Contract no.: TST3-CT-2003-506316
Project acronym: ISLE

Integrated communicating Solid-State Light Engine (ISLE) for use in Automotive Forward Lighting and information exchange between vehicles and infrastructure

SIXTH FRAMEWORK PROGRAMME
PRIORITY 2.7
Advanced design and production techniques
SPECIFIC TARGETED RESEARCH OR INNOVATION PROJECT

Final Activity Report

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Coordinator name: Eike Krochmann
Revision: 1

Project coordinator organisation name: Schefenacker Vision Systems Germany GmbH (SVS)

Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination Level		
PU	Public	**X**
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Document adjustments

Version	Date	Change	Author
Rev. 1	28.03.2007	Original Version	Krochmann / Würtenberger

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1 Summary

This project aimed to develop a new manufacturing technology to produce a new generation of headlamps for vehicles, which could be the base for a future car-to-car or of car-to-infrastructure communication system. For this, new optical concepts for beam forming needed to be developed and had to be approved for production. This included also processing LED chips into a packaging for emitting white light, which again needed to be optimally decoupled into the beam forming elements. In addition a suitable concept for communication and an appropriate electronic driving circuit was developed. All together was put in an automotive environment.

The original idea aimed at simplifying the production process of headlamps by:

- o reducing the number of production steps
- o reducing the components electric bulb, reflector and housing to just one injection moulded component
- o reducing the production time
- o reducing the manufacturing costs

The objectives below highlight the key points of the project. Each of these areas were managed and followed by a specific partner within the consortium.

2 Project Execution

2.1 General Objectives

The major topics for the project cover

- providing a white LED, which fulfils the requirements in respect of colour, applying optical elements and efficiency
- development and implementation of an efficient optical concept an ensure the large scale production suitable for automotive application
- showing, that a communication can be achieved by modulating the light of LEDs in a automotive headlamp
- to develop an integrated electronic driver circuit with all necessary functionality and implementing the concept into an integrated circuit
- solving problems such as thermal management, occurring for a complete headlamp system integration, when LEDs are used
- support all activities to make LED headlamps legal on the road

2.2 Partners involved

Participant name	Participant short name	Country	Core business	Role in the project
Schefenacker Vision Systems Germany GmbH (*)	SVS	D	o Setmaker for automotive signalling lamps o Manufacturer of automotive rear view mirrors	o overall project management o combine all hardware results in a functional headlamp unit o providing reliable functioning in automotive environment o achieve legal premise of

Participant name	Participant short name	Country	Core business	Role in the project
				using LEDs for front lighting in public road traffic
Global Light Industries GmbH	GLI	D	o LED manufacturer	o implement injection moulding process of optics with Chip-on-Board technique
OEC AG	OEC	D	o develop modular optical approach.	o develop modular optical approach.
LED Products Europe S.L.	LPI	SP	o develop integrated optical approach	o develop integrated optical approach o provide prototype optics
TU-Berlin	TUB	D	o University	o develop chip sub-mount and converter placement technology
STMicroelectronics S.r.l.	STM	I	o make ASIC driving module	o make ASIC driving module
Philips Lighting B.V.	PE	NL	o develop LED driving electronics	o develop LED driving electronics
University College Cork	Tyndall (formerly NMRC)	IRL	o Industrial research	o develop and simulate thermal issues
IGS HIGH TECH B.V.	IGS	NL	o Mould flow tool maker	o development of moulding tools for optical components
IFP-Sicomp	IFP	S	o Industrial research foundation	o investigation and simulation of the injection mould process
University of Pannonia (formerly University of Veszprém)	UV	HU	o University	o providing photometric and radiometric testing acc. to state of the art o implement perceptions derived from a previously EU founded project in respect of human vision o contributing in standardisation committees o evaluate method for testing headlamp performance during production process
University of Madrid, Dpto. ETSI Telecomunicación Dpto. Tecnología Fotónica	UPM	E	o University	o develop car-to-car and car-to-infrastructure communication o supporting development of optical concept

Participant name	Participant short name	Country	Core business	Role in the project
Regloplas AG	REG	CH	o Supplier of cooling systems	o develop and provide cooling system for moulding process
Chamberlain Plastics Ltd	CPL	UK	o Manufacturer of thin plastic foils	o develop and provide alternative coating technology on base of thin foils
LITEC-LLL GmbH	LITEC	D	o Manufacturer of fluorescent materials	o develop and provide a new converter for white LEDs suitable for communication issues and fulfilling colorimetric requirements

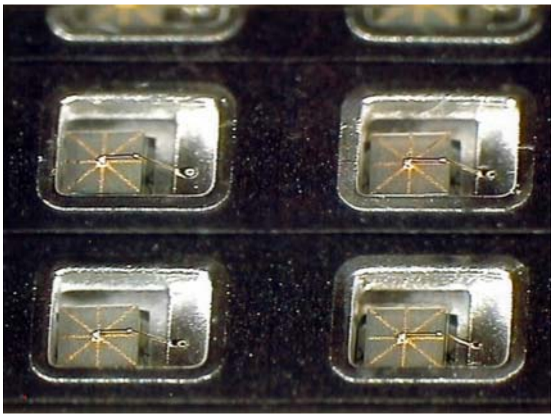
(*) Contact person: E. Krochmann <eike.krochmann@schefenacker.com>

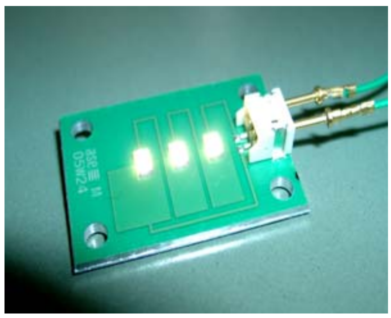
2.3 Work performed

2.3.1 Light Source

One of the key items within this project was the LED emitting white light. This source had to be combined with optical elements for beam forming. But it is essential, that losses in light are minimised. One possibility for this is over moulding or index matching. With those technologies losses on the optical interface can be avoided. This requires the availability of white LEDs at a certain production step without any encapsulation. At the project start these were not available and forced the consortium to start building an own efficient LED.

From the type of chip selected, a sub mount had to be developed and manufactured. This proved to be a challenge and finally did not show the performance as assumed. However, the consortium was able to implement their concept and developed a technology for the chip to sub-mount and sub-mount to board fixation. Important parameter was of course minimising the thermal resistance. Here, the type of insulated metal substrate (IMS) was an additional matter of research.





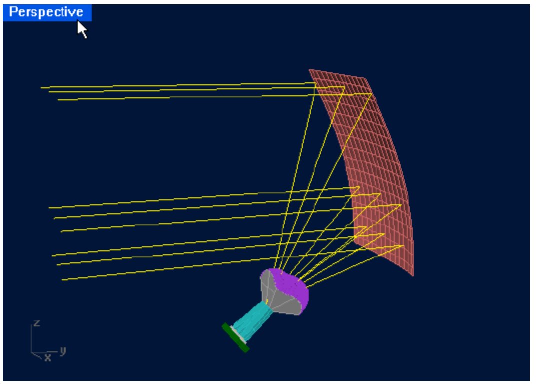
In order to transform the blue light emitted from the chip into white light a suitable phosphor had to be developed. Beside conversion efficiency special requirements in respect of light colour had to be fulfilled within the necessary range of temperature. Moreover a suitable way of placing the phosphor powder on top of the sub-mount chip assembly had to be found. A converter foil was the final solution, which also ensured constant colour in all emitting directions.

2.3.2 Optics

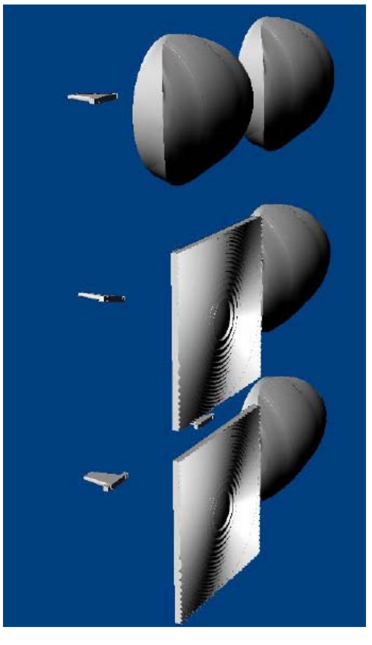
With the beginning of the project two different two technologies seemed particularly interesting for optics design, as there was:

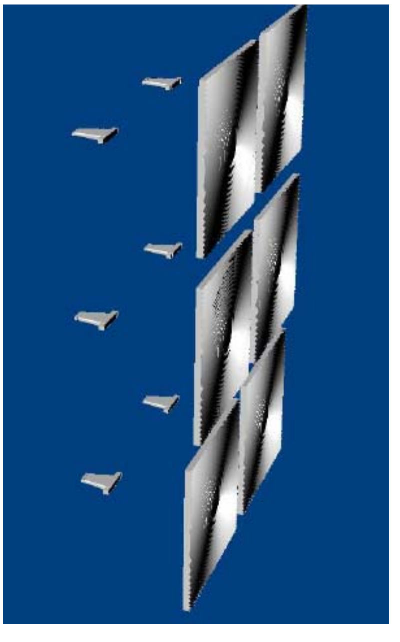
- o tailored beam technology and
- o folded edge ray or (RXI) technology

These approaches employ different methods to achieve the same end of an optical system. As such this project needed to define the most suitable one. Already in an early project stage, the RXI technology turned out to be not very suitable for the one-shot moulding objective. From this a new technology has been invented, called "XR Combiner". This concept was implemented, since it seemed also to be relatively immune in respect to LED beam distribution. The heart of the concept is a light pipe with different inputs for separate LEDs and one output surface (combiner). This surface is a freeform lens, which directs the light towards a freeform mirror structure for final beam shaping. This concept was implemented for the high (driving) and low (passing) beam. For making the mirror, a new technology was used. Instead of metallising a plastic shape, the reflective foil technology was used. Here a reflecting foil with extremely high reflectance was used. The suitable in-mould film coating process was specially developed within the project.



The tailored beam concept was worked out up the stage for creating tooling data for both, high (driving) and low (passing) beam. Because the tailored beam concept is more sensitive to the light source characteristics, which was not available for the ISLE- LED on proper time, the concept had to be worked out on the base of a commercially available 5 by 1 OSRAM O-Star LED module. The concept finally used a light pipe in front of the LED-module and a Fresnel-lens for the driving (high) beam. The passing beam contains modules with Fresnel and 3D tailored free form lenses in front of a light pipe.





Passing beam concept Driving beam concept

The optical efficiency of high and low beam is according to the simulation results 0,50 respectively 0,54 and thus worse compared to that based on the XR Combiner (0,76 respectively 0,8) without any dimensional size advantage.

2.3.3 Communication

The concept for communication is based on a frequency shift keying technology (FSK). The clou of concept ensures together with the electronically driving concept no light loss either with or without sending data. The additional advantages are

- Immunity due to amplitude variations of the signal. This is important if car movement and vibrations are considered.

- The effect of the noise is reduced
- It is insensitive to non-linear amplification both in the emitter and receiver
- Simple integration with the LED driver circuit, based on PWM at (near) zero extra cost.

Beside the sender a receiver was built. Simulated and measured data showed perfect correlation in the laboratory tests of single components. At the end the communication performance of the system headlamp-receiver was tested. The maximum communication distance of the actual headlamps was found to be 29 m for the passing (low) and 39 m for the driving (high) beam, which is only about the eleventh part of the theoretical predicted communication distance. In this arrangement it was at least shown, that a communication is possible, but that further improvements on the LED, the optical components and the receiver's sensitivity would be necessary.

2.3.4 Electronic development

Electronic hardware was built up according to the concept for driving the LEDs and fulfilling the requirements according to the communication concept. It provides a constant voltage rail supply and pulse width modulated (PWM) current control and serves for most efficiently supplying the LEDs. Also provision for thermal runaway and LED failure are provided. Within the project driver boards in SMD-technology were built up.

Even if it had been demonstrated that the chosen architecture perfectly works and it had been the most suitable choice fitting the project's target during its development phase, an integrated solution, replacing most of the discrete components making the current sinker, has been re-evaluated with the aim to improve the overall electronic board performances.

The discrete solution had been initially chosen as it represented the best trade-off between power dissipation and board size for the current control. However, advances in silicon packaging technology and the possibility to place the electronic board together with the optical part has lead to reconsider the development of a dedicated ASIC for the ISLE project.

The new Micro Lead Frame (MLP) silicon packaging technology has been taken into account for the purpose of managing the heat dissipation in a reasonable size. Due to the presence of a large exposed slug able to be both electrically and thermally connected to the PCB board, a very low thermal resistance can be achieved.

With this as a backdrop, the development of the dedicated ASIC named STCS1 has been started. In addition to a better application's thermal management, electrical performance's improvement have been evaluated and eventually easily implemented in the STCS1. This has been possible due to an advanced and smart 0.35um technology integrating power transistors and control logic devices, which is widely used today for automotive applications.

2.3.5 System integration

Within the system integration all aspects within the project had finally to be formed to the headlamp. The most important topics were:

- Size of the head lamp housing: Different over-all design studies for the arrangement of the passing (low) and driving (high) beam modules for the first PMMA-design were made. Commercial head lamp housings were too small. Therefore a design of an appropriate housing and of the arrangement of all components was necessary.
- Appropriate design of the optical components regarding the requirements of the injection moulding process and of the fixation in the housing. Considering tolerances was a very critical aspect here.
- Design of the components of the liquid cooling system accordingly to the results of the thermal simulation
- Design of the device to adjust the beam pattern of high beam and low beam, which are related to each other

- Development of an technological process to prepare the high reflective foil in such a kind, that it can be handled in a following injection moulding process for the manufacturing of an appropriate optical mirror
- Design of the LED-boards and the LED-driver boards
- Design of the control device as the interface between the car itself and the headlamps as well as the data input device and the head lamp, which allows to operate the pump together with the high and low beam alternatively as well as to display a fail state of the LEDs. In addition the characters of the data content will be transformed in frequencies, which represent the communication signal based on light.
- Design of the receiver for the communication signal including the interface to a PC in order to demonstrate the received signal as a character string
- Manufacturing, buying and assembly of all components
- Verification of the parameters of all single components and subassemblies by photometrical, dimensional, electrical measurements and re-simulations ,detecting and fixing of failures
- Operating of the complete system at a car and comparison with the target data

2.3.6 Legal regulations

Already with starting the project extensive efforts have been made to enter the international standardisation body GTB (*GROUPE DE TRAVAIL "BRUXELLES 1952"*), which is the expert sub-committee within the chain of legislative procedure of the UNECE in respect of automotive lighting. It has installed a Task Force on LED Front Lighting aiming to amend the corresponding headlamp regulations to allow LEDs as light source. The Taskforce, were ISLE consortium members continuously attended, has developed respective documents and submitted them to GRE. The expectation to get the proposal approved right away was low. But from the discussion it could be seen, that the process will probably still take some years and outlast the project duration due to the political aspect of the new technology. It will strongly depend on how well that technology will be explained to the government and on convincing them on the advantages. However, an Asian car manufacturer was able to achieve positive reply on a request for an exemption certificate for the European countries to bring a car with LED-headlamps in 2007 on the market.

In the United States the situation looks more relaxed. SAE has published SAE J2350, which includes similar requirements for LEDs as the ECE R112 proposal. In addition the SAE standard allows beside LED-modules also non replaceable LEDs and is therefore not so design restricting. Although the standard is not referenced in the American law FMVSS 108, it has some legal relevance due to the fact that manufacturer are required to apply SAE standards, if available. In addition latest interpretation of the law[1] certifies the compliance, when LEDs are used within an integrated beam headlamp type.

2.4 Results achieved

- Samples of white LED have been manufactured performing with a correlated colour temperature below 4300 K. For this a unique converter material was composed.
- The communication concept has been implemented and its feasibility was approved in the laboratory and at the complete system

[1] Docket No. NHTSA-06-23516

- The integrated optical concept[2] was turned into a complete headlamp including driving (high) and passing (low) beam
- A modular optical concept was designed and its performance simulated. The concept was investigated for producibility.
- A novel concept of laminating high reflective coating on plastic material was developed.
- An electronic driver circuit on a lower scale integration (SMD-technology) with all necessary functionality was developed
- An integrated circuit performing all functionality of the electronic driver circuit has been developed, sample quantities are available on the market
- A fluid based cooling system was investigated[3]
- Development of a high dynamic heating and cooling system with pressurised water for injection moulding tools taking advantage of ultrasonic based water flow measurement.
- At the end the aimed photometrical data of the head lamps were not achieved, which is caused by the imperfectness of the optical components including the LED. Consequently the predicted communication distance is much shorter as predicted. However, with further optimisation loops for the optical components, further improvements are possible. With the suboptimal LED performance we probably have to live with.

2.5 End results

The consortium presented a set of a fully functional headlamp device using LEDs as light source and performing a driving and passing beam. The out coming light can be modulated in order to communicate information to the infrastructure. The device almost provides outline dimensions in accordance with generally available space in today's cars. The system is capable to be mounted on a test rack in front of a vehicle.

With each partner additional knowledge was built up during the project, which enables further commercial benefits or – in case of public bodies – provided contribution to industrial wide training, reputation and contacts to industry.

3 Dissemination and use plan

Planned /actual Dates	Type	Type of audience	Countries addressed	Size of audience	Partner responsible /involved
Sept 07	Conference Talk and Proceedings ISAL 2007: "Investigation in an active liquid cooling system of a LED headlamp"	Customers, Lighting designers	Europe	300	SVS, Tyndall

[2] further information on the used optical concept see O. Dross, A. Cvetkovic, P. Benitez, J.C. Minano, J. Chaves; Novel LED Headlamp Architectures That Create High Quality Patterns Independent of LED Shortcomings; p. 117-127; Proceedings of ISAL 2005 Symposium, Darmstadt; ISBN 3-8316-0499-1

[3] LIQUID COOLING OF BRIGHT LEDS FOR AUTOMOTIVE APPLICATIONS
Yan Lai1, Nicolás Cordero, Frank Barthel, Frank Tebbe, Jörg Kuhn, Robert Apfelbeck, and Dagmar Würtenberger; page 80 -85; ©TIMA Editions/THERMINIC 2006; ISBN: 2-916187-04-9

Planned /actual Dates	Type	Type of audience	Countries addressed	Size of audience	Partner responsible /involved
Jan-July 07	Test runs at customers with cavity control	Customers	Europe	small	REG
June 07	Exhibition Gifa	Customers	Germany	Big	REG
Oct. 07	Exhibition K	Customers	Germany	Big	REG
July 07	Conference publication	Lighting designers	global	300	UP (former UV)
in 2007	Publication	Research	International (worldwide)		Tyndall (former NMRC) / SVS
July 07	Conference	Research	International (worldwide)	500	UP (former UV)
April 2007	Publication of data transmission subsystem	Technical	All		UPM
2004-2006	Presentations of the project and on mould filling simulations	Personnel within management/research etc for various Research Institutes	Sweden	10-15	IFP
2004-2006	Presentations of the project and on mould filling simulations	Personnel within management/research etc for various companies	Sweden	25-30	IFP
September 2006	Conference, invited talk	automotive industry	lamp suppliers and car manufacturers mainly in Europe	about 150 persons	GLI
27-29 Sept. 06 (Nice)	Conference	Research	International (worldwide)	appr. 100	Tyndall (former NMRC) / SVS
24-26 April 2006 (Como)	Conference	Research	International (worldwide)	appr. 100	Tyndall (former NMRC)
March 2006	SPIE News room invited online publications “Etendue-preserving mixing and projection optics for high-brightness LEDs “	Optics community	All		LPI
Oct 2005	“LED Interconnection		worldwide	500	TUB

Planned /actual Dates	Type	Type of audience	Countries addressed	Size of audience	Partner responsible /involved
	and Packaging Technologies”, 3th Intenational Symposium on Nanotechnology and LEDs , Köflach, Austria, 24th – 25th October 2005				
Sept 2005	Conference Talk and Proceedings ISAL 2005 “Novel LED Headlamp architectures that create high quality patterns independent of LED shortcomings”	Entire Automotive lighting community	All	300	LPI (UPM)
August 2005	Conference Talk and Proceedings SPIE 2005 “LED Headlight Architectures that creates a High Quality Beam Pattern independent of LED Shortcomings”	Entire non imaging optics community	All	120	LPI (UPM)
2005	Publication: “Physical and visual requirements for LEDs to be used for future lighting systems”	Lighting community	international	--	UV
2005	Publication: “Visibility and glare under mesopic conditions”	Lighting community	international	--	UV
2005	Publication: "Night-time driving – new light sources in car headlamps – visibility and glare"	Lighting community	international	--	UV