Executive Summary Periodic Activity Report #2

Plasmon Enhanced Photonics (PLEAS)

1st September 2006 – 30th August 2008

24 Month Report
24/10/2008

INTRODUCTION

This report is the second in a series of annual public reports reporting the activities carried out within the EU funded framework 6 project PLEAS on Plasmon Enhanced Photonics. These reports will be made available on the PLEAS website www.eu-pleas.org. These reports will be technical in nature, for non-technical reports please visit the Press Release page of our website. There are also more detailed reports on the simulation and experiments that appear on an annual basis and are available at the website.

Due to the strategic nature of the project for the industrial partners involved in the project, the confidential nature of the results means that the most exciting highlights from the 2nd year cannot yet be discussed. Some of the highlights of the first year have now appeared as publications which are also available on the website.

OVERVIEW

All photonic components need metallic or partly conductive contacts or contact layers, which inherently give rise to plasmon effects when light is involved. Although such effects have often been regarded as unwanted by causing electronic damping effects and radiation losses, recent research efforts in this field have shown that by clever engineering and by understanding the physical sources for such losses, plasmonic effects have the potential to enhance photonic components. There is wealth of new plasmonic phenomena, such as enhanced transmission, optical field enhancement, and sub-wavelength focusing that has been investigated by the European research community. This work paves the way for a new generation of light emitting diodes (LEDs) and photodetectors, where their performance, (e.g. external quantum efficiency, speed, and noise) is enhanced through plasmon effects.

The PLEAS project aims to prove the concept of plasmon enhanced photonic devices for industrial applications related to emission/detection.

Project objectives

This goal can be translated into 3 distinct levels of objectives, ranging from:

1. Exploratory plasmon research aimed at concepts and phenomena that can be exploited in the targeted applications.

2. Investigation of specific plasmon enhancing structures for emitters and detectors, along with an investigation of the technologies to implement them.

3. Achieve a proof of concept of plasmon enhanced photonics devices in 2 applications:

(a) Inorganic LEDs: Enhancing electrical to optical energy conversion.

(b) Silicon photodetectors: Improving signal-to-noise ratio and increasing speed.

The project involves 6 major players from theoretical and experimental research, as well as 2 large industrials, leaders in Solid State Lighting, and Photodetection.

STRUCTURE OF PLEAS PROJECT

The PLEAS project is divided into 7 workpackages:

WP0 Management

WP1 Industrial specifications: The two industrial partners established specifications for industrial relevant devices.

WP2 Simulation and Experiment: Here the basic theory is worked on and experiments are a carried out on passive substrates.

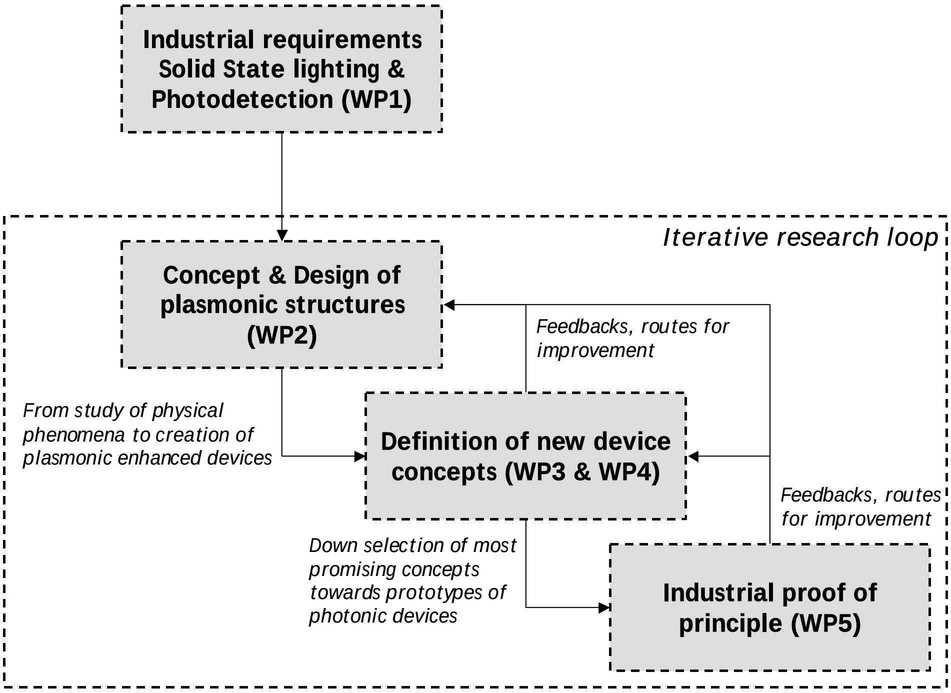
WP3 LED's: Ideas from WP2 are implemented on working LEDs and tested.

WP4 Photodetectors: Ideas from WP2 are implemented with photodetectors.

WP5 Industrialization: The application of the concepts developed in WP2 and tested in WP3 & WP4 to industrial devices, i.e., to fully mounted and encapsulated LED's and to photodetector arrays.

WP6 Dissemination and Use: The dissemination of knowledge generated by the PLEAS project, the organization of workshops and the PLEAS web site. For the use of knowledge, this mainly the exploitation roadmaps for the industrial applications of plasmonics.

The dynamic interaction within the project follows the diagram shown below:



PLEAS iterative research approach

This iteration loop has lead to a very high level of innovation in the project and has allowed the consortium to address directly the challenges of bringing plasmonic concepts to the final devices.

TECHNICAL ORGANISATION OF PLEAS PRINCIPLES

A wide range of materials and technologies have been examined in the project:

The structures have been divided along the lines of the two themes LED'S (WP2, 3 & 5) and Photodetectors (WP2, 4 & 5). In each theme there are both active and passive structures.

For LEDS, the structures can be divided into the following two classes:

(1) Transparent Contacts.
Transparent contacts are supposed to inject current directly into the active region while allowing light to escape through the same surface. The challenge is to have on one hand low ohmic losses and high transparency on the other. A non optimal transparency can be compensated by photon recycling if the optical losses in the transparent contact are low.

Structures acting as transparent contacts include:

- Hole Arrays – with rectangular, triangular, and round holes.
- Annular Hole Arrays.

The physical nature of transmission in annular hole arrays (near cut-off) is significantly different to warrant special attention.

(2) Extractors - filters – either colour or polarizing.
Plasmonic effects can also be used to either enhance light extraction or filter the wavelength or polarization of the light escaping through the metal layer. The restriction on conductivity is dropped so discontinuous structures (e.g., particles) may be considered.

- Slit Arrays
- Circular Hole Arrays
- Particles

Both sets of structures had been tested on the following substrates:

- Glass
- GaP - this transparent high index material is used to test structures before transferring them to LED's
- LED's
- Encapsulated LED's

For photodetectors, the structures can be divided into the following two classes:

(3) Collectors / light harvesting structures, designed to collect light from a large area and "focus" it through a small hole.

Collector structures include:

- Slit & Groove structures
- Bull's Eyes
- Slit & Groove with Antenna structures
- Particles
- Overlapping Bull's Eyes and Slit & Groove structures

(4) Filters – either colour or polarizing.

Filter structures examined include:

- Slit Arrays
- Circular Hole Arrays

Both sets of structure had been made on the following substrates:

- Glass
- Free standing membranes
- Glass with dielectric overlayer

The structures have also been included in the following devices:

- On simple Photodetectors
- On CMOS detectors
- Embedded in CMOS detectors

MAIN WORK CARRIED OUT BY WORKPACKAGE

WP1: Industrial Requirements

Objectives: Define technical requirements of industrial end users. Set detailed performance targets to be achieved by plasmonic enhanced photonic devices in the fields of solid state lighting and photodetection. To study the scalability of fabrication processes and to assess design constraints.

Work Performed/Achievements:

The industrial requirements for solid-state lighting were defined by OSRAM. This includes the identification of the target markets projection and LCD-backlighting and the definition of the technical targets for LEDs, enlarging the possibilities for achieving a significant impact on the market. The developments in the field of LEDs were monitored with respect to the market development and to recent technical advances which could provide alternatives to the technology developed within PLEAS.

Sagem defined the target applications for plasmonic detectors and specified the target characteristics by comparing the targeted detector to the best commercially available detector on the market right now. The target is basically defined by the specifications of the state-of-the-art detector, but with significantly reduced noise.

The technical requirements and the detailed performance targets were collated and detailed in the form of a booklet which set out the requirements for both the LED and Detector targets. This booklet also included a summary of the possible upscale fabrication method which would enable an integrated plasmonic technology on both LED and detectors devices. The detailed specifications and market analysis are currently project confidential.

WP2 Theory and Simulation:

Objectives: Theory to decide on the structures to be modelled for both LED and photodetector devices; to simulate and design plasmonic enhancing structures, in order to do this the fundamentals of plasmons as well as the fabrication constraints need to be investigated. Optimisations of plasmon structures for emitters and for detectors are to be undertaken.

Work Performed/Achievements: Hole arrays, with triangular, square and slit structures have been studied. Absorption effects have been studied and the dispersion of the structures has also been looked at. These quantities as are essential in the assessment of the efficiency of the designs. Particles have been investigated as have the effects of high index substrate. Initial investigations show array structures to be the most promising.

Optimisations of slit and groove structures and bull's eye structure for plasmon enhanced detectors have been performed.

Objectives: Experimental To improve fabrication of plasmonic structures and asses the specific technological needs for the plasmonic designs suggested. To characterise and evaluate the plasmon enhancing structures on test substrates.

Work Performed/Achievements: A study of the effect of grain size on focused ion beam etching was carried out. The effect of using the metals suitable for LED contacts for plasmonic metal structures was measured using ellipsometry measurements. It was shown to be possible to use these metals. Both spectral and polarization filtering functionality was measured for plasmon structures for detector. A 45% increase in transmission was shown in harvesting structures for detectors at normal incidence in line with project milestone.

For more details please refer to the 'Publishable report on simulation and experiment #2' which is on the PLEAS website.

WP3 LEDs:

Objectives: To enhance the transmission and related phenomena, to overcome contact shadowing. To simplify existing device technology by using hybrid electrical-contact/light extraction structures.

Work Performed/Achievements: Test LED wafers were designed and fabricated by OSRAM, and a FIB fabricated hole array as the top contact in a LED was successful. The experiments provide the first evidence that the hole arrays on top of active LEDs show enhanced transmission. This initial result has been repeated on a wide range of structures with various motifs (e.g. square, triangle, circles, annular holes, etc.). Detailed measurements have been carried out on efficiency, effective transparency and angular emission.

WP4 Photodetectors:

Objectives: To enhance photodetector performance using plasmonic structures, with particular emphasis on signal to noise ratio, but polarization and spectral filtering are to be studied as well. In order to do this design and process choices need to be made, test wafers need to be provided, plasmonic structures need to be fabricated on detectors and these need to be characterized. Evaluations of photodetectors with plasmonic structures are to be undertaken.

Work Performed/Achievements: The most promising structures in WP2 were assessed for their contribution to improved photodetection system. Harvesting structures were highlighted as the most promising structures initially. Test wafers were supplied by CSEM and were characterized and contrasted against standard photodetector technology. Particles and harvesting structures were fabricated on photodetector wafers. The harvesting structures were characterized for both efficiency, spectral and polarization selectivity.

WP5 Industrialization:

OSRAM has mounted, encapsulated and tested LEDs with Plasmon enhancing structures. This shows that the Plasmon structures fit within the full industrialization chain and continue to function after full processing.

Sagem has built a fully integrated characterization set-up around the chips produced by CSEM, this is now fully functional. In order to address the possibility of integrating Plasmon structures, CSEM has included such structures in test pixels for a CMOS detector array. These structures have been fabricated and are under test.

HIGHLIGHTS

There major achievements in the first 2 years are:

(1) Design and simulation of a hole array with up 87% transmission.
This is a major achievement on two fronts. First it comes from the selection of a figure of merit for hole arrays for LEDs. This figure of merit comes from following the industrial guidelines of OSRAM , while the calculation was made by UAM. Second, it has been made for real metals, i.e., including absorption losses, which limits the maximum that can be transmitted. 87% is a very high level

(2) Milestone M2.1 a light harvesting in the range of 10% has been achieved.
The goal was to show that 10% of the light falling on the "Plasmon" detecting area is coupled through the central sub-wavelength aperture onto the detector below it. This was achieved using a slit and groove structure.

(3) Milestone M2.2b, transmission in the range of >20% in the normal direction for high index substrates.
The goal was to show similar performances for transparent contacts (hole arrays) on high index substrates as that already achieved on glass substrates. This milestone was very challenging. The issue of high index substrates was never addressed before the start of this project, and they cause some important fundamental limitations in the EOT phenomena.

(4) Hole array working as a transparent conducting contact on LEDS.
This is another major achievement – a commercially grown LED with an hole array working as an alloyed contact, providing current spreading and being transparent. This is a huge step towards the projects goals.

(5) Photodetector arrays working with slit and groove arrays.
Finally, the project leapfrogged forward by not simply looking at Plasmon effects on single photodectors, but on photodetector arrays manufactured through a completely commercial CMOS process. The addition of the Plasmon structures initially gave problems in these devices, but now the primary technical issues have been overcome. A light harvesting and polarization structure has already been placed on a commercially available detector and shown to work.

CONCLUSION

The first two years have seen extensive work on assessing the potential of plasmonics for light emitters and photodetectors. In this report we have shown how the work has advanced and outlined some of the technical approaches taken. The current situation is that plasmonics does indeed have a huge potential in this area, although the technical challenges in making this industrially relevant should not be underestimated.

As the results become public they will appear on the project website as either publishable reports or as paper reprints.

Project Consortium

The project PLEAS (Plasmon Enhanced Photonics) started on 1st September 2006 and united the following partners with the goal of enhancing the performance of LEDs and photodetectors using plasmonics:

Partic. Role	Partic. no.	Participant name	Participant short name	Country
CO	1	Centre Suisse d'Electronique et de Microtechnique S.A	CSEM	Switzerland
CR	2	Universidad Autonoma de Madrid	UAM	Spain
CR	3	Universidad de Zaragoza	UNIZAR	Spain
CR	4	Osram Opto Semiconductors GmbH	OSRAM OS	Germany
CR	5	The Queen's University of Belfast	QUB	United Kingdom
CR	6	Technische Universität Dresden	TUD	Germany
CR	7	Université Louis Pasteur de Strasbourg	ULP	France
CR	8	SAGEM Défense Sécurité	SAGEM	France