Exetutive Summary Periodic Activity Report #1

Plasmon Enhanced Photonics (PLEAS)

1st September 2006 – 30th August 2007

12 Month Report
24/10/2007

IST-FP6-034506

PLASMON ENHANCED PHOTONICS

INTRODUCTION

This report is the first in a series of annual public reports reporting n 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 carried out in the search for novel plasmon devices. These also 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 first year cannot yet be discussed. Instead, this first report discusses the nature of the project, the targets and some planned routes to achieving these targets along with some highlights from the first year.

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 discovered by the European research community. This paves the way for a new generation of photonic components, such as light emitting diodes (LEDs) and photodetectors, where their performance, (e.g. external quantum efficiency, speed, and noise) is enhanced through plasmon effects.

The proposed 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.

GENERAL OBJECTIVES OF THE PROJECT

The proposed project aims to prove the concept of plasmon enhanced photonic devices for industrial applications related to emission/detection. This will enable a new generation of photonic devices benefiting from plasmonic enhancement to emerge.

This ultimate 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.

DETAILED OBJECTIVES

This section presents in more details PLEAS objectives related (1) to targeted exploratory research of plasmon related phenomena, (2) to investigation and fabrication of plasmon enhancing structures, (3) proof of concept of plasmon enhancing devices. From the chosen application targets several generic issues arise. (a) How can structured metal contacts improve LED performance, i.e., external quantum efficiency? (b) How can structured metal contacts improve photodetector performance, i.e., reduced noise, higher speed?

TARGETED EXPLORATORY RESEARCH INTO PLASMON RELATED PHENOMENA

The state of the art in plasmonic phenomena (*see section 2.4*) such as enhanced transmission, beaming apertures, and simple light harvesting structures are just the start of research into plasmonic concepts that can enhance emission and photodetection. Many topics have yet to be addressed, e.g., enhanced transmission structures with high index substrates, the coupling of guided modes through sub-wavelength apertures, and reducing reflection losses in light harvesting structures...

Therefore one objective is to explore plasmonic phenomena while remaining inspired by the targeted applications of PLEAS. It is clear that several phenomena will be central to the axis of PLEAS:

(a) Enhanced Transmission

The enhanced transmission will be one of the surface plasmon phenomena that will be exploited in this project. The fundamental aspects of the enhanced transmission have been studied both theoretically and experimentally since it was first reported in 1998. The enhanced transmission can essentially be understood as a three step process: **coupling of light to surface plasmon on the incident side, transmission through the apertures and decoupling of the surface plasmon to light on the exit surface. The fact that the 3 steps can often be treated as independent events opens the possibility of tailoring each of them to maximize the throughput for a given application.** For instance, the metal surface in contact with the LED could in principle be structured to optimize the coupling of the emission to surface plasmons while the output surface could be structured differently not only to maximize the decoupling but to direct the emission in a given direction.

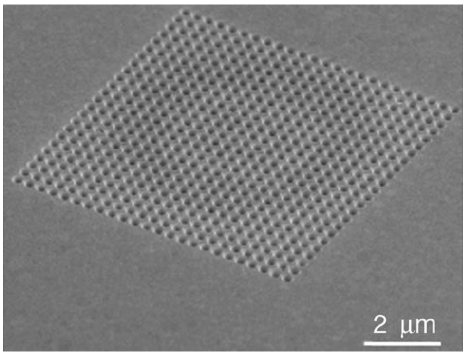

Figure 1: An electron micrograph of a typical hole array used in enhanced transmission experiments.

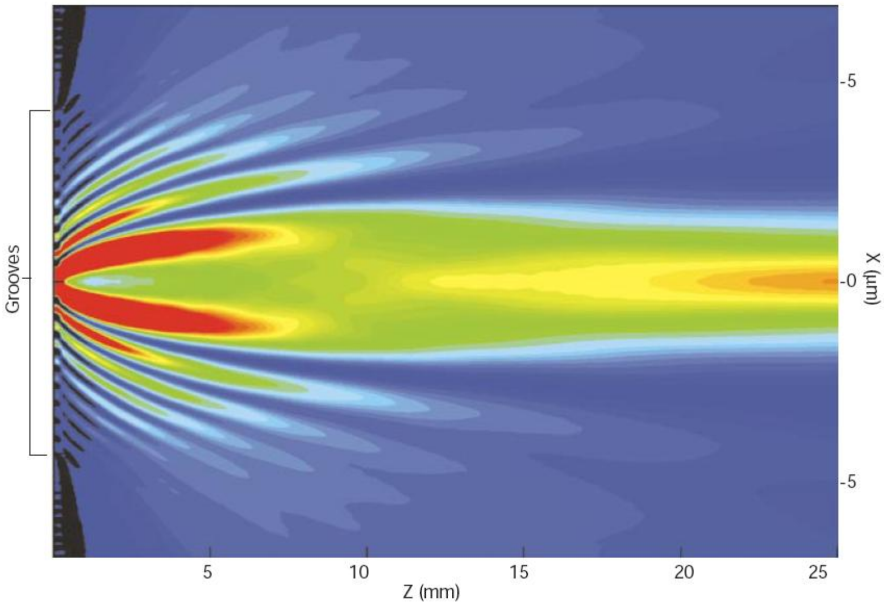

Figure 2: Beaming of light through a sub-wavelength aperture using a structured metal surface.

A fundamental aim is therefore to gain enough understanding of the individual steps of the enhanced transmission to maximize on the one-hand the light collection efficiency and transmission to a detector and, on the other hand, the light extraction from an LED source with directional control. The underlying fundamental issues being similar in both types of applications, a common set of design criteria for optimal device performance is expected to emerge.

(b) Light Harvesting

The principle of light harvesting is based on the effect of transmitting the same optical power density of an incoming light beam onto a smaller detection area. This can be achieved by converting incident photons into surface plasmons (SP) via a structured metal surface e.g., a grating. The SP propagates at the metal surface and then is able to efficiently couple to a detection area that may be located even on the far of the metal structure. Light harvesting is closely related to enhanced transmission (see above).

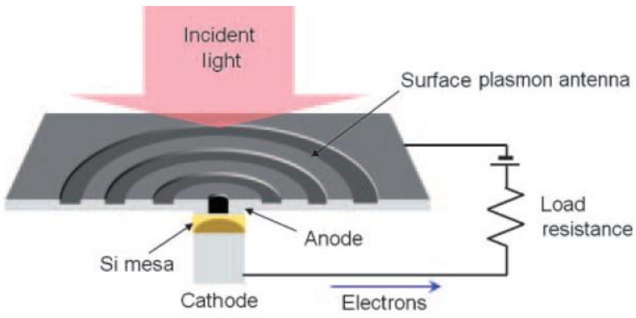

Figure 3: One kind of light harvesting structure for high speed photodetector.

The research objective will be to generalize the concept of light harvesting structures, and eventually provide a set of design tools for such structures. Light harvesting is particularly interesting for detectors.

(c) Local Field enhancement

Understanding the mechanisms giving raise to large field enhancement at the surface, and particularly the interplay between plasmon modes on structures thin films. Expected benefits are the following:

The larger field the better the photo-detection sensitivity that can be achieved, the stronger the confinement the smaller the volume can be used for photodetection.

If the enhancement is achieved on the inner interface of LED metal contact, it can help to transfer more energy to around the metal film contact.

INVESTIGATION AND FABRICATION OF PLASMON ENHANCING STRUCTURES.

To be useful to the photonics industry, plasmonic concepts must be realised as functional plasmon enhancing structures for LEDs and photodetectors, and the nanostructuring technologies needed to fabricate them need to be evaluated.

In particular, the following objectives will be addressed:

(a) Reduced contact shadowing in LEDs

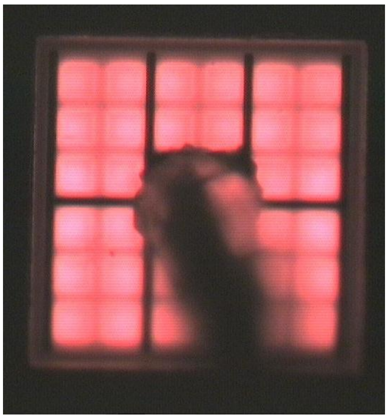

Figure 4: Contact shadowing in thin-film LEDs

The highest efficiency commercial LEDs are in general thin-film LEDs. Narrow current carrying wires are used to distribute current uniformly across the LED. Light emitted beneath these stripes are lost due to shadowing by the contacts, and this loss in efficiency is known to be significant (35%)

To overcome contact shadowing the simplest approach will be to:

(1) get light through the contact via enhanced transmission using hole arrays
(2) get light around the contact
   a. via light transport on the underside of the contact (through propagating surface plasmons)
   b. via the large field intensity at the contact edges to enhance emission from near the edges of the contact.

The first approach can be adapted to the narrow and thin current carrying stripes used to distribute current on thin-film LEDs (see Fig. 6).

(b) Simplified high-efficiency LED technology

Current thin-film technology while being highly efficient is technological complex (see Fig. 7). Therefore, a secondary goal would be to simplify the current thin-film LED technology by using a single structured metal film that would act both as an electrical contact and a light extraction structure: the overall extraction efficiency can be enhanced by extracting light that normally would not escape. This can be achieved in two ways:

(1) Make hole arrays that have a non-zero transmission at angles greater than the angle of total internal reflection at the semiconductor interface. Results from structured devices indicate that even a relatively poor transmission (<10%) but averaged over a wide range of angles can significantly improve the light extraction efficiency.
(2) Make a hole array that can couple guided modes (into which most of the light emitted in the device goes) to external radiating modes.

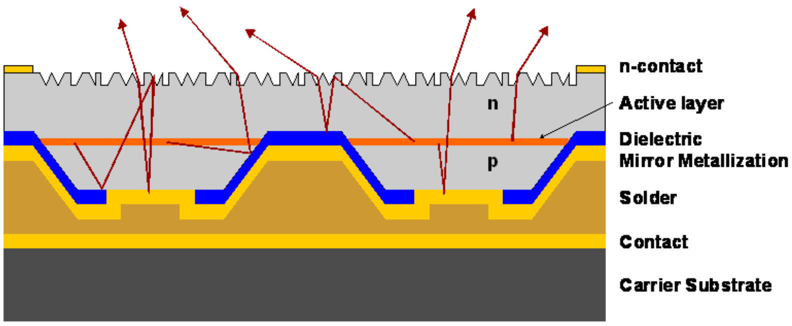

Figure 5: Schematic diagram of a state-of-the-art thin-film LED showing the complexity of the device.

(c) Low noise / high SNR photodetectors

Two major issues that have to be tackled in photodetection are related to speed and noise.

For fast detectors, small active volumes are needed (impedance matching);
For low noise detectors, the main sources of noise are surface recombination and electrical currents generated in the bulk of the detector (volume current). For semiconductors like Silicon, the former is the most important while photodetectors used in the IR wavelength regime, e.g. InAsSb volume current generation is key.

However, simply reducing the size of the detector leads to reduced detection efficiency. Therefore, the target of plasmonic enhanced photodetectors should be to **reduce the active surface/volume without losing efficiency.**

The goal will be to use plasmonic light harvesting and field enhancing structures to collect light from a surface and concentrate it efficiently.

(d) Nanostructuring of plasmon enhanced photonic devices

To enter into the era of practical plasmon enhanced photonic devices, some major technological challenges need to be addressed:

Fabrication of structures with sub-wavelength dimensions in terms of area, possibly possessing non-planar features on a waferscale;
Integration of plasmon structures into fabrication process (CMOS compatibility);
Film quality of metal films/contacts made in industrial process lines must be good enough for plasmonic effects: excess roughness can kill certain effects;
Adding plasmon enhancing structures without having a negative impact on device performance, e.g. current distribution, charge trapping etc.

INDUSTRIAL PROOFS OF CONCEPT OF PLASMON ENHANCED DEVICES

(a) Plasmons for Solid State Lighting

The objective is to prove that plasmon enhancement can make its way from concept to packaged LEDs. The plasmonic enhanced LEDs should have a performance above the current state-of-the-art in one of several areas: external Quantum Efficiency, improved directionality and simplicity of design.

(b) Plasmons for Photodetection

The photodetection technology is not as mature as LEDs when it comes to novel optical structuring. The goal for industrial proof of concept is to:
Create plasmon enhancing structures through CMOS compatible processes.
Open the route for full design plasmon enhanced detectors by characterising relevant electronic parameters of the device.
Demonstrate plasmon enhancement on photodiode arrays.

Major technical challenges need to be overcome, e.g., preventing the electrostatic field of the metal structures from perturbing the current flow in the active region (quenching and damping, size effects).

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

The goals for the first 12 months were to

- Specify (WP1): Establish a list of specifications for LEDs and photodetectors that would meaningful targets in the future market place.
- Develop (WP2): Start the iterative development task of selecting, fabricating and testing promising plasmonic structures relevant to the targets set out in the specification phase.
- Install the infrastructure for correct project management including dissemination and use of knowledge within the consortium and outwards into the public domain (WP0 and WP6).

These phases have been initiated to the level planned as shown by the associated deliverables. The exchange between the academic and industrial partners has been very open, driven by the desire to make market relevant advances in photonics.

HIGHLIGHTS

Highlights of the first 12 months have been:

- The identification of market relevant targets including the broadening of the goals for LEDs and a refinement of the goals for photodetectors.
- First studies of plasmonic effects on high index substrates.
- First results on spectral imaging using plasmonics
- Overcoming issues caused by FIB on photodetectors.
- Novel structures – annular hole arrays, triangles in bull's eyes, overlapping bull's eyes.