunable by the applied current over a range of 5 nm.
Possible market applications	WMS, PAS
Stage of development	prototype
Collaborations sought or offered	-
Collaborator details	-
Intellectual property rights	-
Contact details	Walter Schottky Institut, A. Bachmann, bachmann@wsi.tum.de

Title	*CO, CH4 detection with 2.3 µm GaSb-based single-mode VCSELs*
Abstract	Application of recently realized GaSb-based single mode vertical-cavity surface-emitting lasers (VCSELs) for gas-sensing at 2.3 µm is reported. Using a few ten cm optical path, carbon monoxide and methane were detected simultaneously in ppm range using wavelength modulation spectroscopy with laboratory equipments. The laser device showed stable single frequency operation during wavelength tuning by current and temperature. Influences of the laser PI characteristics for sensor application and data processing concepts for improving the gas-sensing performance are discussed.
Possible market applications	WMS
Stage of development	prototype
Collaborations sought or offered	-
Collaborator details	-
Intellectual property rights	-
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At the current stage of the project, the main results are the optimization of electrically pumped GaSb-based VCSEL particularly with respect to output power, mode behavior, wavelength extension and the application of these devices in sensing experiments. Further results could be achieved and were published (see section 2) in the fields:

1. Device simulation
2. Epitaxy and processing techniques for BTJ and monolithic GaSb-based VCSELs
3. Parameters of GaSb-based materials
4. Technology of TDLAS

2.4 Conclusions

The plan for using the knowledge is changed due to the early withdrawal of Omnisens from the project. The NEMIS related PAS activities are discontinued. The remainder of the plan is however unaffected. The NEMIS website is up-to-date. A remarkable number of conference contributions and publications have been produced up to now, which demonstrates the efforts towards dissemination of knowledge to the international expert public. The award of the Kaiser-Friedrich-Forschungs-Preis initiated considerable press activities which made the capabilities of the new VCSELs for gas sensing known to the interested professionals in industry. In the third year, conference visits, publications and other means for dissemination of knowledge to the interested public like open days and the participation in exhibitions were organized. Joint publications show the cooperation efforts of the project partners. By contacting further FP6 projects, initiating the VCSEL-day workshop the consortium tries to enhance the cooperations beyond the NEMIS project.