

ESF Exploratory Workshop on

Polaritonics: from basic research to device  
applications

Rome (Italy), 20-23 March 2012

Convened by:

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Cosponsored by:

**Mediterranean Institute of Fundamental Physics**

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**SCIENTIFIC REPORT**

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## 1. Executive summary (approx. 2 pages)

The international workshop “Polaritonics: from basic research to device applications” took place in Marino (a picturesque suburb of Rome) from 20 to 23 of March 2012. It has been attended by 21 researchers from 7 countries. All the participants have been lodged in the comfortable Helio Cabala hotel having a magnificent view on Rome. This hotel, which has been frequently used for cinema events in the époque of 1960s-1970s, offers a plenty of space and excellent surroundings for the scientific discussions. In addition to two large conference halls it possesses a large open area for coffee-breaks bordered by a beautiful terrace-garden. The participants had lunches, dinners and welcome party at the restaurant of the hotel, which offers delicious local food and wine.

The relaxing atmosphere of Helio Cabala and beautiful spring weather greatly helped the overall success of this international event.

The motivation of this workshop came from the recent intensive studies of the strong – light matter coupling in semiconductor quantum microcavities which have allowed to observe many fascinating fundamental effects (polariton lasing, polariton bistability and multistability, polariton superfluidity). Fundamental knowledge obtained allowed to formulate a new concept of polariton based coherent light sources, all-optical information processing systems, and THz sources and detectors. The workshop helped bringing together researchers working in the area of polaritonics and neighbouring areas in order to discuss recent progress and construct a roadmap for the development of new concepts of polaritonic devices and its commercialisation.

The specific scientific objectives of this workshop are:

- Achieve an agreement on interpretation of the recent data on polariton superfluidity;
- Formulate the concept of a terahertz laser based on exciton-polaritons;
- Analyse the perspectives for realisation of polariton spin devices.

These objectives have been largely achieved during the multiple round-tables and brainstorming sessions organised during the workshop. In particular, the participants agreed that the recent experiments on superfluid propagation of polaritons do not prove a phase transition. It has been concluded that vertical cavity surface emitting terahertz lasers may be built on the basis of polariton lasers and that the most efficient way of realisation of polariton spin devices is via exploiting the polarisation multistability.

One of the round-table discussions has been devoted to the question of nomination of solid state physicists to the Nobel prize. The most likely candidatures from the experts on excitons have been discussed.

The overall atmosphere of the meeting was very creative. Each presentation has been followed by an animated discussion. Coffee breaks and lunches have been arenas of tens of informal meetings, and plans for several new joint works have been made.

## 2. Scientific content of the event

The scientific programme was presented by a wide range of important and interesting presentations along with the following discussions on the results presented in the talks.

Most of the presentations you can find and download from the ESF Workshop site here <http://www.mifp.eu/ESF/program.htm>

Below we would like to give some ideas and general overviews of most important talks at the workshop.

Dr. Timothy Liew in his talk "Multimode entanglement in semiconductor microcavities" proposed a new theoretical scheme for the generation of quantum entanglement, using coupled polariton boxes. Through full density matrix calculations and quantum Monte Carlo calculations, it was predicted that both bipartite and quadripartite continuous variable entanglement could be realized. Due to quantum interference, the scheme works even in the regime of weak nonlinearity, which is realized in a range of existing semiconductor systems including coupled micropillars and photonic crystal arrays.

Dr. Paola Gori's talk "Electronic and optical properties of graphene-and graphane-like SiC layers" was about the ab-initio calculated electronic and optical properties of graphene- and graphane-like SiC-based 2D sheets are presented. Hydrogenated 2D SiC shows a peculiar side-dependent electron affinity. Both 2D SiC and SiC:H have strongly bound excitons and could result promising for applications in polaritonics.

Mr. Sergey Andreev in his presentation "Thermodynamic model of the macroscopically ordered exciton state" was talking about thermodynamic model of the external photoluminescence ring fragmentation based on the fundamental principles of BEC (long-range order and symmetry-breaking). He introduced a novel concept of the macrospin associated with any particular bead in the ring and showed that the instability occurring during the phase transition into the low-temperature coherent state is due to the rushing of the system to increase its entropy. In this way, taking into account the nearest neighbors spin-spin interaction, it is possible to calculate the dependence of the number of the beads and its sizes on the ring radius, and it turned out to be in a good agreement with experiment.

Prof. Pavlos Savvidis gave a talk "Manipulating polariton condensates on a chip". In this presentation they explore the possibility of manipulation of two-dimensional polariton condensates on a semiconductor microcavity chip using optically imprinted external potential. The control is achieved on the fly by optically injecting polaritons onto the chip with specific spatial profile to create potential energy landscape in which condensate propagates. A prototype polariton condensate transistor switch is demonstrated.

Prof. Olivia Pulci in her presentation "Universal infrared absorbance in graphene, silicene and germanene" said that using the complex dielectric function for optical interband transitions, they have shown the universal result that the low-frequency absorbance in undoped graphene, silicene, and germanene is only determined by the Sommerfeld finestructure constant. The result was derived by means of ab-initio electronic-structure calculations for two-dimensional (2D) crystals with honeycomb geometry without assuming chiral massless Dirac fermions. It does not depend on the group-IV atom, the sheet buckling, the orbital hybridization, and the gauge used to calculate the optical oscillator strength. An explanation was given by an analytical derivation of the relationship between absorbance and finestructure constant for 2D Bloch electrons.

Dr. Mikhail Glazov gave a talk "Spin noise in quantum microcavities". A theory of spin fluctuations of exciton-polaritons is developed. It is demonstrated, that the condensation results in the strong narrowing of the spin noise power spectrum. The effect of interactions is analyzed.

Dr. Natalia Berloff gave a presentation "Pattern formation in polariton condensates". In her talk she reviewed a number of universal equations which describe various regimes of the dynamics of exciton-polariton condensates: the Gross-Pitaevskii equation, which models weakly interacting equilibrium condensates, the complex Ginsburg-Landau equation - the universal equation that describes the behaviour of systems in the vicinity of a symmetry--breaking instability, and the complex Swift-Hohenberg equation that in comparison with the complex Ginsburg-Landau equation contains additional nonlocal terms responsible for spacial mode selection. All these equations can be derived asymptotically from a generic laser model given by Maxwell-Bloch equations. Such an universal framework allows the unified treatment of various systems and continuously cross from one system to another. We discussed the relevance of these equations, and their consequences for pattern formation.

Dr. Gabriela Slavcheva had a presentation "Model of the time-resolved photoluminescence from resonantly excited p-doped InAs/GaAs QDs: Towards realistic modelling of a dot-cavity system was talking about". A dynamical model of the experimentally detected time-resolved polarised photoluminescence (TRPL) following resonant pulsed excitation into excited positive trion ( $X^+$ ) states is developed. The model takes into account all possible spin relaxation channels and decoherence processes, yielding the time-evolution of the spin population of the ground trion state, compared with the experimentally detected polarised PL. The spin relaxation times of the respective relaxation channels are extracted by comparison with the TRPL data. The model explains the increased circular dichroism observed in the excited state emission from QD ensembles compared to the ground state. This spin-filter effect is promising for realisation of high-fidelity schemes of all-optical spin manipulation.

Prof. Rafael Butte gave a presentation "Present status of polaritonic nonlinearities in planar III-nitride microcavities". In this talk, he said, we focus on specific properties of polariton condensates in GaN/AlGaIn multiple QW microcavities (MCs) up to temperatures otherwise inaccessible to more conventional semiconductor compounds such as GaAs or CdTe. Depending on the accessible exciton-cavity photon detuning  $d$  and the temperature (ranging from -120 to 0 meV and 4 to 340 K, respectively), the phase diagram of polariton condensation exhibits an optimum threshold corresponding to the transition from a kinetically to a thermodynamically driven condensation threshold. Thermal detrapping from the condensate is found to play a supplementary role among the processes governing polariton condensation at high temperatures. The role played by biexcitons in the relaxation kinetics as well the impact of oscillator strength saturation on renormalization of the polariton branches are also highlighted.

Mrs Nina Voronova gave a presentation "On vortices and solitons formation in polariton Bose condensate". Equilibrium polariton Bose condensate is considered as a two-component condensate of photons and excitons with mutual transformation. A set of two Gross-Pitaevskii-like equations with sources was introduced, and it allows to show that vortices and solitons created in the condensate components can have essentially different healing lengths, with the ratio up to two orders of magnitude, depending on the chemical potential of the polariton condensate.

Dr. Marzena Szymanska in her talk "Spatial correlation functions and topological defects in polariton condensates" has discussed that the Berezinskii-Kosterlitz-Thouless (BKT)- like phase order i.e. the power law decay of spatial correlations is not an artifact of equilibrium two-dimensional condensates, but survives more generally in a non-equilibrium context. Experimental observation of the larger value of the coefficient of that power-law that is possible in equilibrium indicates that BKT-like ordered phase is in fact more robust against noise than in equilibrium. I have also discussed the behaviour of topological defects such as vortex-antivortex pairs in these non-equilibrium superfluids focusing mainly on the OPO regime.

Dr. Paola Gori gave a presentation “Electronic and optical properties of graphene- and graphane-like SiC layers”. The ab-initio calculated electronic and optical properties of graphene and graphane-like SiC-based 2D sheets were presented. Hydrogenated 2D SiC shows a peculiar side-dependent electron affinity. Both 2D SiC and SiC:H have strongly bound excitons and could result promising for applications in polaritonics.

### **3. Assessment of the results, contribution to the future direction of the field, outcome**

The meeting helped building up a scientific community of theorists and experimentalists studying exciton-polaritons in semiconductor microcavities. The recent discoveries in polaritonics have opened very wide horizons both in the area of fundamental studies and in the field of practical applications. A very new emerging research area of terahertz polaritonics seems to be the most promising. The community met with a great enthusiasm the news of a grant for organisation of the International Conference on Polariton Terahertz Devices given by ESF to the present convenor. This conference will take place in Austria in June 2013. Many participants of the workshop in Rome are willing to take part in the conference in Austria. Further follow-up actions would be writing the new Marie-Curie network proposal “CLERMONT5” which would follow three previous “CLERMONT” network projects coordinated by the present convenor. The work on this new proposal has already started. Another attempt to attract funding to the research in Polaritonics will be through the individual ERC projects. One of the speakers of this workshop, Dr. Daniele Sanvitto, has been just recently awarded by the ERC Starting grant. The materials of the ESF workshop in Rome will be presented at the site of the Mediterranean Institute of Fundamental Physics, which unites some of the speakers of this workshop. An overall assessment of the workshop by all its participants is very positive.

### **4. Final programme – please, see Appendix I to the report.**

### **5. Final list of participants**

Below is the final list of people with their affiliations and countries they presented at the workshop:

- **Alexey Kavokin (Convener)** - University of Southampton, UK
- **Alberto Amo** - LPN-CNRS, France
- **Raphaël Butté** - EPFL, Switzerland
- **Marzena Szymanska** - University of Warwick, UK
- **Ivan Shelykh** - Nanyang Technological University, Singapore; University of Iceland
- **Pavlos Savvidis** - University of Crete, Greece
- **Marlene Glauser** - EPFL, Switzerland
- **Natalia Berloff** - University of Cambridge, UK
- **Olivia Pulci** - University of Rome Tor Vergata, Italy
- **Gabriela Slavcheva** - Imperial College London, UK
- **Alberto Bramati** - UPMC, France
- **Nina Voronova** - MEPhI, Moscow, Russia
- **Tim Liew** - EPFL, Switzerland

- **Guilherme Tosi** - University of Cambridge, UK
- **Paola Gori** - CNR, Italy
- **Sergey Andreev** - CNRS, France
- **Aldo Di Carlo** - University of Rome Tor Vergata, Italy
- **Mikhail Glazov** - Ioffe Institute, S-Petersburg, Russia
- **Laura Pilozzi** - CNR, Italy
- **Fabio Liaci** - Ioffe Institute, S-Petersburg, Russia
- **Daniele Sanvitto** - Istituto Nanoscienza CNR, Italy

You can find and download the presentations of most participants at the site of the Workshop here - <http://www.mifp.eu/ESF/program.htm>

## 6. Statistical information on participants

As you can see from the final list of the participants at the Workshop on Polaritonics a wide range of countries and ages was presented. There were 21 scientists from 7 countries, about 30 percent was young scientists not older than 30 years old, the average age was 37 years old. 38 percent was female participants and 62 percent was male accordingly.

We also have to mention that the rapporteur was Dr. Ana Helman from France (she was not counted in the main list above)

The repartition of countries of origin is presented in the table below.

Total	21	percentage
UK	5	24%
Italy	5	24%
France	3	14%
Switzerland	3	14%
Russia	3	14%
Greece	1	5%
Iceland	1	5%

## FINAL PROGRAMME

### Tuesday 20 March 2012

Afternoon

Arrival

19.00

*Get-together - Buffet welcoming reception, Grand Hotel Helio Cabala*

### Wednesday 21 March 2012

- |                    |  |
|--------------------|--|
| 09.00-09.20        | <b>Welcome by Convenor</b><br><b>Alexey Kavokin</b> (University of Southampton, UK)  |
| 09.20-09.40        | <b>Presentation of the European Science Foundation (ESF)</b><br><b>Ana Helman</b> (ESF Standing Committee for Physical and Engineering Sciences - PESC)                |
| <b>09.40-12.40</b> | <b>Morning Session</b>   |
| 09.40-10.10        | <b>"Polariton condensates in optical traps"</b><br><b>Alberto Amo</b> (LPN-CNRS, Marcoussis, France)   |
| 10.10-10.40        | <b>"Present status of polaritonic nonlinearities in planar III-nitride microcavities"</b><br><b>Rafael Butte</b> (EPFL, Lausanne, Switzerland)                         |
| 10.40-11.00        | <i>Coffee Break</i>  |
| 11.00-11.30        | <b>"Polaritonic crystals: from optical response to Casimir effect"</b><br><b>Laura Pilozzi</b> (CNR, Italy, Rome)  |
| 11.30-12.00        | <b>"Spatial correlation functions and topological defects in polariton condensates."</b><br><b>Marzena Szymanska</b> (University of Warwick, Coventry, United Kingdom) |
| 12.00-12.40        | <b>Discussion.</b>   |
| 12.40-14.00        | <i>Lunch</i>   |
| <b>14.00-18.00</b> | <b>Afternoon Session</b>   |
| 14.00-14.30        | <b>"Polariton-electron mixtures"</b><br><b>Ivan Shelykh</b> (Nanyang Technological University, Singapore; University of Iceland, Reykjavik, Iceland)                   |
| 14.30-15.00        | <b>"Manipulating polariton condensates on a chip"</b><br><b>Pavlos Savvidis</b> (University of Crete, Heraklion, Greece)   |
| 15.00-15.30        | <b>"Toward InGaN/GaN quantum well based polariton laser diodes: experimental and theoretical status"</b><br><b>Marlene Glauser</b> (EPFL, Lausanne, Switzerland)       |
| 15.30-16.00        | <i>Coffee / tea break</i>  |
| 16.00-16.30        | <b>"Universality class of polariton condensates"</b><br><b>Natalia Berloff</b> (University of Cambridge, United Kingdom)   |
| 16.30-18.00        | <b>Discussion Workshop</b>   |
| 19.30              | <i>Dinner</i>  |

## Thursday 22 March 2012

<b>09.00-12.40</b>	<b>Morning Session</b>
09.00-09.30	<b>"Universal infrared absorbance in graphene, silicene and germanene"</b> <b>Olivia Pulci</b> (University of Rome Tor Vergata, Rome, Italy)
09.30-10.00	<b>"Model of the time-resolved polarised photoluminescence from resonantly excited p-doped InAs/GaAs quantum dots: Towards realistic modelling of a dot-cavity system"</b> <b>Gabriela Slavcheva</b> (Imperial College London, United Kingdom)
10.00-10.30	<b>"Microcavity polaritons: quantum fluid phenomena and optoelectronic applications"</b> <b>Alberto Bramati</b> (UPMC, Paris, France)
10.30-11.00	<i>Coffee / Tea Break</i>
11.00-11.30	<b>"Vortices and solitons formation in polariton Bose condensate"</b> <b>Nina Voronova</b> (National Research Nuclear University MEPhI, Moscow, Russia)
11.30-12.00	<b>"Spin noise in quantum microcavities"</b> <b>Mikhail Glazov</b> (Ioffe Institute, Saint-Petersburg, Russia)
12.00-12.40	<b>Discussion</b>
12.40-14.00	<i>Lunch</i>
<b>14.00-18.30</b>	<b>Afternoon Session:</b>
14.00-14.30	<b>"Entanglement with Quantum Boxes"</b> <b>Tim Liew</b> (EPFL, Lausanne, Switzerland)
4.30-15.00	<b>"Spontaneous harmonic oscillations and vortex lattices in polariton condensates"</b> <b>Guilherme Tosi</b> (University of Cambridge, United Kingdom; University of Madrid, Spain)
15.00-15.30	<b>"Electronic and optical properties of graphene- and graphane-like SiC layers"</b> <b>Paola Gori</b> (CNR, Italy, Rome)
15.30-16.00	<i>Coffee / tea break</i>
16.00-16.30	<b>"The thermodynamic model of the macroscopically ordered exciton state"</b> <b>Sergey Andreev</b> (CNRS, University of Montpellier, France)
16.30-18.30	<b>discussion on follow-up activities. setting the main goals of the polaritonic devices implementation</b>
19.30	Social dinner, Dancing hall

## Friday 23 March 2012

<b>09.00-12.40</b>	<b>Morning Session</b>
09.00-09.30	<b>"Simulation of electrically driven polariton lasers"</b> <b>Aldo Di Carlo</b> (University of Rome Tor Vergata, Rome, Italy)
09.30-10.00	<b>"Electron Spin and Exciton Emission Polarization in Heterovalent Coupled Quantum Wells III-V/II-(Mn)-VI Structures"</b> <b>Fabio Liaci</b> (Ioffe Institute, Saint-Petersburg, Russia)
10.00-10.30	<b>"Polariton transistor: towards all-optical logics"</b> <b>Daniele Sanvitto</b> (CNR, Lecce, Italy)



10.30-11.00	<i>Coffee / Tea Break</i>
11.00-11.30	<b>"Vertical Cavity Surface Emitting Terahertz Lasers"</b> <b>Alexey Kavokin</b> (University of Southampton, United Kingdom)
11.30-13.00	<b>Collaborative work, development of new concepts of polaritonic devices</b>
13.00-14.00	<i>Lunch</i>
14.30	<i>End of Workshop and departure</i>