Project no:	**NMP-CT-2003-505699**
Project acronym:	**SPP**
Project title:	**Surface Plasmon Photonics**
Instrument:	**STREP**
Thematic Priority:	**NMP**

Publishable Final Activity Report

Period covered: from *January 1st 2004* to *December 31st 2006*
Date of revision: *July 7th, 2006*

Start date of project: January 1st 2004 Duration: 3 Years

Project coordinator name Prof. William L Barnes
Project coordinator organisation name University of Exeter

PUBLISHABLE FINAL ACTIVITY REPORT

Table of contents

1 Project Execution

Project goal – **<u>Surface Plasmon Photonics</u>** (**SPP**) had as its aim an exploration of the potential that electromagnetic surface waves known as surface plasmons may have in building both photonic elements and a new photonics technology based on nanostructured metals.

1.1 Summary of project objectives

To meet this goal the project had two key objectives.

- To significantly extend our understanding and control over surface plasmon properties through nano-scale engineering so as to build new knowledge.
- To explore the potential for innovative photonic devices using such control.

1.2 Contractors involved

Including the coordinator there were six contractors involved in SPP, they were,

Consortium Overview				
Partner Number	Organisation	Country	**Main Activity**	**Role in Project**
1	**UNEXE**	UK	Periodic photonic structures at optical and microwave frequencies. Solid state QED. Liquid crystal displays. Light emitting diodes. Polymer lasers. Surface plasmon physics.	Project management. Development of periodically textured surfaces. Assessment of SP mode structure. Development of radiative decay engineering. Device trials.
2	**ULP**	F	Nano-structure fabrication using Focused Ion Beam lithography. Electron microscopy. Light-matter interactions. Surface science.	Use of Focused Ion Beam (FIB) lithography to develop nano-structures. Assessment of coupling efficiency. Development of periodic structures for field enhancement. Assessment of all-optical non-linear SP based photonics.
3	**KFUG**	A	Nano-structure fabrication using electron-beam lithography. Near-field optical microscopy. Photonic control over optical properties of molecules.	Use of e-Beam lithography to develop nano-structures. Assessment of control over SP propagation, inc near-field optical techniques. Development of low dimensional structures for field enhancement. Development of radiative decay engineering.
4	**UAM**	E	Computational modelling of solid state and optical physics.	Theoretical modelling. Design of nano-structures. Simulation of non-linearity and device performance.
5	**UNZAR**	E	Computational modelling of solid state and optical physics.	Numerical simulations. Assessment of potential for field enhancement.
6	**IC**	UK	Design and understanding of new photonic materials	Provision of strategies for design of periodic structures and modelling.

1.3 Co-ordinator contact details

The coordinator of the project was,

Professor William L. Barnes,		
School of Physics,		
University of Exeter	Tel:	+44 1392 264151
Stocker Road,	Fax	+44 1392 264111
Exeter,	email	w.l.barnes@ex.ac.uk
UK, Europe.	Project URL	http://newton.ex.ac.uk/research/emag/surface/

1.4 Introduction to topic

With this project we set out to answer one question – was a new kind of photonics based on surface plasmons viable? Surface plasmons are a way of guiding light. Optical fibres are well known guides of light enabling information to be communicated very effectively over great distances, many tens of kilometres. Surface plasmons on the other hand can guide light only over distances of tens or hundreds of microns. Given that surface plasmons have such short propagation distances, why did we wish to investigate them as a way to guide light? To answer this we need to know a little more about what surface plasmons are.

Surface plasmons (SP) are electromagnetic (optical) modes that arise from the interaction between light and the mobile conduction electrons in the surface of a metal. This light-matter interaction leads to the light associated with SP modes being concentrated near the surface thereby giving surface plasmons two unique advantages.

The advantages.

- The concentrated optical field means that if light is first coupled to a surface plasmon, any further interaction, for example with adjacent molecules, or a non-linear material, will be much more effective. An example of how we harnessed this effect is in demonstrating enhanced optical non-linear effects by using surface plasmons (***deliverable 10***).
- The concentrated optical field can also be exploited to confine light to sub-wavelength spaces, well below the usual diffraction limit. Surface plasmons thus offer a unique attribute for nanotechnology and nanophotonics in particular – they allow us to bridge the gap between the nano world and the optical world, thereby allowing the power of optics to be put to use more fully in nano-science and technology (***deliverable 15&17***).

These advantages were very appealing – but there was a serious problem that if it could not be overcome would have prevented any chance of exploiting the advantages that surface plasmons have to offer.

The same light-matter interaction that leads to the optical field being concentrated in the vicinity of the metal also leads to a concentration of field ***inside*** the surface of the metal. Despite their every-day reflective appearance, metals ***do*** absorb some light – this absorptive character of metal means that surface plasmons have an associated loss. It was this loss that threatened to hold back the full exploration of plasmons in photonics. Based on our previous work we thought this problem could be overcome. We wanted to show that one could use nanofabrication techniques to provide sufficient control over the structure of the metal at the nanometre scale so that functionality could be achieved before the energy in the surface plasmon was dissipated.

We are pleased to report that we were successful in our aim, we found that surface plasmon-based photonics is viable, indeed, so attractive are the possibilities that it is already being actively pursued by researchers and technologists around the world. Furthermore, it is clear that this topic, which is now known as *plasmonics*, has emerged as an important new topic in science and technology with the potential to have a strong impact in fields as diverse as data storage and health care. It is also clear that the SPP-STREP project was an important part of this development, and helped Europe to stay at the forefront of this fast moving area.

1.5 Work performed during the project (2004-2006)

In the project we demonstrated experimentally that one can efficiently launch, control and collect surface plasmons, and we developed new computational models that will enable design tools to be developed. Further we demonstrated a number of concepts through proof-in-principle experiments that have helped shape the view not just of the specialized community in which we work, but of a much wider science and technology based community. The rapidly increasing number of scientific publications, conferences, new research groups and commercial activity in surface plasmon-based photonics all show that this is an area of rapid growth (see ***deliverable 19***). Through our work we were able to take a leading role in many of these activities. We had the good fortune to receive funding for this project at a crucial time, a time that has maximised the impact of the work we have carried out.

To incorporate surface plasmons into any kind of device architecture one needs to be able to do three things, couple light into surface plasmons, propagate and manipulate surface plasmons, and couple light back out from surface plasmons to light. These aspects are summarised in figure 1.

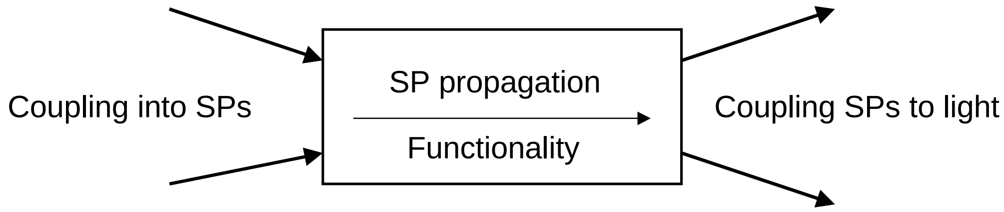

Figure 1 The three key stages in being able to make use of surface plasmons, coupling light into surface plasmons, manipulating surface plasmons, and coupling surface plasmons back to light.

By making use of nanofabrication techniques in tandem with developing a better understanding (knowledge) of the underlying physics we were able to show that all three aspects depicted above can be successfully and efficiently achieved.

Work was organised around four workpackages, three technical ones and one devoted to project management. All workpackages were successfully completed. In the technical workpackages we,

- explored the coupling between light and surface plasmons (WP1).
- investigated how to control surface plasmons (WP2).
- applied our understanding to demonstrating surface plasmon-based devices (WP3).

Project management ensured the smooth running of the project, and appropriate reporting to the Commission (WP4).

1.6 Results achieved

A large number of results during the course of the project. Here we give some illustrative examples, organised by appropriate workpackage.

1.6.1 WP1 - Coupling Surface Plasmons and Light.

Here we offer two examples, one experimental the other computational. The experimental example shows how a small array of holes in a metal film may be used as a grating to couple light into SPs. The hole array (10 μm x 10 μm) was made on a metal film using focussed ion-beam milling, a powerful nanofabrication technique that we made extensive use of throughout the project, it allows one to sculpt metal films with a precision of only a few nanometres.

As with many of the aspects of surface plasmon photonics that we investigated, there are many subtleties that require careful control of the details if best advantage is to be gained.

Here an intense narrow beam of SPs is produced if the hole array is arranged along the diagonal rather than the normal axis with respect to the launching direction. This is shown below in figure 2, both in the simulation (left) and in the experimental data (right) from the experiment. The experimental near-field image was recorded using scanning probe optical microscopy.

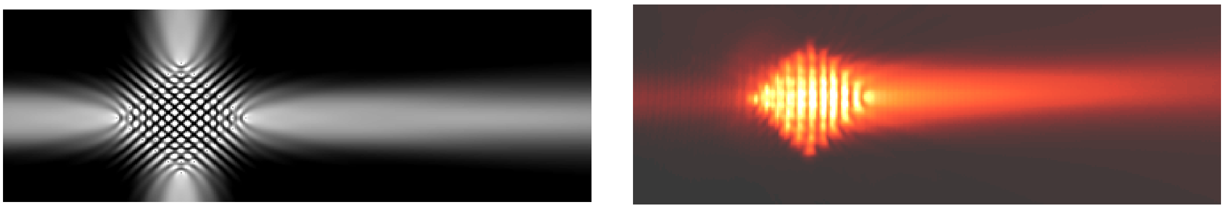

Figure 2. Left: a simple Huygens-Fresnel based simulation of the SP beam shape produced by a small hole-array grating coupler, assuming each hole is a point source. Right: the corresponding experimental near-field image recorded with an input wavelength of 800 nm from the real structure milled in 160 nm thick Au film. The array period is 760 nm, and the hole diameter is 220 nm. (Each image is approx. 50 microns in width.)

Our second example makes use of a new computational model we developed during the project specifically to model surface plasmon photonic structures. We used this model to compute the efficiency with which a miniature grating couples SPs to light. Figure 3 shows the calculated scattering efficiency (emittance) as a function of ridge height and the ridge period of the structure, shown in the left panel, whist the dependence on ridge width (a) is shown in the right panel.

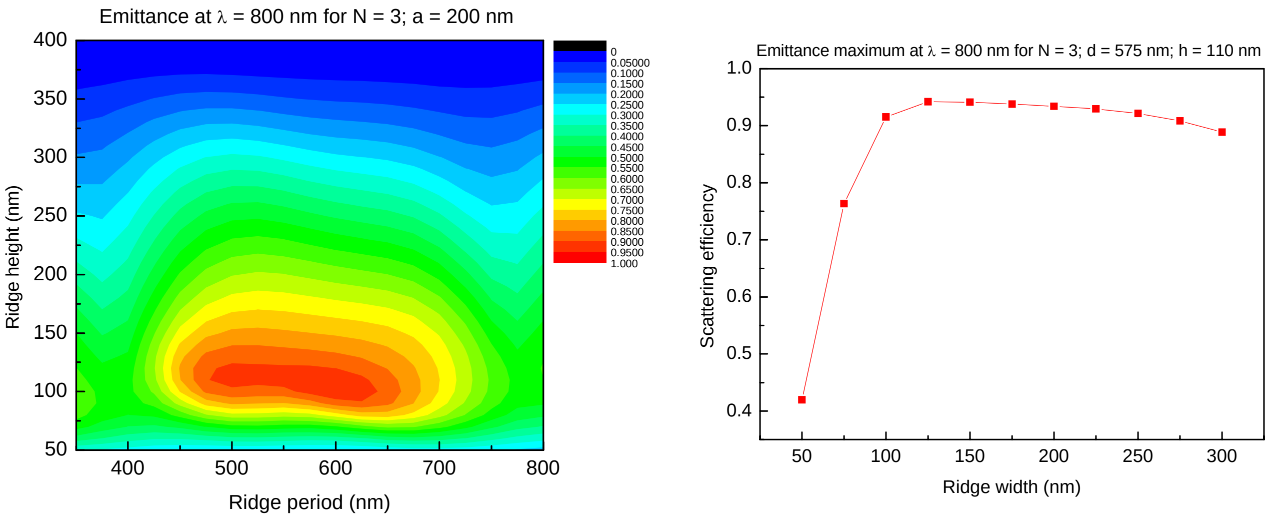

Figure 3. SP-light coupling efficiency (emittance) as a function of ridge height and ridge period (left), and as a function of ridge width (right). The system considered was a grating made of gold and comprising three ridges.

The power of this computational model as a design tool is apparent when we used it to look at how the efficiency of the coupler depends on design parameters. For the 3 ridge grating coupler considered above, we found the following tolerances, these tolerances are all within the capabilities of existing nanofabrication techniques.

Parameter	Tolerance for 95% of best performance
Ridge period	+/- 10%
Ridge width	+/- 20%
Ridge height	+/- 10%

Table 1. SP-light coupling efficiency. Tolerance on design parameters indicate the percentage change that can be made in a given parameter without sacrificing more than a 5% reduction in performance.

1.6.2 WP2 – Controlling Surface Plasmon Propagation.

Our first example here involved a new type of SP waveguide. In the project as originally envisaged we did not anticipate investigating new types of waveguide for surface plasmons. However, we were involved during year 2 in developing just that – a new type of waveguide based on the SP mode associated with a channel or trench cut in to a metal surface, figure 4. This had been predicted many years ago but had to wait for a combination of appropriate fabrication techniques and a team of able researchers to exploit those techniques. These guides show promise for sub-wavelength control over guiding [1].

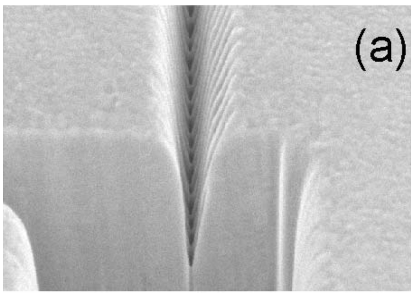

Figure 4. Scanning electron micrograph of channel cut into silver. This trial structure acts as an effective waveguide for SPs at a wavelength of 1.5 μm. (Channel width at top is ~0.5 μm.)

We followed this initial work by demonstrating a proof-in-principle surface plasmon circuit (in a collaboration with other researchers in the NoE PlasmoNanoDevices), so as to show that different SP components can be successfully integrated. Figure 5 shows a plasmonic waveguide ring resonator based on channel SP guides. The channel structures were again cut by focussed ion-beam milling, and plasmons were launched by end-fire coupling from an optical fibre, they were imaged using a scanning near-field technique [2].

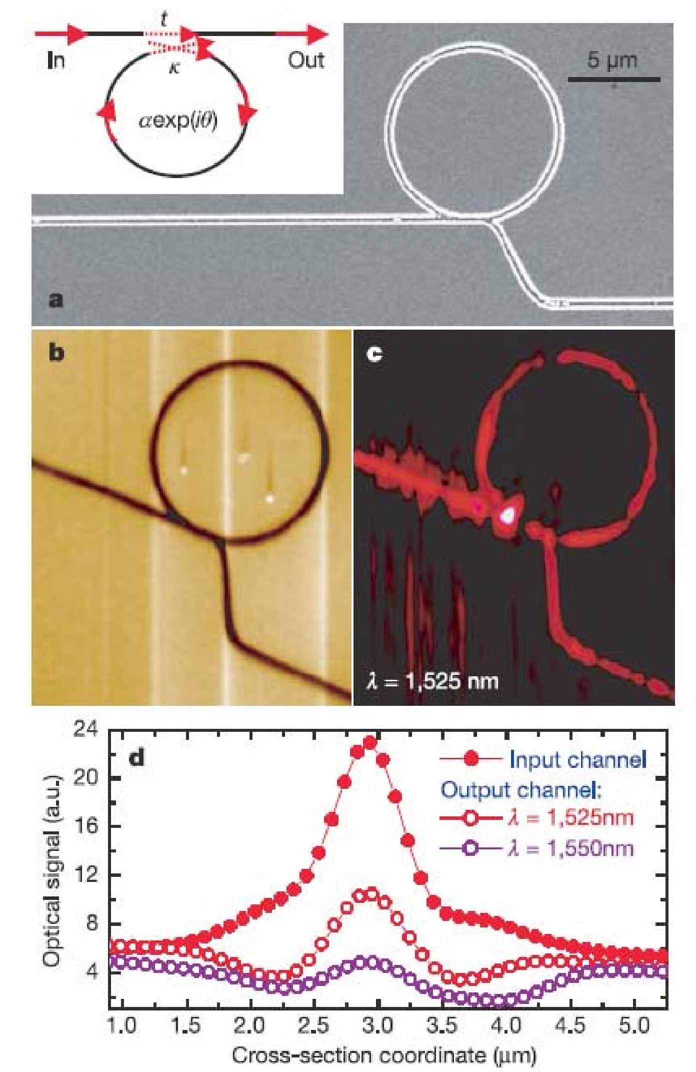

Figure 5 Plasmonic waveguide–ring (WR) resonator. A schematic of the circuit is shown top-left. (a) SEM image, along with (b) topographical and (c) near-field optical (wavelength 1.525 microns) SNOM images of the WR resonator. (d) shows the recorded field profile across the guide (SNOM).

Our second example from this workpackage is again one based on computational modelling, this time showing that optical non-linear behaviour, such as bistability, is possible with surface plasmons. This was accomplished by calculating the response of an array of slits in a metallic film in which a non-linear (Kerr effect) material fills the slits [3].

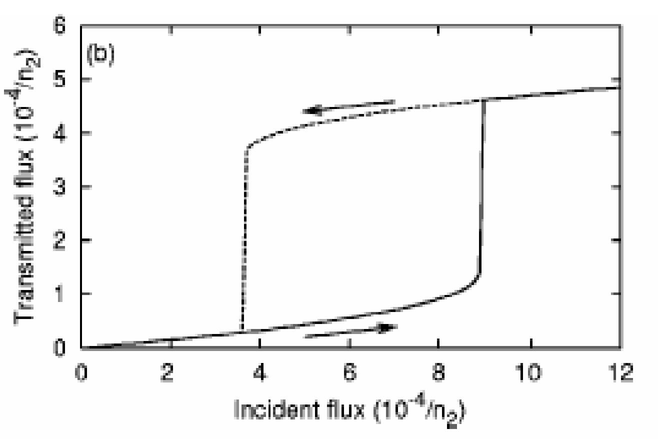

Figure 6. Light transmitted through a slit array where the slits are filled with an optically non-linear material as a function of the incident optical flux. The transmission shows very marked bistability, pointing the way to one means of accomplishing all optical control over SPs.

1.6.3 WP3 - Surface Plasmon Devices.

One of the devices that become the subject of a multinational/multimillion euro project of its own is the light-emitting diode. Within the SPP project we pursued organic light-emitting diode with a view to exploiting surface plasmons. These devices were (and still are) of increasing commercial importance. We established that one of the limiting factors in their efficiency is the loss of power to surface plasmon modes [4]. We showed that this lost power can be recovered in devices that are fabricated with the addition of periodic nanostructure that enables the SP modes to be coupled to light, provided the design of the nanostructure is appropriately chosen [5]. Samples were fabricated using a combination of focussed ion-beam milling and photolithography.

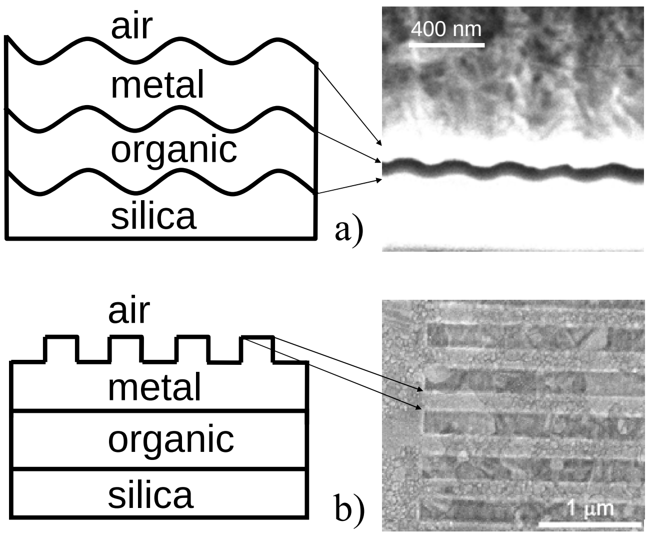

Figure 7. Schematic of two light-emitting structures (left). SEM pictures of the samples used in the experiment (right). The upper panels (a) show the structure that has a metallic film with a grating profile on both top and bottom metal surfaces. The lower panel (b) shows the structure for which only the top surface of the metal is textured. We found that structure (a) is an order of magnitude more efficient in coupling surface plasmons to light, and have been able to explain the origin of this surprising finding.

Our second example from WP3 is a wavelength division multiplexer. This time we used electron-beam lithography to produce the structures. This technique is complimentary to focussed ion-beam milling and better suited to nano-sized structures that are made of metal rather than formed by the removal of metal. The structure we used was based around the concept of a plasmon crystal, and comprises an array of metallic dots whose collective effect is to Bragg scatter surface plasmons in different directions according to their wavelength. Figure 8 shows a scanning electron microscope picture of the structure.

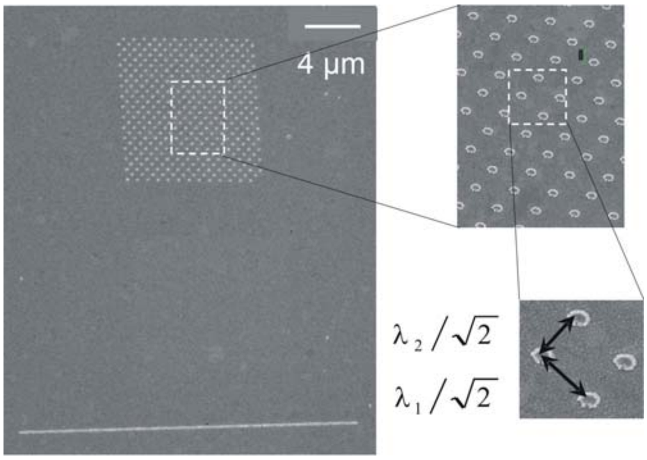

Figure 8. Scanning electron microscopy (SEM) images of a multiplexer designed for SP wavelengths λ_1=885 nm (laser vacuum wavelength λ_0=900 nm) and λ_2 =730 nm (λ_0=750 nm) respectively, corresponding to d_1=516 nm and d_2=626 nm. The protrusion diameter is 200 nm. The ridge (200 nm width) on bottom of the large SEM image is used to launch a SP beam by focussing the laser beam onto it [6].

Surface plasmons launched along the surface at such a structure are deflected in different directions according to their frequency (wavelength). This is clearly shown in the pictures below, figure 9, obtained using our leakage radiation technique. Note that the entire structure is only a few μm in size.

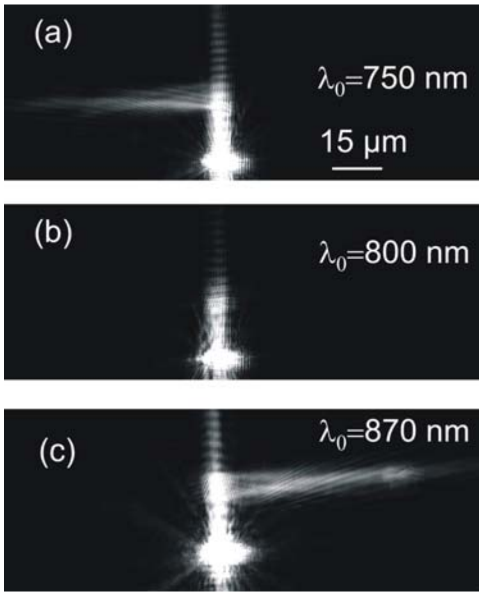

Figure 9 Leakage radiation microscopy (LRM) images corresponding to the multiplexer in figure 3. (a) LRM image of a SP beam for λ_0=750 nm. At this wavelength SPs are Bragg-reflected to the left hand side of the plasmonic crystal. (b) Same as in (a) but for a λ_0=800. SPs are not reflected by the multiplexer and propagate in straight line. (c) Same as in (a) but for λ_0=870 nm. SPs are Bragg-reflected to the right hand side of the plasmonic crystal.

1.7 End result

The end result of the project was summarized in our last technical deliverable, a report providing a critical assessment of the viability of surface plasmon photonics (***deliverable 19***). We were amply able to show that the concerns expressed prior to the start of the project about whether absorption in the metal would prevent functionality being achieved can be overcome. Appropriate use of nanofabrication techniques together with a much improved understanding of the underlying science has enabled us to demonstrate levels of functionality that had not been seen before the project commenced. Based on the work we undertook during the project, and our assessment of the work carried out by others, we were able to conclude with confidence in that report that surface plasmon photonics is a scientifically viable technology, indeed, one that is already being pursued by many commercial organisations world-wide. Further evidence of this came from our 'Open to Industry' workshop which helped disseminate the results of our project to a number of key commercial organisations in Europe. We should not finish this section without mentioning that one of the prime responsibilities of project management has been to ensure that our results were published and communicated to as wide a relevant audience as possible – this we succeeded in doing.

1.8 Meeting the objectives

How well were the objectives met? Recall that these objectives were,

- *To significantly extend our understanding and control over surface plasmon properties through nano-scale engineering so as to build new knowledge.*
- *To explore the potential for innovative photonic devices using such control.*

On both counts we were very successful. A large fraction of the achievements of the project set the state-of-the-art, this can be seen from the high impact factor journals many of the results were published in (6 in Science, 2 in Nature, 8 in Physical Review Letters, 2 in Advanced Materials etc.. (see ***deliverable 20***)). In terms of lasting impact, it is clear that the project helped act as a major spur to others and that during its course, provided a strong, clear message as to the importance that Europe places on this topic area, and the leading role that its researchers can take. At the end of the project the whole field was still in a state of rapid growth, see both the state-of-the-art interim report (***deliverable 25***) and the critical assessment (***deliverable 19***). The project was an important part of both the growth, and the reasons for the growth, discussions we had indicated that much of the activity in the US and Japan was been triggered by the existence of this project.

2 The dissemination of knowledge

A very considerable amount of new knowledge was been gained directly as a result of the project. Given the basic research nature of the programme the vast bulk of this knowledge was disseminated in the most appropriate way for such information, through publication in peer-reviewed journals and through presentation at international conferences. Details of such dissemination activity is given below. We should add at this point that the visibility of these results has been heightened, and thus made of greater lasting value, by being under the STREP umbrella – the coherency of the project that was made possible by EU finding has enabled greater value to be achieved than if the same funds were simply spent on several independent projects that accomplished the same science.

2.1 Exploitable knowledge and its Use

The exploitable knowledge from this project is our published work, most of which is now available in the open literature (see section 1.2). Concerning intellectual property (patents), we had nothing to report during the project in this category, although at least one item of intellectual property was followed up in the months following the close of the project. The lack of IP arising from the project was twice been discussed extensively with the project officer. This lack was primarily because the participants in the project had already taken out IP before the project commenced, and because of the difficulty of filing patents at the European level.

2.2 Dissemination of knowledge

Overview table

Planned/ actual Dates	Type	Type of audience	Countries addressed	Size of audience	Partner responsible /involved
May 2005 (SPP-2)	Conference	Research	**All**	~200	UNEXE/ KFUG
2004-06	73 Publications	Research	**All**	Unknown	All
2004-06	Project web-site	All	**All**	Unknown	UNEXE
2006	Open to industry workshop	Research/funding agencies/journalists	**EU**	~20	All
2004-06	81 Conference presentations	Research	**All**	Variable	All
2006	Meeting with Japanese R&D consortium to discuss EU funded research in plasmonics	Invited	**Japan**	n/a	UNEXE
2006	Seminar	French R&D association	**France**	~20	UNEXE

- The primary output of the project has been published articles in the international, peer reviewed, scientific press.
- We also gave a very large number of conference presentations – a substantial fraction of them as invited or plenary talks. We further gave a large number of seminars. Several of

the participants have been involved in conferences outside of Europe, to a significant degree as a result of their participation in this STREP project; examples include the International Workshop on Plasmonics in Singapore, December 2006, and the first Gordon Conference on Plasmonics in the US, July 2006. We were not able to meet all of the invitations we received.

- **Contact with Industry**. In addition to considerable informal contact between the project participants, an important part of our dissemination activities was the 'Open to Industry' meeting we held in London in November 2006. Representatives from many companies attended including, Qinetiq, Osram, DSTL, Sagem, Seagate, Sharp and Philips.

Follow on projects

A number of projects among the participants arose wholly or in part as a result of this SPP STREP project, they were,

- "2D Attogram Surface Plasmon Imaging", a UK project funded by RCUK, 2005-2009, value 4M€.
- "PlasmonUK - A new interdisciplinary research landscape for sub-wavelength photonics", a UK project to be funded by EPSRC, 2007-2009, value 200k€ (Note this proposal arose from a lobbying exercise brought about in part by the success of the SPP project.)
- "Plasmon Enhanced Photonics (PLEAS)", an EU funded STREP project on light emitting diodes, 2006 – 2009, funding 2.8M€.
- "Molecule – Surface Plasmon interactions", a French ANR project, 2006 – 2009, value 480k€.
- "Fotonica en Superficies metalicas", a Spanish Government funded 'Nacional de I+D+I' project (MAT 2005-06608-C02-2), 2006 – 2008, value 60k€.

In addition we anticipated that the results from the project would be important for future research projects undertaken by the partners. Further, we understood from a variety of discussions with interested parties, and also anticipated, that others will make use of the knowledge we gained in future R&D projects.

2.3 Publishable results

Below are the details of the outputs for the project, publications and conference presentations. Note that outputs continued to emerge after the funding period had ceased.

2.3.1 *Publications produced wholly or in part through support from SPP funding,*

J. Bravo-Abad, F. J. García-Vidal and L. Martín-Moreno
'Resonant transmission of light through finite chains of subwavelength holes',
Physical Review Letters, **93**, 227401, (2004).

A. Degiron and T. W. Ebbesen
'Analysis of the transmission process through single apertures surrounded by periodic corrugations',
Optics Express, **12**, 3694-3700, (2004).

A. Degiron, H. J. Lezec, N. Yamamato and T. W. Ebbesen
'Optical transmission properties of a single subwavelength aperture in a real metal',
Optics Communications, **239**, 61-66, (2004).

H. Ditlbacher, J. R. Krenn, A. Leitner and F. R. Aussenegg
'Surface plasmon polariton-based optical beam profiler',
Optics Letters, **29**, 1408-1410, (2004).

P. Andrew and W. L. Barnes
'Energy Transfer Across a Metal Film Mediated by Surface Plasmon Polaritons',
Science, **306**, 1002-1005, (2004).

W. L. Barnes, A. W. Murray, J. Dintinger, E. Devaux, H. J. Lezec and T. W. Ebbesen
'Surface plasmon polaritons and their rôle in the enhanced transmission of light through periodic arrays of sub-wavelength holes in a metal film',
Physical Review Letters, **92**, 107401, (2004).

W. L. Barnes and J. R. Sambles
'PHYSICS: Only Skin Deep',
Science, **305**, 785-786, (2004).

W. L. Barnes
'Turning the tables on surface plasmons',
Nature Materials, **3**, 588-589, (2004).

M. Beruete, M. Sorolla, I. Campillo, J. S. Dolado, L. Martín-Moreno, J. Bravo-Abad and F. J. García-Vidal
'Enhanced millimiter wave trasnmission through subwavelength hole arrays',
Optics Letters, **29**, 2500-2502, (2004).

N. Félidj, S. L. Truong, J. Aubard, G. Levi, J. R. Krenn, A. Hohenau, A. Leitner and F. R. Aussenegg
'Gold particle interaction in regular arrays probed by surface enhanced Raman scattering',
The Journal of Chemical Physics, **120**, 7141-7146, (2004).

A. Giannattasio, I. R. Hooper and W. L. Barnes
'Transmission of light through thin silver films via surface plasmon-polaritons',
Optics Express, **12**, 5881-5886, (2004).

J. R. Krenn and J.-C. Weeber
'Surface plasmon polaritons in metal stripes and wires',
Philosophical Transactions of the Royal Society of London, A., **326**, 739, (2004).

E. Moreno, F. J. García-Vidal, D. Erni, J. I. Cirac and L. Martin-Moreno
'Theory of plasmon-assisted transmission of entangled photons',
Physical Review Letters, **92**, 236801, (2004).

J. B. Pendry, L. Martín-Moreno and F. J. García-Vidal
'Mimicking surface plasmons with structured surfaces',
Science, **305**, 847-848, (2004).

J. B. Pendry and D. R. Smith
'Reversing light with negative refraction',
Physics Today, **2004**, 37-43, (2004).

J. A. Porto, L. Martín-Moreno and F. J. García-Vidal
'Optical bistability in subwavelength slit apertures containing nonlinear media',
Physical Review B, **70**, 081402, (2004).

R. Ruppin
'Comment on 'Focusing light using negative refraction'',
Journal of Physics-Condensed Matter, **16**, 8807-8809, (2004).

D. R. Smith, J. B. Pendry and M. C. K. Wiltshire
'Metamaterials and Negative Refractive Index',
Science, **305**, 788-792, (2004).

S. Wedge and W. L. Barnes
'Surface plasmon-polariton mediated light emission through thin metal films',
Optics Express, **12**, 3673-3685, (2004).

T. J. Yen, W. J. Padilla, N. Fang, D. C. Vier, D. R. Smith, J. B. Pendry, D. N. Basov and X. Zhang
'Terahertz Magnetic Response from Artificial Materials',
Science, **303**, 1494-1496, (2004).

S. I. Bozhevolnyi, V. S. Volkov, E. Devaux and T. W. Ebbesen
'Channel Plasmon-Polariton Guiding by Subwavelength Metal Grooves',
Physical Review Letters, **95**, 046802, (2005).

A. Degiron and T. W. Ebbesen
'The role of localized surface plasmon modes on the enhanced transmission of periodic subwavelength apertures',
Journal of Optics A: Pure and Applied Optics, **7**, S90-S96, (2005).

J. Dintinger, S. Klein, F. Bustos, W. L. Barnes and T. W. Ebbesen
'Strong coupling between surface plasmon-polaritons and organic molecules in subwavelength hole arrays',
Physical Review B, **71**, 035424, (2005).

J. Dintinger, A. Degiron and T. W. Ebbesen
'Enhanced light transmission through subwavelength holes',
Mrs Bulletin, **30**, 381-384, (2005).

H. Ditlbacher, A. Hohenau, D. Wagner, U. Kreibig, M. Rogers, F. Hofer, F. R. Aussenegg and J. R. Krenn
'Silver nanowires as surface plasmon resonators',
Physical Review Letters, **95**, 257403, (2005).

F. J. Garcia-Vidal, E. Moreno, J. A. Porto and L. Martin-Moreno
'Transmission of light through a single rectangular hole',
Physical Review Letters, **95**, 103901, (2005).

F. J. García-Vidal, L. Martín-Moreno and J. B. Pendry
'Surfaces with holes in them: new plasmonic metamaterials',
Journal of Optics A: Pure and Applied Optics, **7**, S97-S101, (2005).

S. Garrett, J. A. E. Wasey and W. L. Barnes
'Fluorescence in the presence of metallic hole arrays',
Journal of Modern Optics, **52**, 1105-1122, (2005).

A. Giannattasio and W. L. Barnes
'Direct observation of surface plasmon-polariton dispersion',
Optics Express, **13**, 428-434, (2005).

U. Kreibig, D. Wagner, A. Graff and H. Ditlbacher
'Oberflachenplasmonen auf Silber-Nanodrahten',
Photonik, **2**, 105, (2005).

F. Lopez-Tejeira, F. J. Garcia-Vidal and L. Martin-Moreno
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