Optical Properties of SOI Waveguides Functionalized with Close-Packed Quantum Dot Films

Zeger Hens, Abdoulghafar Omari, Pieter Geiregat, Dries Van Thourhout
Physics and Chemistry of Nanostructures, Ghent University, Belgium
Center for Nano and Biophotonics, Ghent University, Belgium
Photonics Research Group, Ghent University, Belgium
Tel: (32) 92644863, Fax: (32) 92644983, e-mail: Zeger.Hens@UGent.be

ABSTRACT
It is shown that dipolar coupling between neighboring quantum dots enhances the absorption of light in close packed monolayers of colloidal quantum dots. Based on this concept, the experimentally determined losses in planarized waveguides coated by a quantum dot monolayer can be successfully simulated. These simulations rely on replacing the quantum dot layer by an effective medium with a dielectric function determined by dipolar coupling and use the dielectric constant of the quantum dot host medium as the only adjustable parameter. This leads to a generic approach for the simulation of optical materials including close packed quantum dot layers.

Keywords: functionalized waveguides, colloidal quantum dots, optical losses, silicon, telecommunication.

1. INTRODUCTION

Colloidal quantum dots offer a unique combination of size-tunable optical properties and a suitability for solution-based processing [1]. This implies that their properties can be fit to the application and that they can be readily combined with a variety of materials or technology platforms. These include silicon-on-insulator (SOI) and silicon nitride based integrated photonic circuits, where colloidal quantum dots can be used for the on-chip generation, detection or processing of light. These applications typically rely on close-packed mono- or multilayers of quantum dots.

In this paper, we analyse the optical properties of such quantum dot layers. We first start from absorption measurements, where we find that the absorption cross section of a quantum dot in a close packed film can be enhanced by a factor of 5 relative to the value found in a dilute dispersion. We show that an effective medium model that explicitly includes the dipolar coupling between neighboring quantum dots can account for this enhancement and its particular dependence on the quantum dot size and the quantum dot material. In a second step, we use this effective medium model to simulate experimentally determined losses in planarized SOI waveguides coated by monolayers of quantum dots. Using the host dielectric constant as the only adjustable parameter, we find excellent correspondence between the experimental losses and the simulation results for dielectric constants of the host in the range 1 – 2, a reasonable value for quantum dots coated by apolar organic ligands. As such, this work provides the conceptual basis needed for the optical simulation of hybrid photonic devices based on thin films of colloidal quantum dots.

2. EXPERIMENTAL

The oleate-capped PbS and PbS/CdS quantum dots used in this work were synthesized using established literature procedures [2],[3] and subsequently deposited as close packed monolayers using Langmuir-Blodgett deposition [4]. Importantly, this leads to the formation of large area, homogeneous films both on glass substrates (see Fig. 1A) and on silicon-on-insulator chips, where local deposition is achieved in combination with optical lithography[5].

When deposited on glass substrates, the absorption cross section σ_f of a quantum dot can be determined from the film absorbance A, corrected for the film reflectance R:

$$\sigma_f = \ln 10 \times \frac{A - R}{N_s} . \quad (1)$$

Here, N_s denotes the surface density of quantum dots, a number that can readily be determined using transmission electron microscopy (TEM). In equation (1), scattering is neglected since the wavelengths used (> 400 nm) are much larger than the quantum dot diameter. The correction of the absorbance for reflection is typically very small (< 10%).

When deposited on waveguides, the net absorption coefficient α of the QDs is obtained by loss measurements on waveguides covered by a strip of QDs with varying length L (see Fig. 2B). Using one of the waveguides as a reference, the transmitted power P_t in the other waveguides can be expressed as:

$$\log \frac{P_{t,ref}}{P_t} = \alpha (L - L_{ref}) . \quad (2)$$

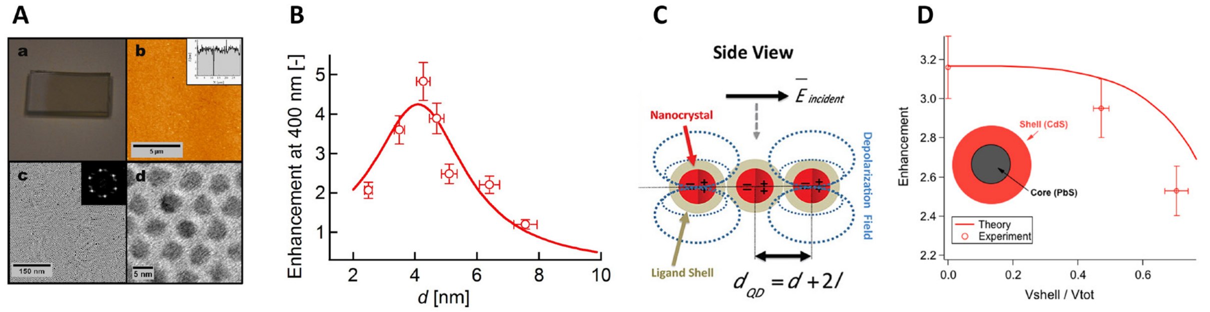

Figure 1: (A) Langmuir-Blodgett monolayer of PbS quantum dots, including (a) a contrast picture of a monolayer of PbS quantum dots ($d = 5$ nm) on a glass surface (2×1 cm) showing homogeneous cm^2 coverage; (b) an atomic force microscope scan of the same PbS monolayer indicating excellent area uniformity (inset: cross section); (c) a larger area TEM image showing the PbS quantum dot superlattice with local hexagonal ordering (inset: Fourier transform image) and (d) a zoomed-in TEM image showing the individual quantum dots and their interdistance. (B) Absorption enhancement for PbS quantum dots stabilized by oleate ligands at 400 nm as a function of QD diameter d. The full line represents the predictions based on the coupled dipole model. (C) Side view schematic of monolayer subject to incident field polarized in-plane. The relevant geometrical parameters are indicated by d_{QD}, d, and l as the (nearest-neighbor) interdot distance, QD size, and ligand length, respectively. Absorption enhancement for PbS/CdS core/shell quantum dots as a function of the ratio between shell volume and total volume. The full line represents the enhancement according to the coupled dipole model.

Following equation (2), we calculate α from the slope of a log $P_{t,ref}/P_{ref}$ *vs*. L-L_{ref} plot.

3. RESULTS

In Figure 1B, we plot the ratio between σ_f measured on monolayers of PbS QDs at 400 nm and the absorption cross section σ_0 of the same quantum dots in a dilute dispersion in tetrachloroethylene [6]. We find that this ratio, which we call the enhancement E, shows a marked dependence on the QD diameter, with a maximum value of about 5 for 4 nm PbS QDs. As shown before, this enhanced absorption of quantum dots in monolayers and its size dependence finds its origin in the dipolar coupling of the polarization fields in neighbouring quantum dots induced by the incident optical field (see Fig. 1C) [7]. This results in the following expression for σ_f:

$$\sigma_f = \frac{2\pi}{\lambda n_h} \mathrm{Im}\left(\frac{a_{0,h}}{1 - \frac{a_{0,h}}{\varepsilon_h} S} \right). \tag{3}$$

Here, λ is the wavelength of light, n_h and ε_h are the refractive index and the dielectric constant of the host in which the QDs are embedded, respectively while $a_{0,h}$ is the polarizability of an isolated quantum dot in the host medium and S is the so-called dipole sum, a term grouping the dipolar contributions of the neighboring particles to the field that drives a given QD. As shown by the full line in Fig. 1B, equation (3) reproduces the experimentally determined absorption enhancement when taking $\varepsilon_h = 1.5$ and a QD size dispersion of 10%. This correspondence indicates that the optical properties of QDs in close packed arrays indeed strongly depend on dipolar coupling between neighboring QDs. Importantly, the same expression also accounts for the absorption enhancement measured with PbS/CdS core/shell QDs in close-packed monolayers (see Fig. 1D), provided that the appropriate expression for the polarizability of a core/shell nanocrystals is used.

In Fig. 2, we show the results of loss measurements in the wavelength range 1.48 – 1.56 μm of planarized SOI waveguides coated with a close packed monolayer of PbS/CdS QDs. For these experiments, core/shell QDs were chosen with a maximum of their first exciton absorbance at 1450 nm (see Fig. 2A). In this way, we will probe the well discernible long wavelength tail of these QDs. By measuring waveguides coated with QD strips of different length (Fig. 2B), we obtain the waveguide absorbance related to the presence of the QDs as plotted in Fig. 2C. We find, depending on the wavelength, absorption coefficients in the range 2 – 5 cm^{-1}, that clearly follow the slope of the first exciton absorbance of the QDs in this wavelength range.

To compare the experimental QD with model predictions, we use an approach where the real QD layer covering the PWG is replaced by an effective medium with a dielectric function ε_{eff} (see Fig. 3A). Using the real geometry of the PWG – which includes a slightly submerged waveguide top surface, coated by a thin native silica layer – this enables us to extract a theoretical absorption coefficient α from the simulated effective refractive index $\tilde{n}_{eff} = n_{eff} + i\kappa_{eff}$ of the propagating quasi-TE mode:

$$\alpha = \frac{4\pi\kappa_{eff}}{\lambda}. \tag{4}$$

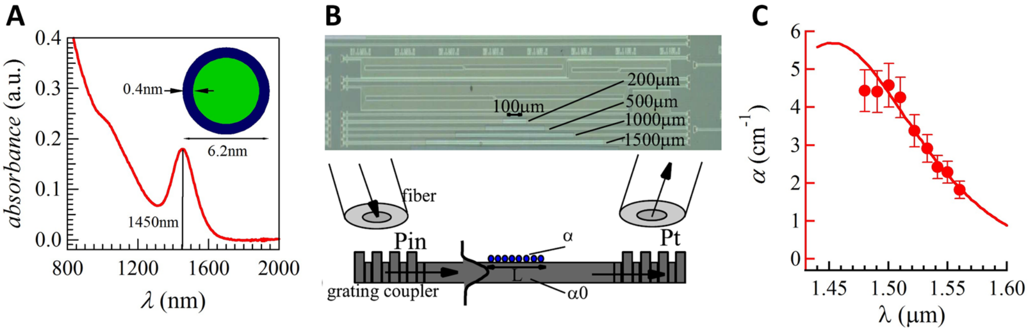

Figure 2: (A) Absorption spectrum of the PbS/CdS QD used here, as recorded on a dilute QD dispersion in tetrachloroethylene. (B) Optical microscopy image of a sample with planarized waveguides coated by a QD monolayer with various strip lengths and a cartoon representation of the optical field coupled from the fiber through the grating in the QD coated PWG. (C) Absorption coefficient of the QD coated waveguides related to the presence of the QDs. The full line represents the QD absorption spectrum, scaled to the measured waveguide absorption coefficient.

This approach however requires that the dielectric function of each material or medium involved is known. For silicon and silica, we use typical values at 1520 nm of 3.45 and 1.45, respectively. For ε_{eff}, we use the expression based on the coupled dipole modelled introduced above:

$$\varepsilon_{eff} = \varepsilon_h\left(\varepsilon_0 + \frac{N_s}{\delta}\frac{a_{0,h}}{\varepsilon_h - a_{0,h}S}\right). \tag{5}$$

Here, δ denotes the assumed thickness of the effective layer. Importantly, the dipole sum S is in general different for fields parallel ($S_{\parallel}$) or perpendicular ($S_{\perp}$) to the QD film. However, since the main field component of the quasi-TE modes in the PWG used here lies parallel to the QD film, only $S_{\parallel}$ – which was also used for the analysis of the absorption enhancement (see Fig. 1) is of relevance here.

Opposite from S, which only depends on the position of the particles relative to each other, $a_{0,h}$ is a function of ε_h and the dielectric function $\varepsilon_{QD} = \varepsilon_{QD,\mathrm{Re}} + i\varepsilon_{QD,\mathrm{Im}}$ of the QDs. While we consider ε_h as an adjustable parameter in this study, we use calculated values for $\varepsilon_{QD,\mathrm{Re}}$ and $\varepsilon_{QD,\mathrm{Im}}$, taking care that they yield the experimental absorption coefficient spectrum of the QDs in a dilute dispersion while obeying the Kramers-Kronig transformation [8]. Importantly, in this analysis, we assume that the absorption coefficient of the PbS/CdS core/shell QDs at wavelengths shorter than 400 nm can be derived from the bulk dielectric function of PbS and CdS, respectively – as was demonstrated for PbSe/CdSe QDs [9] – and we neglect possible quantization effects in the CdS shell.

Combining the geometry of the PWG cross section and the expression for ε_{eff} – based on the coupled dipole model and the self-consistently determined ε_{QD} – the electric field of the guided optical mode in the PWG can be calculated, resulting in theoretical values for $\tilde{n}_{eff}$ and α. As an example, Fig. 3B represents the electric field at a wavelength of 1520 nm for a PWG covered by a QD monolayer as obtained using Fimmwave 3.4 complex mode solver. The figure clearly shows the overlap between the QD film and the evanescent field, which makes that light absorption by the QDs affects κ_{eff} and leads to a non-zero α.

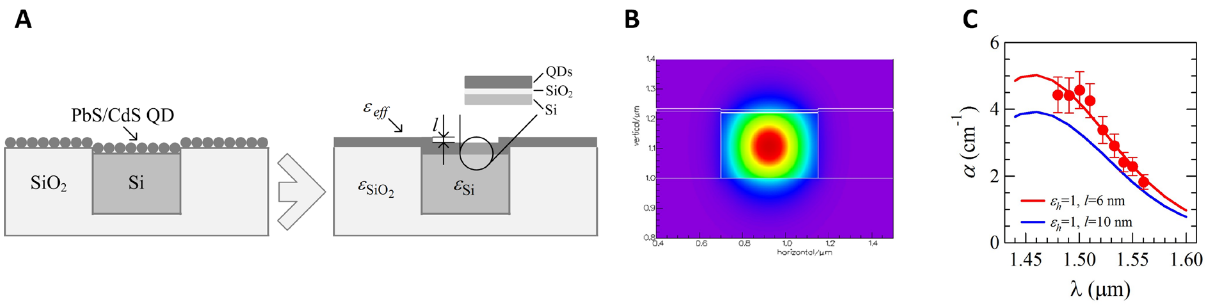

Figure 3: (A) Cartoon representation of the replacement of the real QD film on top of an SOI planarized waveguide by an effective medium. Indicated are the height difference l between the top surface of the PWG and its silica cladding and the native silica layer in between the PWG top surface and the effective medium representing the QD film. (B) Cross-sectional representation of the simulated electric field for 1520 nm light guided by a PWG coated by a QD monolayer. Colors represent the field strength, increasing from blue to red. (C) Comparison of the experimental and simulated α spectrum of a QD coated PWG for two different combinations of l and ε_h.

As shown in Fig. 3C, a close match can be obtained between the simulated and experimental α spectrum for a QD monolayer-coated PWG by adjusting ε_h. It should be noted that the ε_h value needed to match the experimental and simulated α spectrum somewhat depends on the geometry of the PWG. Using AFM, a height difference l between the top surface of the PWG and its silica cladding in the range 6 – 10 nm has been obtained. Varying l between both values as extreme cases, we obtain agreement between experiment and simulation for $\varepsilon_h = 1.0$ (l = 6 nm) to $\varepsilon_h = 1.16$ (l = 10 nm). For QDs capped by oleic acid ($\varepsilon = 2.1$ at 2000 nm) [10], both figures are relatively low yet the same holds for the $\varepsilon_h = 1.5$ found for PbS QD monolayers deposited on glass (see Fig. 1).

4. CONCLUSION

We have studied light absorption in close packed PbS and PbS/CdS QD monolayers formed by Langmuir-Blodgett deposition. The measured absorption enhancement has been explained by dipolar coupling between neighbouring QDs, implying that each QD is driven by a combination of the external optical field and the polarization fields of surrounding QDs. Using similar Langmuir-Blodgett QD monolayers as a top coating on SOI planarized waveguides, we clearly retrieve the QD absorbance in the waveguide losses. The experimental absorption coefficients due to the QD top layer can be simulated using an approach where the QD layer is replaced by an effective medium with an effective dielectric function determined again by dipolar coupling between neighboring QDs. This approach leaves the host dielectric constant ε_h as the only adjustable parameter and provides a generic scheme to model optical properties of composite materials containing close packed QD films.

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We.D6 (continued)

Z. Hens, A. Omari, P. Geiregat, D. Van Thourhout

16:35 **We.D1.3** Synchronization of the time-domain wavelength interleaved networks
I. Popescu, L. Sadeghioon, A. Gravey, P. Gravey, M. Morvan

16:50 **We.D1.4** Performance enhancement of partial-42.7Gb/s DPSK via an asymmetrical receiver design
N.J. Murray, O.A. Olubodun, P. Harper, N.J. Doran

17:05 **We.D1.5** Performance evaluation of strongly filtered asymmetric 42.7 Gb/s coherent 50% RZ-BPSK system
O.A. Olubodun, N.J. Murray, P. Harper, N.J. Doran

16:30 **We.D2.3** Application of extended Taylor series based finite difference method in photonics (***Invited***)
S. Sujecki

16:50 **We.D2.4** Modelling the bandwidth behaviour of fibre Bragg gratings excited by low-frequency acoustic waves (***Invited***)
A. de Almeida Prado Pohl, R.E. da Silva, M.A. Ruggieri Franco, P. de Tarso Neves Jr., H. Bartelt

16:10 **We.D3.3** High resolution optical spectral filtering technology: Reaching the sub-GHz resolution range (***Invited***)
D.M. Marom, D. Sinefeld, O. Golani, N. Goldshtein, R. Zektzer, R. Rudnick

16:30 **We.D3.4** Almost-optimal design for optical networks with Hadoop cloud computing: Ten ordinary desktops solve 500-node, 1000-link, and 4000-request RWA problem within three hours (***Invited***)
Gangxiang Shen, Yongcheng Li, Limei Peng

16:50 **We.D3.5** Towards 400G/1T flexible optical transport networks (***Invited***)
E. Pincemin, M. Song, Y. Loussouarn, G. Thouenon, C. Betoule

16:20 **We.D4.3** Optimal technicians' allocation problem with respect to failure reparation (***Invited***)
C. Mas Machuca, B. de la Cruz Miranda

16:40 **We.D4.4** Balancing the benefits inherent in reconfigurable coherent optical transceivers (***Invited***)
B.T. Teipen, M.H. Eiselt

17:00 **We.D4.5** Energy saving in access networks: Gain or loss from the cost perspective? (***Invited***)
P. Wiatr, J. Chen, P. Monti, **L. Wosinska**

17:20 **We.D4.6** Dynamic traffic provisioning in mixed-line-rate networks with launch power determination (***Invited***)
H. Cukurtepe, **A. Yayimli**, M. Tornatore, B. Mukherjee

16:50 **We.D5.3** Low-loss and multi-band metamaterials (***Invited***)
C. Sabah

17:10 **We.D5.4** Energy flow canalization of evanescent cylindrical-vector beams (***Invited***)
C.J. Zapata-Rodríguez, J.J. Miret

17:00 **We.D6.3** Light coupling from active polymer layers to hybrid dielectric-plasmonic waveguides (***Invited***)
I. Suárez, E.P. Fitrakis, H. Gordillo, P. Rodríguez-Cantó, R. Abargues, I. Tomkos, J. Martínez-Pastor

17:20 **We.D6.4** Low energy routing platforms for optical interconnects using active plasmonics integrated with silicon photonics (***Invited***)
K. Vyrsokinos, S. Papaioannou, D. Kalavrouziotis, F. Zacharatos, L. Markey, J-C. Weeber, A. Dereux, A. Kumar, S.I. Bozhevolnyi, M. Waldow, G. Giannoulis, D. Apostolopoulos, T. Tekin, H. Avramopoulos, N. Pleros

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Thursday, June 27

SESSION Th.A1
ICTON XII
Chair: ***Jarmila Müllerová***
(8:30 Thursday, June 27)

8:30 **Th.A1.1** The time lens concept applied to ultra-high-speed OTDM signal processing (***Invited***)
A.T. Clausen, E. Palushani, H.C. Hansen Mulvad, H. Hu, J. Laguardia Areal, M. Galili, L.K. Oxenløwe, P. Jeppesen

8:50 **Th.A1.2** Effect of all-optical phase regeneration on fiber transmission capacity (***Invited***)
G. Hesketh, **P. Horak**

9:10 **Th.A1.3** Digitally processed modulation formats and integrated photonics for flexible optical metro-access networks (***Invited***)
J.A. Lázaro, B. Schrenk, M. Malligaraj, I. Cano, M. Sridharan, G. Junyent

SESSION Th.A2
ICTON XVI
Chair: ***Elzbieta Bereś-Pawlik***
(8:30 Thursday, June 27)

8:30 **Th.A2.1** WDM-enabled optical RAM architectures for ultra-fast, low-power optical cache memories (***Invited***)
G.T. Kanellos, T. Alexoudi, D. Fitsios, C. Vagionas, P. Maniotis, S. Papaioannou, A. Miliou, **N. Pleros**

8:50 **Th.A2.2** Optimizing silicon-on-oxide 2D-grating couplers
L. Carroll, D. Gerace, I. Cristiani, L.C. Andreani

9:05 **Th.A2.3** Dynamics of SHB and SDP on 9XX EDFAs: Dependence on spectral allocation of input channels
J.M. Ferreira, D. Fonseca, P. Monteiro, A.N. Pinto, L. Rapp

SESSION Th.A3
NeO III
Chair: ***Walter Cerroni***
(8:30 Thursday, June 27)

8:30 **Th.A3.1** Anycast end-to-end resilience for cloud services over virtual optical networks (***Invited***)
Minh Bui, B. Jaumard, **C. Develder**

8:50 **Th.A3.2** Routing and network design for HEAnet (***Invited***)
D. Mehta, B. O'Sullivan, L. Quesada, M. Ruffini, D. Payne, L. Doyle

9:10 **Th.A3.3** A column generation approach for large-scale RSA-based network planning (***Invited***)
M. Ruiz, M. Żotkiewicz, L. Velasco, J. Comellas

SESSION Th.A4
WAOR II
Chair: ***Pablo Pavón Mariño***
(8:30 Thursday, June 27)

8:30 **Th.A4.1** Performance of ring-resonator based optical backplane in high capacity routers (***Invited***)
G. Rizzelli, D. Siracusa, **G. Maier**, M. Magarini, A. Melloni

8:50 **Th.A4.2** Scalable and energy-efficient optical tree-based greedy router (***Invited***)
S. Sahhaf, A. Dixit, W. Tavernier, **D. Colle**, M. Pickavet, P. Demeester

9:10 **Th.A4.3** An adaptive path restoration algorithm based on power series routing for all-optical networks (***Invited***)
C.J.A. Bastos-Filho, R.C. Freitas, **D.A.R. Chaves**, R.C.L. Silva, M.L.P. Freire, H.A. Pereira, J.F. Martins-Filho

SESSION Th.A5
SWP XII
Chair: ***Sergei Zhukovsky***
(8:30 Thursday, June 27)

8:30 **Th.A5.1** Radial Bragg laser as a miniaturized rotation sensor (***Invited***)
E. Ben-Basat, Y. Karni, **J. Scheuer**

8:50 **Th.A5.2** Simulation of optical Bloch oscillations and breathing modes in the waveguide arrays
M. Gozman, Y. Polishchuk, I. Polishchuk

9:05 **Th.A5.3** Giant circular dichroism in chiral metamaterials
F. Dincer, M. Karaaslan, E. Unal, M. Bakir, U. Erdiven, C. Sabah

SESSION Th.A6
NSON
Chair: ***Marian Marciniak***
(8:30 Thursday, June 27)

8:30 **Th.A6.1** Inverse design of novel nanophotonic structures (***Invited***)
I. Andonegui, A. Blanco, I. Calvo, A.J. Garcia-Adeva

8:50 **Th.A6.2** Nonlinear complex photonic structures (***Invited***)
M. Boguslawski, P. Rose, F. Diebel, S. Brake, C. Denz

9:10 **Th.A6.3** Ways to optimize the second-harmonic response from metamaterials (***Invited***)
R. Czaplicki, H. Husu, M. Zdanowicz, J. Mäkitalo, K. Koskinen, R. Siikanen, J. Laukkanen, J. Lehtolahti,

D1	D2	D3	D4	D5	D6
Tu.D1.3 Spectral and energy efficiency considerations in mixed-line rate WDM networks with signal quality guarantee (*Invited*) *A. Udalcovs, **P. Monti**, V. Bobrovs, R. Schatz, L. Wosinska, G. Ivanovs*	Tu.D2.3 Membrane InP saturable absorbers on silicon as building blocks for transparent optical networks (*Invited*) ***O. Raz**, G. Roelkens, H.J.S. Dorren, M. Tassaert*	Tu.D3.3 Results from the EU project ACCORDANCE on converged OFDMA-PON networks (*Invited*) ***K. Kanonakis**, I. Tomkos, H.-G. Krimmel, F. Schaich, C. Lange, E. Weis, M. Dreschmann, R. Schmogrow, P. Kourtessis, M. Milosavljevic, I. Cano, J. Prat, J.A. Torrijos Gijón*	Tu.D4.3 Storage, schedule and switching – A new data delivery paradigm in the big data era? (*Invited*) ***Weiqiang Sun**, Fengqin Li, Wei Guo, Yaohui Jin, Weisheng Hu*	Tu.D5.3 Inverse scattering problems in subsurface diagnostics of inhomogeneous media (*Invited*) ***K.P. Gaikovich***	Tu.D6.3 Eu-doped polymer fibers (*Invited*) ***R. Caspary**, S. Möhl, A. Cichosch, R. Evert, S. Schütz, H-H. Johannes, W. Kowalsky*
17:00 Tu.D1.4 Energy efficiency analysis of next-generation passive optical network (NG-PON) technologies in a major city network (*Invited*) *S. Lambert, J. Montalvo, J.A. Torrijos, **B. Lannoo**, D. Colle, M. Pickavet*	17:00 Tu.D2.4 Highly efficient channel waveguide lasers at 2 µm (*Invited*) *K. van Dalfsen, S. Aravazhi, C. Grivas, S.M. García-Blanco, **M. Pollnau***	16:40 Tu.D3.4 Passive optical networks based on OFDM: Perspectives and experimental verifications (*Invited*) ***J. von Hoyningen-Huene**, W. Rosenkranz*	17:00 Tu.D4.4 Adaptive coded-modulation for the next-generation intelligent optical transport networks ***Yequn Zhang**, I.B. Djordjevic*	17:00 Tu.D5.4 Why optical nonlinear characterisation using imaging technique is a better choice? (*Invited*) ***G. Boudebs**, V. Besse, C. Cassagne, H. Leblond, F. Sanchez*	
17:20 Tu.D1.5 Adaptive bit loading in FHT-based OFDM transponders for flexi-grid optical networks ***L. Nadal**, M. Svaluto Moreolo, J.M. Fàbrega, G. Junyent*	17:20 Tu.D2.5 Microring resonators: Opportunities and challenges for future optical networks (*Invited*) ***A. Bianco**, M. Garrich, R. Gaudino, Jinan Xia*	17:00 Tu.D3.5 GPON redundancy eraser algorithm for long-reach extension (*Invited*) ***J. Segarra**, V. Sales, J. Prat*	17:20 Tu.D4.5 Traffic demand estimation for hybrid switching systems ***Pingqing Li**, Weiqiang Sun, Shilin Xiao, Weisheng Hu*	17:20 Tu.D5.5 Plasmonic materials and metamaterials by bottom-up approach: Manufacturing and properties (*Invited*) ***D.A. Pawlak**, M. Gajc, P. Osewski, K. Sadecka, A. Stefanski, A. Klos, A. Belardini, G. Leahu, C. Sibilia*	

20:00 ***Gala Dinner at Restaurant "La Cartuja"***

Wednesday, June 26

SESSION We.A1 ICTON VIII Chair: *João Pedro* (9:00 Wednesday, June 26)	SESSION We.A2 PICAW II Chair: *Peter Horak* (9:00 Wednesday, June 26)	SESSION We.A3 Access III Chair: *Ioannis Tomkos* (9:00 Wednesday, June 26)	SESSION We.A4 GOC I Chair: *Lena Wosinska* (9:00 Wednesday, June 26)	SESSION We.A5 SWP VIII Chair: *Brana Jelenković* (9:00 Wednesday, June 26)	SESSION We.A6 ESPC I Chair: *Crina Cojocaru* (9:00 Wednesday, June 26)
9:00 We.A1.1 Creating new generation optical network service (*Invited*) ***N. Yamanaka**, H. Takeshita, S. Okamoto, T. Sato*	9:00 We.A2.1 Optical delay in silicon photonic crystals using ultrafast indirect photonic transitions (*Invited*) ***D.M. Beggs**, I.H. Rey, T. Kampfrath, N. Rotenberg, L. Kuipers, T.F. Krauss*	9:00 We.A3.1 Optical single sideband generation optimized to support multi-services OFDM over hybrid long-reach FTTH networks ***P. Almeida**, H. Silva*	9:00 We.A4.1 Energy-efficient space-time optical interconnection architectures for data centers (*Invited*) ***P. Castoldi**, I. Cerutti, P.G. Raponi, N. Andriolli, O. Liboiron-Ladouceur*	9:00 We.A5.1 Self-pulsing and nonlinear dynamics in micro and nanolasers (*Invited*) ***S. Barbay**, F. Selmi, S. Haddadi, R. Braive, I. Sagnes, R. Kuszelewicz, A.M. Yacomotti*	9:00 We.A6.1 Asymmetric light propagation in photonic devices (*Invited*) ***H. Kurt***
9:20 We.A1.2 Dynamic grooming and spectrum allocation in optical metro ring networks with flexible grid (*Invited*) *F. Musumeci, F. Puleio, **M. Tornatore***	9:20 We.A2.2 Numerical simulation and design of organic integrated optical circuits: The PHOTOPOLIS approach (*Invited*) ***T. Kamalakis**, D. Alexandropoulos, G. Dede, P. Kanakis, T. Politi, N. Vainos*	9:20 We.A3.2 OFDM-PON performance with limited quantization ***X. Escayola**, I. Cano, M. Santos, J. Prat*	9:20 We.A4.2 Enhancing data centre networking using energy aware optical interconnects (*Invited*) ***I. Glesk**, T. Osadola, S. Idris*	9:20 We.A5.2 Effect of shell size on single photon emission performances of core/shell dot-in-rods colloidal nanocrystals (*Invited*) *F. Pisanello, G. Leménager, L. Martiradonna, L. Carbone, A. Bramati, **M. De Vittorio***	9:20 We.A6.2 Controlling the emission from single quantum dots with electro-opto-mechanical photonic crystal cavities (*Invited*) ***L. Midolo**, F. Pagliano, T. B. Hoang, T. Xia, F.W.M. van Otten, A. Fiore, L.H. Li, E.H. Linfield, M. Lermer, S. Höfling*
9:40 We.A1.3 Flexible next-generation optical access (*Invited*) ***M. Forzati**, A. Gavler*	9:40 We.A2.3 A polymer waveguide-based 40 Gb/s optical bus backplane for board-level optical interconnects (*Invited*) ***N. Bamiedakis**, A. Hashim, R.V. Penty, I.H. White*	9:35 We.A3.3 16×2.5 Gbit/s and 5 Gbit/s WDM PON based on self-seeded RSOA ***Sy Dat Le**, Q. Deniel, F. Saliou, A. Lebreton, P. Chanclou*	9:40 We.A4.3 Energy-efficient, high-performance optoelectronic packet switching for intra-data center network (*Invited*) ***Ken-ichi Kitayama**, S. Debnath, Y. Yoshida, R. Takahashi, A. Hiramatsu*	9:40 We.A5.3 Super spontaneous four-wave mixing (*Invited*) ***M. Liscidini**, T. Onodera, L.G. Helt, J.E. Sipe*	9:40 We.A6.3 Active photonic crystal switches: Modeling, design and experimental characterization (*Invited*) ***M. Heuck**, Y. Yu, P.T. Kristensen, N. Kuznetsova, K. Yvind, J. Mørk*
10:00 We.A1.4 Dispersion constraints in optical burst switched metropolitan networks with WDM/OCDM technology ***L.H. Bonani**, A.B. dos Santos, L. Galdino*	10:00 We.A2.4 Robust multi-objective optimization of 2x2 multimode interference coupler using expected improvement ***S. ur Rehman**, M. Langelaar, F. van Keulen*	9:50 We.A3.4 Optimal trade-off for a bidirectional single-fibre single-wavelength TDM-PON rSOA-based ONU ***E.T. López**, V. Polo, J.A. Lázaro, J. Prat*	10:00 We.A4.4 Energy saving in TWDM(A) PONs: Challenges and opportunities (*Invited*) ***L. Valcarenghi**, P. Castoldi, Y. Yoshida, A. Maruta, Ken-ichi Kitayama*	10:00 We.A5.4 Surface enhanced Raman scattering and photo-luminescence through Bloch surface waves in dielectric multilayers (*Invited*) *S. Pirotta, X.G. Xu, A. Delfan, S. Mysore, S. Maiti, G. Dacarro, M. Patrini, G. Guizzetti, D. Bajoni, J.E. Sipe, G.C. Walker, M. Liscidini, **M. Galli***	10:00 We.A6.4 Multiple functionality in III-V on SOI hybrid photonic crystals for systems applications (*Invited*) *F. Raineri, P. Monnier, **R. Raj**, A. Bazin*
10:15 We.A1.5 An efficient add/drop architecture for large-scale subsystem-modular OXC ***H. Ishida**,*		10:05 We.A3.5 Off-set filtering for enhanced transmission in RSOA based WDM-PON ***A. Gatto**, P. Parolari, L. Marazzi, M. Brunero,*	10:20 We.A4.5 A blocking analysis for green WDM networks with transponder power management ***F. Musumeci**, M. Tornatore,*		

Tremblay **(13:50 Tuesday, June 25)**	Pohl **(13:50 Tuesday, June 25)**	**(13:30 Tuesday, June 25)**	Parca **(13:50 Tuesday, June 25)**	Chair: **Rafał Kotyński** **(13:50 Tuesday, June 25)**	Vigreux **(13:30 Tuesday, June 25)**
13:50 Tu.C1.1 Trunk reservation for elastic optical networks (***Invited***) *F. Lezama Cruzvillasante*, ***F. Callegati***, *W. Cerroni*, *L.H. Bonani*	13:50 Tu.C2.1 Are few-mode fibres: A practical solution to the capacity crunch? (***Invited***) ***A. Ellis***, *N. Doran*	13:30 Tu.C3.1 UltraFlow Access Networks: A dual-mode solution for the access bottleneck (***Invited***) ***L.G. Kazovsky***, *A.R. Dhaini, M. De Leenheer, T.S. Shen, Shuang Yin, B.A. Detwiler*	13:50 Tu.C4.1 On the cost efficiency of flexible optical networking compared to conventional SLR/MLR WDM networks (***Invited***) *I. Stiakogiannakis, E. Palkopoulou*, ***I. Tomkos***	13:50 Tu.C5.1 3D optical data storage by nonlinear processes in thin films of coumarin-containing copolymers (***Invited***) ***D. Gindre***, *E. Champigny, K. Iliopoulos, M. Sallé*	13:30 Tu.C6.1 Chalcogenide-silica fibers: A new base for linear and nonlinear nanophotonic devices (***Invited***) ***M.A. Schmidt***
14:10 Tu.C1.2 An elastic networks OMNET++ -based simulator (***Invited***) *A. Asensio, A. Castro, L. Velasco*, ***J. Comellas***	14:10 Tu.C2.2 Ultra-large capacity transmission over trans-oceanic distances with multi-core fibers and EDFAs (***Invited***) ***M. Suzuki***, *H. Takahashi, K. Igarashi, K. Takeshima, T. Tsuritani, I. Morita*	13:50 Tu.C3.2 Towards ultra-dense wavelength-to-the-user: The approach of the COCONUT project (***Invited***) *J. Prat, M. Angelou, C. Kazmierski, R. Pous, M. Presi, A. Rafel, G. Vall-llosera, I. Tomkos*, ***E. Ciaramella***	14:10 Tu.C4.2 Twenty years of open fibre network in Stockholm: A socio-economic study (***Invited***) ***M. Forzati***, *C. Mattsson*	14:10 Tu.C5.2 Self-assembly of nanostructures by a phase separation in holographic layers of dichromated polysaccharide (***Invited***) *S. Savić-Šević, D. Pantelić, B. Jokić*, ***B. Jelenković***	13:50 Tu.C6.2 Chalcogenide glass fibers for photonic devices (***Invited***) ***J.L. Adam***, *L. Brilland, P. Toupin, V. Nazabal, J. Troles*
14:30 Tu.C1.3 Optimization algorithms for data center location problem in elastic optical networks (***Invited***) ***M. Klinkowski***, *K. Walkowiak, R. Goścień*	14:30 Tu.C2.3 On the dependence of differential mode delay of few-mode fibers with the number of modes (***Invited***) *F. Ferreira*, ***D. Fonseca***, *H. Silva*	14:10 Tu.C3.3 High-speed coherent WDM PON for next-generation access network (***Invited***) ***Y.C. Chung***	14:30 Tu.C4.3 Total cost of ownership comparison between single and mixed line rates networks (***Invited***) ***A.N. Pinto***, *R.M. Morais, J. Pedro, P. Monteiro*	14:30 Tu.C5.3 Fluorescent nanoparticles for biosensing applications (***Invited***) ***S. Tomljenovic-Hanic***, *B.C. Gibson, T.J. Karle, A. Khalid, K. Chung, D.A. Simpson, P. Tran, P. Domachuk, H. Tao, J.E. Moreau, D.L. Kaplan, F.G. Omenetto, H. Amekura, A.B. Djurisic*	14:10 Tu.C6.3 Third-order non-linear optical response in chalcogenide glasses: Measurement and evaluation (***Invited***) ***E. Romanova***, *K. Chumakov, A. Mouskeftaras, S. Guizard, N. Abdel-Moneim, D. Furniss, A.B. Seddon, T.M. Benson*
14:50 Tu.C1.4 Spectrum-sliced elastic optical networking (***Invited***) ***H. Waldman***, *R.C. Almeida Jr., K.D. Assis, R.C. Bortoletto*	14:50 Tu.C2.4 Generating versatile waveforms using single dual-drive modulator (***Invited***) *B. Dai, S. Shimizu*, ***Xu Wang***, *N. Wada*	14:30 Tu.C3.4 Ultra high capacity PON systems (***Invited***) ***A. Teixeira***, *G. Parca, A. Shahpari, J. Reis, R. Ferreira, A. Abdalla, M. Lima, V. Carrozzo, G. Tosi-Beleffi*	14:50 Tu.C4.4 The cost dependence between the grooming scheme, the node architecture and the traffic pattern in optical networks (***Invited***) ***R.M. Morais***, *J. Pedro, P. Monteiro, A.N. Pinto*	14:50 Tu.C5.4 Investigations at nanoscale by using fluorescence in apertureless scanning near field microscopy (***Invited***) ***G.A. Stanciu***, *D.E. Tranca, R. Hristu, C. Stoichita, S.G. Stanciu*	14:30 Tu.C6.4 Nd^{3+} doped phosphate glass optical fibre lasers (***Invited***) ***N.G. Boetti***, *J. Lousteau, E. Mura, G.C. Scarpignato, D. Milanese*
15:10 Tu.C1.5 Flexible-sense optical transmission (***Invited***) *V. Rozental, G. Bruno, A. Soso, M. Camera*, ***D.A.A. Mello***	15:10 Tu.C2.5 Robustness to mechanical perturbations of centre-launching technique in multi-mode fibres for transparent optical interconnects ***A. Boletti***, *P. Boffi, A. Gatto, P. Martelli, E. Centeno Nieves, M. Martinelli*	14:50 Tu.C3.5 COCONUT requirements for residential, business and outdoor scenarios ***G. Vall-llosera***, *A. Rafel, E. Ciaramella, J. Prat*	15:10 Tu.C4.5 Performance comparison of optical channel formats to realize 400G data rates in transport networks under dynamic traffic (***Invited***) ***J. Pedro***, *A. Eira, J. Pires*	15:10 Tu.C5.5 Detecting cancerous tissues in human body by means of fiber fluorescent spectroscopy (***Invited***) ***E. Bereś-Pawlik***, *H. Sławska, Ł. Klonowski*	14:50 Tu.C6.5 Design of rare-earth doped microspheres lasers (***Invited***) *P. Bia, L. Mescia, O. Losito, M. De Sario, D. Ristic, M. Ferrari, G.C. Righini*, ***F. Prudenzano***
Coffee break (15:30 – 16:00)	**Coffee break** (15:30 – 16:00)	**Coffee break** (15:05 – 15:40)	**Coffee break** (15:30 – 16:00)	**Coffee break** (15:30 – 16:00)	**Coffee break** (15:10 – 15:40)
SESSION Tu.D1 **ICTON VII** Chair: **Burak Kantarci** **(16:00 Tuesday, June 25)**	**SESSION Tu.D2** **PICAW I** Chair: **Lech Wosinski** **(16:00 Tuesday, June 25)**	**SESSION Tu.D3** **Access II** Chair: **Leonid Kazovsky** **(15:40 Tuesday, June 25)**	**SESSION Tu.D4** **ISOND** Chair: **Milorad Cvijetic** **(16:00 Tuesday, June 25)**	**SESSION Tu.D5** **SWP VII** Chair: **Pavel Cheben** **(16:00 Tuesday, June 25)**	**SESSION Tu.D6** **Glasses II** Chair: **Sławomir Sujecki** **(15:40 Tuesday, June 25)**
16:00 Tu.D1.1 Dynamic deployment of virtual GMPLS-controlled elastic optical networks using a virtual network resource broker on the ADRENALINE testbed (***Invited***) ***R. Vilalta***, *R. Muñoz, R. Casellas, R. Martínez*	16:00 Tu.D2.1 Photonic components for signal routing in optical networks on chip (***Invited***) *G. Calò*, ***V. Petruzzelli***	15:40 Tu.D3.1 A study of flexible bandwidth allocation in statistical OFDM-based PON (***Invited***) ***I.N. Cano***, *X. Escayola, A. Peralta, V. Polo, M.C. Santos, J. Prat*	16:00 Tu.D4.1 An evolutionary spectrum assignment algorithm for elastic optical networks (***Invited***) ***R.C. Almeida Jr.***, *R.A. Delgado, C.J.A. Bastos-Filho, D.A.R. Chaves, H.A. Pereira, J.F. Martins-Filho*	16:00 Tu.D5.1 High resolution Fourier-transform microspectroscopy based on spiral silicon waveguides (***Invited***) *A.V. Velasco*, ***M.L. Calvo***, *P. Cheben, M. Florjańczyk, P.J. Bock, A. Delâge, J.H. Schmid, J. Lapointe, S. Janz, Dan-Xia Xu, M. Vachon*	15:40 Tu.D6.1 Te-Ge-Se thermally co-evaporated films: Elaboration, characterization and use for the manufacture of IR rib waveguides, basic elements of CO_2 microsensors (***Invited***) ***C. Vigreux***, *M. Vu Thi, G. Maulion, R. Kribich, A. Pradel*
16:20 Tu.D1.2 Dynamic management of bursty traffic over multiple channels (***Invited***) ***A.K. Somani***	16:20 Tu.D2.2 Silicon CMOS photonics platform for enabling high-speed DQPSK transceivers (***Invited***) ***P. Sanchis***, *M. Aamer, A. Brimont, A.M. Gutierrez, N. Sotiropoulos, H. de Waardt, D.J. Thomson, F.Y. Gardes, G.T. Reed, K. Ribaud, P. Grosse, J.M. Hartmann, J-M. Fedeli, D. Marris-Morini, E. Cassan, L. Vivien, D. Vermeulen, G. Roelkens, A. Hakansson*	16:00 Tu.D3.2 Dynamic bandwidth allocation with optimal wavelength switching in TWDM-PONs (***Invited***) ***A. Dixit***, *B. Lannoo, D. Colle, M. Pickavet, P. Demeester*	16:20 Tu.D4.2 Flow controlled scalable optical packet switch for low latency flat data center network (***Invited***) ***N. Calabretta***, *S. Di Lucente, Jun Luo, A. Rohit, K. Williams, H. Dorren*	16:20 Tu.D5.2 Optical Haar transform for 2D processing and compression (***Invited***) ***G. Parca***, *P. Teixeira, C. Vicente, A. Teixeira*	16:00 Tu.D6.2 Active waveguides for Mid-IR (3–4 µm) wavelengths fabricated by femtosecond laser inscription in Dy^{3+} doped tellurite glass (***Invited***) ***T.T. Fernandez***, *B.D.O. Richards, G. Jose, A. Jha, J. Hoyo, A. Ruiz De la Cruz, J. Solis*
16:40	16:40	16:20	16:40	16:40	16:20