

SIXTH FRAMEWORK PROGRAMME
PRIORITY [2]
INFORMATION SOCIETY TECHNOLOGIES
Strategic Objective 2.5.1: Photonic Components



Project no: 033793

PROJECT ACRONYM: PHODYE

Project title: New **PHO**tonic Systems on a Chip based on **DYE**s for Sensor Applications
scalable at Wafer Fabrication

Instrument: STREP

Thematic Priority: INFORMATION SOCIETY TECHNOLOGIES
Strategic Objective 2.5.1: Photonic Components

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Project coordinator organisation name Consejo Superior de Investigaciones Científicas

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1.- Partners involved

PHODYE project has been carried out by eight partners of five different European countries. Affiliation, acronyms and relevant address and web information are gathered in Table 1. Contact person and details can be founded in www.phodye.icmse.csic.es

Participant no.	Participant organisation name	Participant Org. Short name	
1 Co-ordinator	Consejo Superior de Investigaciones Científicas-Instituto de Ciencia de Materiales de Sevilla-	CSIC-ICMS	www.icmse.csic.es Dr. Angel Barranco Prof. A.R. González-Elipe
2 Contractor	Universidad Politécnica de Valencia-Nanophotonics Technology Centre	UPVLC-NTC	http://www.ntc.upv.es/ Dr. Amadeu Griol
3 Contractor	Royal Institute of Technology	KTH	http://www.kth.se/ Dr. Hans Sohlström
4 Contractor	Multitel	MULTITEL	http://www.multitel.be/ Dr. Fabian Dortu
5 Contractor	Swiss Federal Laboratories for Materials Testing and Research	EMPA	http://www.empa.ch Dr. Pierangelo Gröning
6 Contractor	Centre Suisse d'Electronique et de Microtechnique	CSEM	http://www.csem.ch Dr. Marc Schniepper
7 Contractor	Etra Investigación y desarrollo	ETRA I+D	http://www.grupoetra.com Dr. Santiago Cáceres
8 Contractor	Universidad Politécnica de Madrid-Centro Láser de la UPM	UPM-CLUPM	http://www.upmlaser.upm.es Dr. Miguel Holgado

Table 1.-Phodye consortium

2.-Project objectives

The general objective of PHODYE is the development of a new photonic sensing technology based on the use of a new kind of dye sensor films and photonic structures and/or subwavelength grating structures. Final chip devices should respond to modification in the environment, so that the changes produced in the absorption and/or fluorescence signals coming from the films can be selectively monitored by the implementation of the developed photonic structure. Sensing capacities towards NO₂, UV light and surface temperature have been developed. For

the selective monitoring of the dye thin film signals photonic structures consisting of vertical cavities, Fabry-Perot resonators and Ring resonators have been developed. In addition, through the integration of the fluorescence films onto subwavelength grating structures, visual tags capable to modify their aspect when changes occur in the aforementioned environmental magnitudes have been also developed.

Specific project objectives of PHODYE, according to the technical WPs planned in the final approved proposal are summarized in Table 2, where main partners involved in their achievement and the degree of the accomplishment of the objective are also listed.

Table 2.- Specific objectives of PHODYE

Technical Work Packages	Specific Objective	Partners involved	Degree of accomplishment
WP1. Project conception. Technical and application specifications	<i>Determination of technical specifications of chip prototypes and final devices</i>	All partners	Redefinition during project development
WP2: Dye thin film fabrication and characterization	<i>Fabrication and characterization of dye thin films</i>	CSIC, EMPA	High
WP3: Photonic components: design, fabrication and characterization	<ol style="list-style-type: none"> 1. Design and fabricate photonic components to be integrated with the dye thin films² 2. Photonic device modelling to determine the optimum structures of VCs and subwavelength devices. 3. Fabrication of the designed VC photonic structures 4. Characterization of the fabricated photonic test VC structures 5. Planar Fabry-Perot and ring/disk resonators circuits have been also fabricated and tested. 	KTH, CSEM, NTC, UPM	High
WP4: Integration of dye thin films and photonic structures	<ol style="list-style-type: none"> 1. Design of full photonic chips on a wafer based on VCs or subwavelength structures 2. Fabrication of VC chips 3. Fabrication of subwavelength gratings 	KTH, NTC, CSEM, CSIC	High
WP5: Test platform fabrication	<i>Fabrication of a portable platform to host, power and test the chips</i>	MULTITEL	High

WP6: Device fabrication and packaging	<ol style="list-style-type: none"> 1. Fabrication of sensor devices incorporating VC photonic chips 2. Fabrication of sensor devices incorporating visual subwavelengths chips 3. Integration of the photonic chips in the real measurement systems 4. Processes qualification assessment for industrial exploitation 	UPVLC-NTC, KTH, CSEM, CSIC, ETRA	High
WP7: Final trial and validation	<ol style="list-style-type: none"> 1. Validate of the PHODYE devices in a tunnel safety scenario 2. Feasibility report to integrate the photonics devices in real measurement systems 	MULTITEL, ETRA, UPM, CSIC	Medium

As indicated in this table, most specific objectives have been largely accomplished and devices, test and a large series of results are available. Some of these results can be immediately transferred to the industry. Only in the case of the final validation and testing of the NO₂ sensor chips, the degree of accomplished can be considered medium. This is so because the developed measurement platform, a first prototype capable of measuring the response of the sensor chips has been tested for a limited period of time. Longer times (e.g., six months or more) should be necessary to properly ascertain the performance of the measuring platform.

In the following, a brief summary is included describing the work performed in trying to achieve the listed specific objectives, as well as a general appraisal evaluating the developed technology as a whole.

3.- Work Performed and Main Results

To accomplish the previous results different activities have been carried out within each work package. These activities and the main publishable results are described.

3.1 WP1. Project conception. Technical and application specifications

Since the beginning of the project, both the partners and the Commission were aware of the high innovative character of PHODYE. To make it successful one of the main activities within the project was to clearly define specific targets where to apply the project development. This, besides approving an extension of the project duration to a total time of four years, the partners in agreement with the Commission pursuit a deep analysis of the market possibilities and restrictions of the developed technology in order to defined clear and achievable targets. To achieve this, a redefinition of the sensor chip capabilities was approved, focussing them into the detection of NO₂, UV light and temperature. For that, it was also decided to concentrate the efforts on the

development of chips based on the simplest and most reliable photonic structure. Therefore, most results presented herein refer to just one type of photonic structure (the so called Vertical Cavity), although other type of devices were also designed, built and fabricated.

3.2 WP2: Dye thin film fabrication and characterization

Dye thin films prepared by partial plasma polymerization of evaporated dye molecules have been prepared by partners CSIC and EMPA. This new developed method consist of the evaporation of a dye in the presence of a mild plasma. The dye molecules are partially decomposed by interaction with the plasma species and a polymerized thin film is obtained where embedded entire molecules of the dye are preserved. Very thin film with a high optical quality (i.e., high transparency) are thus prepared. The intense absorption coefficient of the film and its high fluorescence makes that very thin film of the order of 100 nm can be used for photonic applications. Fig. 1 shows as an example a series of dye thin films made of different molecules and therefore presenting different colours.

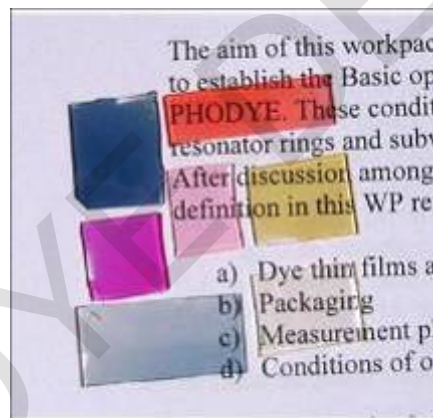


Fig. 1.- Picture of Phodye of ~100 nm dye containing thin films deposited on quartz.

In PHODYE, the prepared films, besides a high intensity colour, presented a specific fluorescence. Another characteristic of the dye thin films prepared in the project is that they change colour or fluorescence following changes when exposed to NO₂, UV light, pH, temperature, etc. This specific behaviour depends on the type of dye molecule considered in each case, each one characterized by a given absorption and fluorescence spectrum. An example of the type of response that can be considered is reported in Figure 2 where we show the evolution of the fluorescence signal coming from the film as a function of the NO₂ exposure of one of the dye thin films.

Other outstanding characteristics of the dye thin films prepared in PHODYE are their low roughness (RMS values of the order of one nm) and their relatively high mechanical and chemical stabilities.

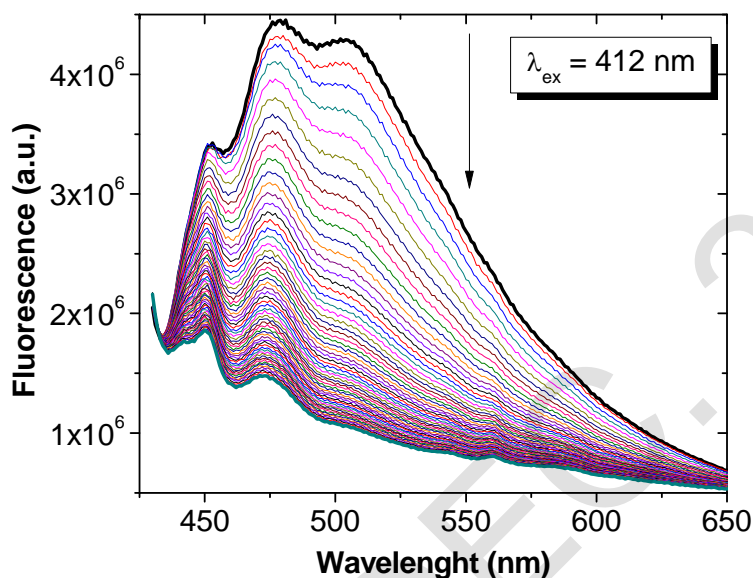


Fig. 2.- Evolution of luminescence emission of a Phodye perylene containing thin films exposed to NO_2 in air

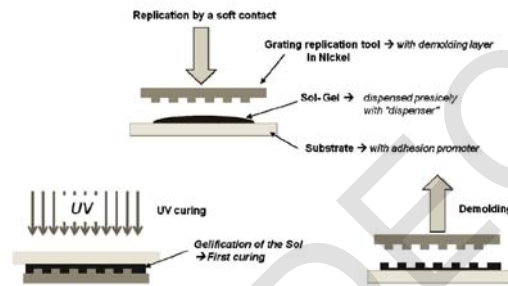
3.3 WP3: Photonic components: design, fabrication and characterization.

Different types of photonic components have been designed, fabricated and tested. Basically, PHODYE has worked with photonic structures and with subwavelength gratings. The latter type of components consists of gratings designed and fabricated on polymer materials. The idea is to adjust the grating period and other morphological characteristics (e.g., high of the grooves) of the structures to get an optimum coupling with the absorption and/or fluorescence bands of the dye thin films in order to get angular colour effects that are directly and easily observable by the bare eye. Design and fabrication of these components has been carried out by CSEM as described in Figure 3a). An example of the observed behaviour for some of the dye thin films deposited on the structures is reported in Fig. 3b). It is important to remark that this effective coupling between the dye thin films and the subwavelength grating is possible because the deposition process of the polymeric thin films is perfectly conformal on the grating structure.

A requisite for the fabrication of the PHODYE films is to get photonic structures where there exist a perfect coupling of the fluorescence signal coming from the dye and the photonic component. This means that the photonic structure can be used to

select a given wavelength and transmit this signal to the exterior of the system out to a detector. To fulfil this requisites the photonic structures must be designed and constructed according to a given and proved pattern with a great accuracy in their dimensions up to the nanometer scale. Note that this requisite changes from one dye thin film to another owing to the fact that each dye molecule is characterized by a different fluorescent wavelength. Another important requisite that has been accomplished within PHODYE is that fabrication of the structures is carried out at wafer scale. VC were fabricated by the successive deposition of successive layers of SiO₂ and Si₃N₄ with different refraction indices.

a)



b)

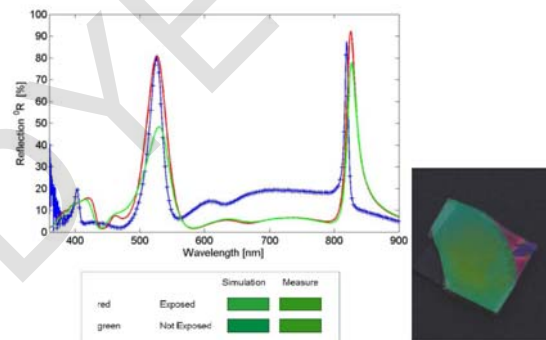


Figure 3 a) Scheme of the grating replication process b) A comparison between measurements (blue curve) and two simulations (red and green curves) using the exposed and non exposed optical parameters of a Perylene layer. On the left side, a picture shows the reflected color of the sample. Mentioned below, an estimation of the colors the sample should have by a calculation of the spectrums' color RGB components (measured and simulated above).

F-P and RR structures required the use of e-beam tool combined with a dry etching process based on Inductive Coupled Plasma equipment (ICP) on a previously formed stacked structure (Si+SiO₂+Si₃N₄). A fabrication process based on e-beam and lift-off was developed to reach structures with critical dimensions close to 100 nm. Figure 4 depicts the developed fabrication process employed in PHODYE.

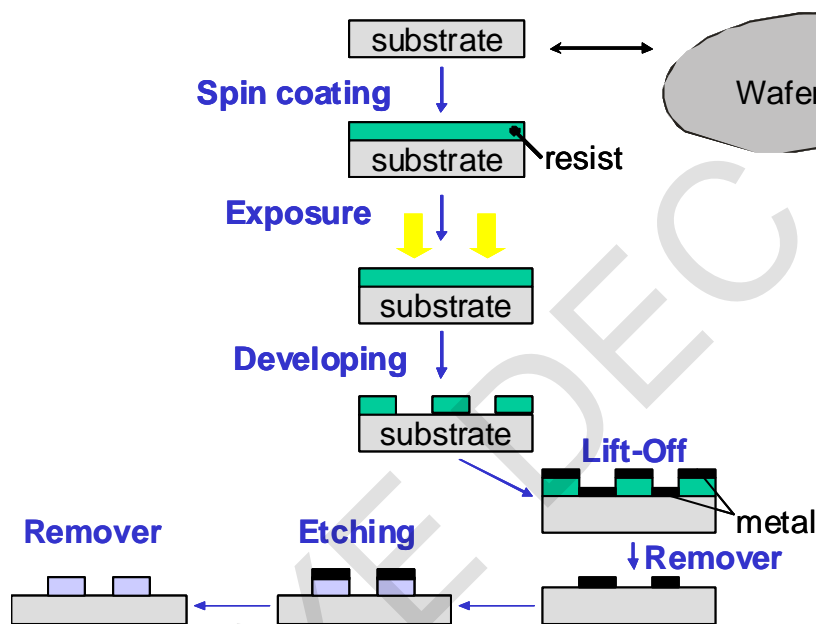


Figure 4.- Phodye fabrication process employed at NTC

As mentioned, three types of photonic structures have been designed, fabricated and tested with and without the dye thin films deposited on their surface. These are: ring resonators (RR), Fabry Perot Resonators (FPR) and Vertical cavities (VC). Design of these structures has been carried out by UPM and their fabrication by NTC (RR and FPR) and KTH (VC). For the three of them, the effective coupling between the fluorescence signals coming from the dye thin films has been proved. However, fabrication of final chips for detection and monitoring of the environmental changes was based exclusively on VCs. Fig. 4a) shows some enlarged views of the fabricated structures and, in the case of the VCs, a scheme (Figure 4b)) of its structure and a spectrum showing its optical behaviour acting as selective filter.

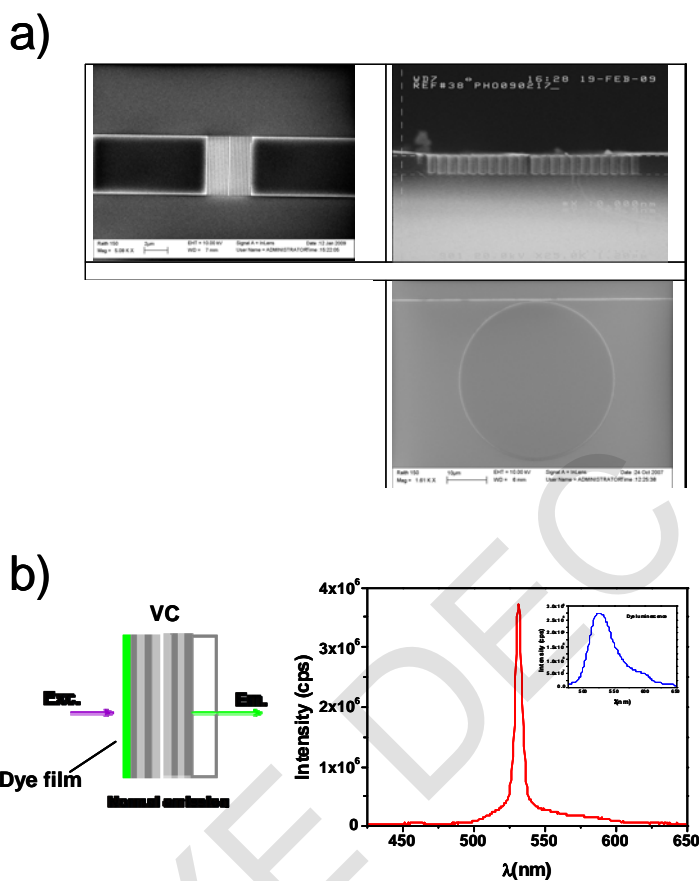


Figure 5.- a) Phodye photonic structures (FP, resonant disk and ring) b) Scheme of a vertical cavity and luminescent emission of a dye containing film sensor filtered by this structure.

3.4 WP4: Integration of dye thin films and photonic structures

The main idea of PHODYE was that the fluorescence signal coming from the fluorescence dye could be efficiently coupled into the photonic structure which will act as a selective device of given wavelengths. In the course of the investigations, this working hypothesis was demonstrated to be true and proved for the three types of photonic structures. Different ensembles photonic structure-dye thin films were prepared and characterized attending to the final application envisaged. This implies to adjust the characteristics of the photonic structure to the absorption/fluorescence spectra of the films and to carefully select the morphological and optical characteristics of the dye thin films (roughness, refraction index, etc.).

Generally speaking, the deposition of the dye thin films onto a photonic structure is not a very complicated procedure. However, a challenge is to make it at a wafer scale. Successful experiments were carried out by CSIC onto VCs grown onto glass wafers prepared by KTH and onto RR structures grown onto silicon wafer by NTC. Fig. 6 shows one 3 inch silicon wafer covered by a dye containing thin films demonstrating wafer scale luminescent film deposition. In the project, wafer scale grown structures were covered by dye thin films. It must be noted that, depending on the structure, the wafer could be covered completely by the thin film or, alternatively, only in certain areas. In this case suitable shadow masks had to be used to selectively deposited the active layer in the desired zones (e.g., onto the disks in the RR or onto the grating area in the FPR)

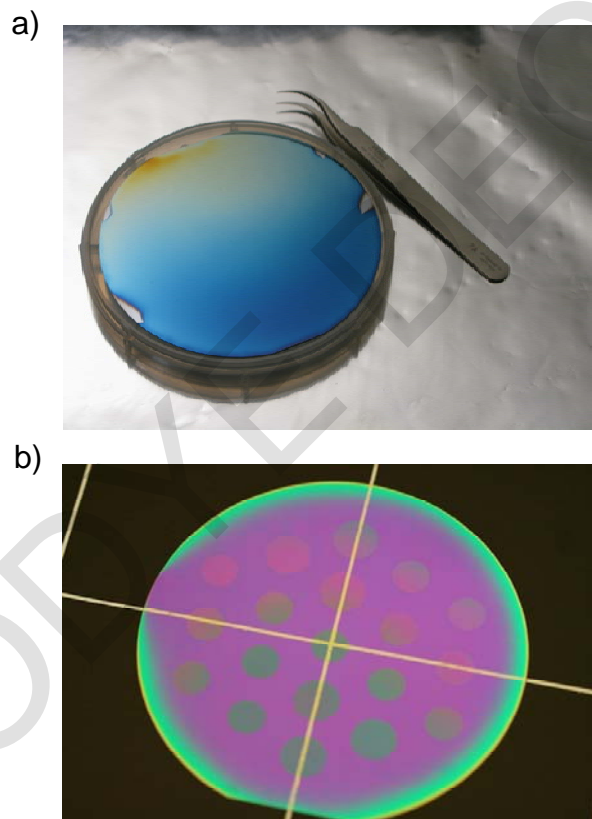


Figure 5: a) Si(100) wafer covered by a 100 nm dye containing sensor films. b) Glass wafer with wafer scale deposited vertical cavity (purple-green) and dye thin film. The dye has been patterned into circles with a diameter of around 10 mm. The wafer is lying on a table with a white cross.

3.5 WP5: Test platform fabrication

Two platforms have been fabricated for hosting the sensitive photonic components developed in WP3. One platform has been implemented to obtain quantitative information from the integrated vertical cavity (VC) structures. This information is sent to a remote monitor by a pair of electric current conductor. The second platform has been implemented to obtain qualitative visible (color readable by a human) information using the subwavelength grating (SWG) as core sensitive photonic components. Photographs of those two platforms are showed in Fig 7 a) and Fig.7b) The elements to be detected have different nature (gas, temperature, UV light) but share a quite similar detection set-up. Consequently, the test platforms have been fabricated so that they can address the different detection problems provided that a few optical component changes are made.

a)



b)



Fig 5.1: VC platform demonstrator for NO₂ and temperature detection b)Fig 5.2: SWG platform demonstrator for visual detection

One of the challenges has been to detect a very low signal in a much stronger noisy environment using a portable and cost effective platform: the fluorescent light power can be several orders of magnitude lower than the excitation light sources power (LED or sunlight depending on the application). This issue has been addressed by using spatial and spectral light filtering, choice of optimized and cost-effective optical components, black anodizing of the platform surfaces and electronic amplification and filtering. Fig 5.3 shows a laser diode excited PHODYE VC chip mounted in the test platform.

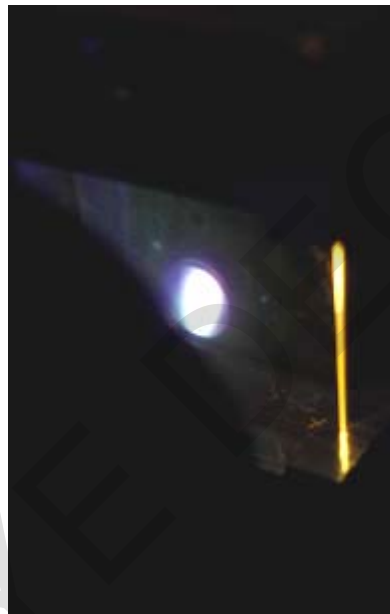


Fig. 8. PHODYE chip mounted in the test platform, excited by a laser diode for NO₂ detection. Yellow light emission is visible at the edge of the chip.

Tests and reports on the platform performance have been done in the case of temperature and solar UV detection. As Multitel does not process gas flow equipments, the NO₂ platform tests were performed thanks to the contribution of CSIC before the final test in a tunnel in the city of Valencia by ETRA.

3.6 WP6: Device fabrication and packaging

The preparation of final PHODYE chip devices based on photonic structures implies a series of steps posing specific problems that were solved during the project development. Basically they involved dicing the wafer to separate single chips and the encapsulation of the chips within a specific packaging. It is important to indicate that photonic structure deposition and packaging is carried out at wafer scale before the dicing of the chips. For silicon substrates a new dicing procedure using laser was developed by UPM. Packaging has been a quite complicated issue taken into account the specific requirements imposed by the detection problem to be addressed. Thus, for example, differences should be considered in packaging depending on whether the chip will be used to detect NO_2 or to monitor UV radiation. In the first case, the packaging must provide access to air to the chip area. In the second, light should impinge onto the active thin films. An additional difficulty in the case of the NO_2 sensor chips is that no polymeric material can be used, as polymers react with NO_2 and may change the actual concentration monitored by the chip. These difficulties have been overcome by developing new types of packaging system at wafer scale at room temperature and avoiding the use of chemical solvents in contact with the polymeric dye containing thin films. Thus, the vertical photonic structures were packaged using a novel hermetic glass-gold package that was mechanically reinforced by an almost enclosed polymer underfill. A packaged NO_2 sensitive vertical cavity sensor is shown in Fig 9. This package has access holes into the dye enclosure, and the dye itself is separated from the polymer underfill by a gold seal. This process was developed at wafer scale using commercially available tools.

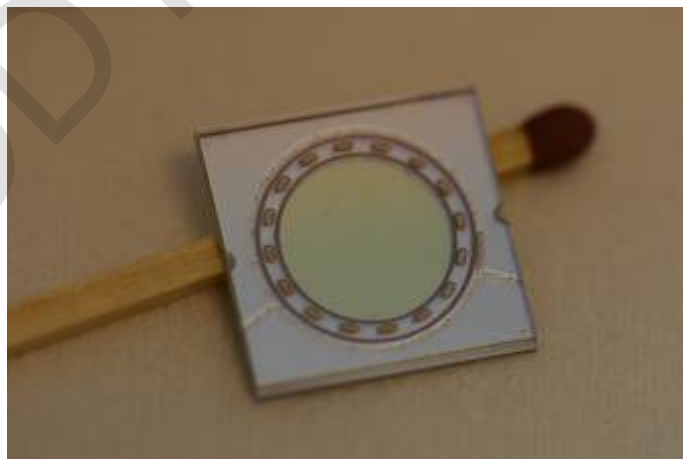


Figure 9: Fully integrated and packaged vertical cavity NO_2 sensor. The dye is seen as a slightly yellow hue inside the gold rings and ventilation holes. The inner ring is a filter stopping particles bigger than 2-3.

3.7 WP7: Final trial and validation

The whole technology developed in PHODYE has been tested by using the measurement platform developed in WP5 and photonic chips. Basically essays aiming at detecting NO_2 have been done in a real scenario consisting in an urban tunnel in the city of Valencia (Spain). The tests have been done by TETRA assisted by MULTITEL, UPM and CSIC. Final photonic chips were used for these experiments. The idea is to measure the amount of NO_2 accumulated in the environment during a certain period of time and to compare the measurements with those provided by the conventional measurement instruments already available in the tunnel. The communication between the measurement platform and the communication system of the tunnel was also incorporated into the platform, so that the data can be stored within the tunnel monitoring system. Fig. 10 shows a luminescence decay curve measured using the measurement platform and where the chips were exposed to an environment with presence of NO_2 . At present the platform is being use to complete the study of NO_2 coming from road traffic in a tunnel in the city of Valencia (Spain).

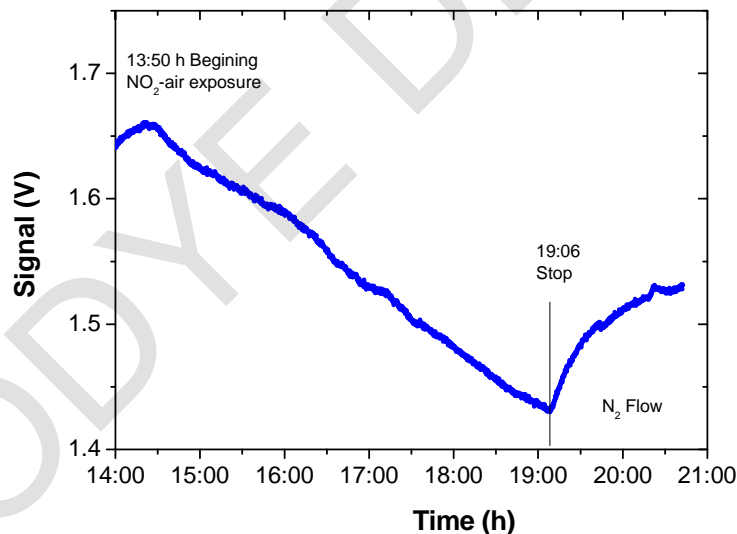


Fig. 10.- Evolution of the signal of the measurement platform when a Phodye chip is exposed to NO_2 containing atmosphere.

4. Summary

PHODYE has successfully developed a new technology for environmental detection based on the combination of photonic structures and subwavelength gratings on the

one hand and fluorescent dye thin films on the other. Visual chips devices prepared at wafer scale and usable as sensitive tags and photonic chips have been manufactured and tested in real scenarios. Annex 1 presents some specification sheets for the main final devices developed in PHODYE as compared with possible equivalent products already in the market.

PHODYE DEC. 2010

ANNEX 1: SPECIFICATION SHEETS

In this annex, specification sheets are provided where the performance, potential applications, dynamic range of applications, other technical details and a comparative assessment of the PHODYE technology are compared with other potential procedures/devices existing in the market. The characteristics reported in the present specification sheets are a summary of a much more thorough description included in different deliverables issued during the project development. Additional details can be found in the following deliverables and internal reports:

D3WP5: Report on the platform performance and optical coupling efficiency according to the chips

D3WP7: Report with the evaluation results: VC sensor chips and visual tags. Feasibility analysis about the integration of photonic sensors in real measurement systems.

D4WP8: Final plan for using and disseminating the knowledge.

Plan for using and disseminating the knowledge

This analysis is carried out for the following four application devices developed in PHODYE which are those closer to a final application and use:

- 1.- DISPOSABLE VISUAL TAGS FOR NO₂ EXPOSURE DOSIMETERS**
- 2.- QUANTITATIVE NO₂ MONITORING**
- 3.- DISPOSABLE VISUAL TAGS FOR UV DETECTION**
- 4.- QUANTITATIVE UV MONITORING SYSTEM**

DISPOSABLE VISUAL TAGS FOR NO₂ EXPOSURE DOSIMETERS

Function: Change in the color/visual aspect after exposure of the tag to air with NO₂ for a given period of time

Alternatives in the market: No equivalent product exists in the market

Cost: 2-3 euros in mass production

Size: any size possible but recommended 2x3 cm²

Other characteristics:

- Tags with different sensitivity ranges available for different average NO₂ concentration in the environment. Saturation values of 5 ppmxhour (high sensitivity), 50 ppmxhour (medium sensitivity) and 500 ppmxhour (low sensitivity) are available¹.
- Possibility to draw different figures, letters, etc. (e.g., danger, SOS, etc.)
- Portable on any substrate material

Possible niches of applications:

Control of people working in the street (traffic controllers, police, public workers, taxi and bus drivers, etc.).

Control in kitchens and other domestic areas.

Control in petrochemical industries

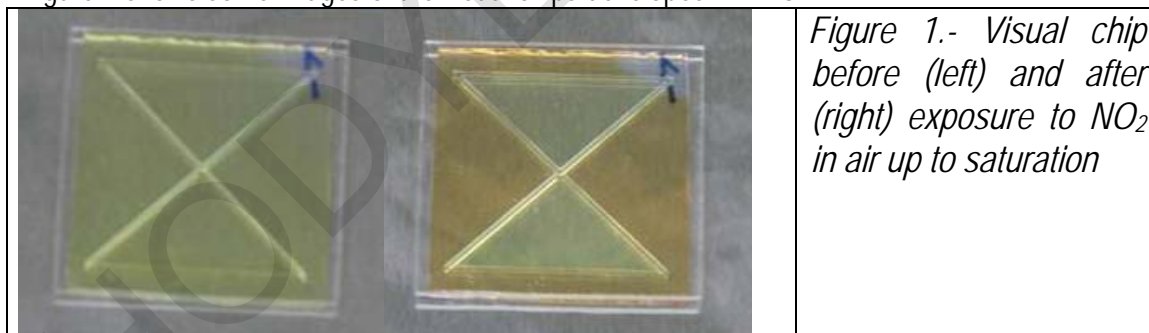
Control in fuel electrical plants working with oil or coal.

Control of explosive environments

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Example of visual chip:

Figure 1 shows some images of the visual chips developed in PHODYE



¹ These values mean that the available tags will be saturated after exposure for 5, 50, 500 hours for a NO₂ concentration of 1 ppm. Longer/shorter saturation times would be required if the concentration of NO₂ is lower/higher than these values.

QUANTITATIVE NO₂ MONITORING

Function: Quantitative monitoring in real time of the NO₂ concentration in the environment

Components:

- a) Photonic sensor chips
- b) Measurement platform including communication system with any storage or data representation system.

Alternatives in the market: electrochemical cells, conductivity sensors, etc. Usable for just a given range of NO₂ concentration.

Cost:

- a) sensing elements: 6 euros in mass production.
- b) Measuring platform: 900 euros for a prototype. Up to half this price for mass production depending of the size of the series.

Working characteristics:

- Battery or network supply of electricity
- Replacement of the sensing chips when saturated. Sensor chips with saturation values of 5 ppmxhour (high sensitivity), 50 ppmxhour (medium sensitivity) and 500 ppmxhour (low sensitivity) are available.²
- Portable monitoring system possible.

Possible niches of applications:

- Control and monitoring of pollution in traffic areas of big cities³
- Control and monitoring in petrochemical industries
- Control and monitoring in fuel electrical plants working with oil or coal combustion.
- Control and monitoring in laboratories

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Critical assessment of working parameters and comparison with products available in the market.

A critical comparison of the working parameters and other commercial issues of the PHODYE NO₂ sensing technology as compared with equivalent figures for NO₂ electrochemical cells (ECCs) currently used for traffic environmental control.

² These values mean that the sensor chips will be saturated after exposure for either 5, 50, or 500 hours for NO₂ concentrations of 1 ppm. Longer/shorter saturation times would be required if the concentration of NO₂ is lower/higher than these values.

³ Only in Spain the volume of this market is estimated in approximately 1.2 M euros for just the approximately 300 tunnels where NO₂ detection systems could be installed. Using the PHODYE technology could produce savings in the order of 660.000 euros every two years (see deliverable D4WP8)

	Limit of Detection ¹	Response Time	Noise level	Cost disposables (€)	Life time disposable elements ¹	Cost measuring platform (€)	Supply	Output signal range
PHODYE	0.2 ppm ²	1 second	0.1 ppm	6	250 hours at 2 ppm ³	900 ⁴	24 V DC	4 - 20 mA
ECCs	0.2 ppm	1 second	0.1 ppm	160	2 years	2000	24 V DC	4 - 20mA

- 1) Adjustable according to the used range of sensor chips
- 2) Values for the 50 hoursxppm chip
- 3) Values for the 500 hoursxppm chip.
- 4) Lower price for mass production

Technology demonstrator of the measuring platform and PHODYE chips

Views of the technology demonstrator of the measuring platform and the PHODYE chips are shown in Figure 2 below. Note that the dimensions for an industrial prototype could be reduced to approximately 20x30x10 cm.



Figure 2.- View of the measuring platform (left) and a PHODYE NO₂ sensor chip (right)

DISPOSABLE VISUAL TAGS FOR UV DETECTION

Function: Change in the color/visual aspect when exposing the tag to UV light. Changes observed upon sun irradiation

Alternatives in the market: Various alternatives in the market in the form of inks.

Cost: 2-3 euros in mass production

Size: any size possible but recommended 2x3 cm²

Other characteristics:

- Invisible tags which
- Possibility to draw different figures, letters, etc. (e.g., danger, SOS, etc.)
- Portable on any substrate material (paper, plastic, etc.).
- Sensitive to a wide range of UV intensities
- Complete reversibility

Possible niches of applications:

Control of UV irradiation when exposed to the sun light. Observable with the bare eyes

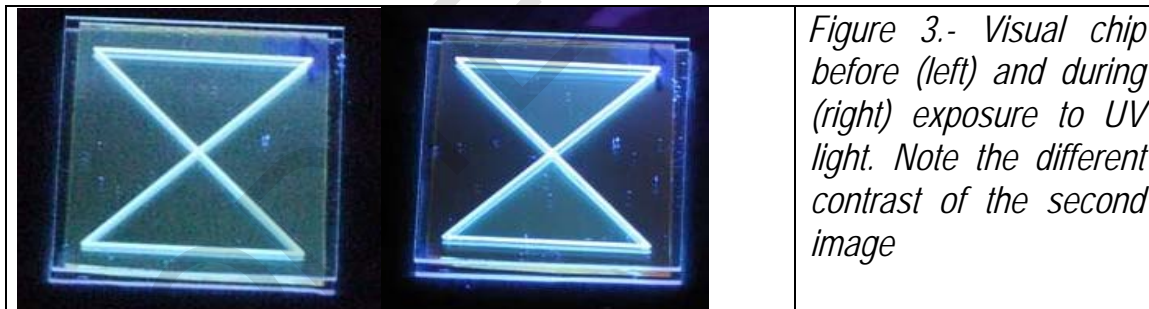
Anti-counterfeit applications.

Control over very UV sensitive materials or products.

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Example of visual chip:⁴

A visual chip intended to maximize the visual sensitivity is shown in Figure 3



Other possible forms:

The UV sensitive material can be deposited on any substrate (Figure 4). This could be ideal for anti-counterfeit applications

⁴ The reported images corresponds to the UV tags in the form of visual chips. The UV sensitive material can be incorporated under other formats or directly on any substrate as exemplified with the 5 euro banknote in Figure 4.

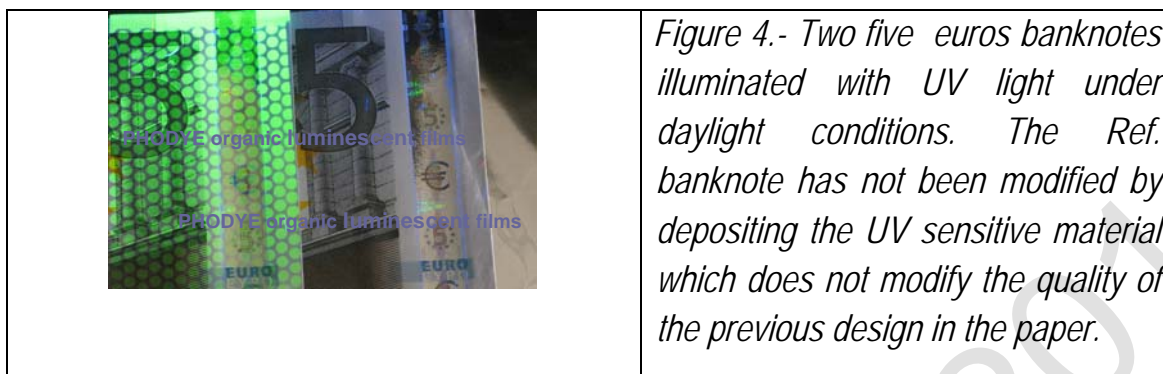


Figure 4.- Two five euros banknotes illuminated with UV light under daylight conditions. The Ref. banknote has not been modified by depositing the UV sensitive material which does not modify the quality of the previous design in the paper.

QUANTITATIVE UV MONITORING

Function: Quantitative monitoring in real time of the UV light intensity

Components:

- a) Photonic sensor chips
- b) Measurement platform including communication system with any storage or data representation system.

Alternatives in the market: reliable alternatives exist in the market based on different procedures of detection based on measuring a change in some transport properties.

Cost:

- Sensing elements: 6 euros in mass production.
- Measuring platform: 900 euros for a prototype. Up to half this price for mass production depending of the size of the series.

In market there are a large variety of UV monitoring systems with prices that range from 100 to 2000 euros depending on the accuracy, limits of detection, etc.

Working characteristics:

- Battery or network supply of electricity
- No replacement of the sensing chips required. Long working life for the chips.
- Portable monitoring system possible.
- Measuring platform usable for NO₂ detection as well, after small modifications.

Possible niches of applications:

- Control during air purification with UV light
- Control during water purification with UV light
- Control of solar irradiance

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Critical assessment of working parameters and comparison with products available in the market.

A critical comparison of the working parameters and other commercial issues of the PHODYE UV sensing technology as compared with equivalent figures for other UV detecting systems available in the market.

	Lower Detection	Maximum limit of	Wavelength range	Response	Noise level	Cost disposable	Life time disposable	Cost measuring	Supply	Output signal
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	Limit ¹	detection		Time	es (€)	e elements	g paltform (€)		range	
PHODYE	0.0014 mW/cm ²	Up to 10 mW/cm ²	$\lambda < 400$ nm	immediate	0.001 mW/cm ²	6	No replacement required	900 ²	24 V.	4 – 20 mA
Market ⁴	Up to 200 mW/cm ²	$\lambda < 400$ nm	immediate	0.001	Integrated within the system	No replacement required	100-2000 ³	Batteries or DC supply	0-5 V

1) A typical value of solar UV irradiation in Sevilla (Spain) is 0.8 mW cm⁻²

2) Lower price for mass production

3) Many systems available in the market. Their price depends on their performance. For systems similar to that of PHODYE prices amount to approximately 1000-1500 euros

4) Data corresponding to a specific system in the market

Example of application of the measuring platform and PHODYE chips

The monitoring response obtained with the PHODYE platform of the UV solar light irradiation during one day is reported in Figure 5. The data are compared with those obtained in a meteorological station place in another part of Belgium

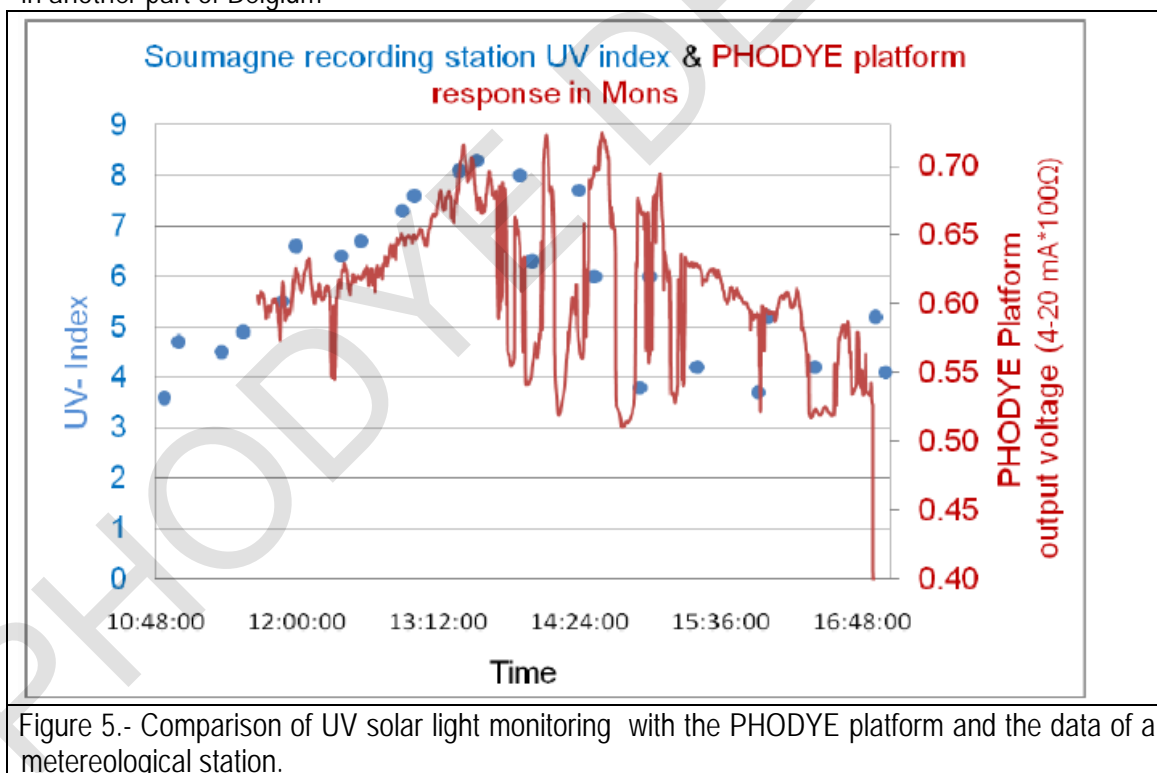


Figure 5.- Comparison of UV solar light monitoring with the PHODYE platform and the data of a meteorological station.

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