RESUME FOR EXPERT REGISTRY

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I am an experimental physicist who is interested in the control and manipulation of light-matter interaction in low-dimensional systems. During my research in doctoral and post-doctoral stages, I have developed and demonstrated a unique optoelectronic system, in which the light-matter coupling has reached an unprecedented regime called the ultrastrong coupling regime. Accessing the ultra-strong coupling regime offers a new key ingredient for the applications in solid-state quantum information processing. This ground-breaking result was published in Nature, one of the highest impact factor journals in science. I have gained adequate hands-on experience in semiconductor nanofabrication techniques, for about seven years. My experimental competence includes time-integrated as well as time-resolved measurements using femtosecond laser systems. On the simulation part, I have vast expertise in carrying out the design and implementation of semiconductor heterostructures meant for optoelectronic applications. In addition to my expertise in semiconductor optics, I have worked and published few articles in the field of ceramic-metal nanocomposites as well as silica aerogels. I have been an independent researcher in the NEST (National Enterprise for nanoScience and nanoTechnology) laboratory of Scuola Normale Superiore (Italy) from January '07 to June '08, and later got an Alexander von Humboldt (AvH Fellowship) for carrying out independent research in University of Konstanz (Germany), from October '08 to October '10. I have been a referee of American Physics Society Journals such as Phys. Rev. Lett, Phys. Rev. A and Phys. Rev. B; have refereed more than 20 articles, so far.

Currently my research is focused on the optoelectronics (linear and non-linear optics) of graphene and graphene-composites; fluorescent carbon nanoparticles; solar thermal fuels based on carbon nanoparticles and light-activated molecular machines.

Current research interests

- Optoelectronics of nanocarbon (quantum dots, carbon nanotubes and graphene)
- Solar thermal fuels based on carbon nanoparticles
- Coherent Perfect Absorbers (*"time-reversed"* lasers)
- Light-matter interaction in low-dimensional systems (semiconductor quantum wells, quantum dots, nanometals) embedded in optical resonators

Educational Profile

- Doctor of Philosophy (Ph.D.) in Physics, Scuola Normale Superiore, Italy
- Master of Philosophy (M.Phil.) in Physics, University of Kerala, India
- Bachelor of Education (B.Ed) in Physics, University of Kerala, India
- Master of Science (M.Sc.) in Physics, University of Kerala, India
- Bachelor of Science (B.Sc.) in Physics, University of Kerala, India

Research Accomplishments

- Experimental implementation of sub-cycle switch-on of ultra-strong light-matter coupling and the demonstration of world's fastest optical switch ever **(Nature 458, 178, 2009, Nature-News & Views, 458, 157, 2009 and also Editors summary 458, 119, 2009)**
- First experimental demonstration of ultra-strong coupling of light-matter interaction in a solid-state semiconductor system at room-temperature (Phys. Rev. B 79, 201303[**R**], 2009)
- Experimental implementation of room-temperature external control of light-matter interaction using depletion gate bias (Appl. Phys. Lett., 87, 051105, 2005)
- Design and implementation of intersubband microcavity based on surface-plasmon waveguide (Appl. Phys. Lett., 87, 051105, 2005)

Honours and Fellowships

- Alexander von Humboldt (AvH) Fellowship
- Assegni di ricerca (funding for carrying out independent research) from Scuola Normale Superiore, Italy
- Doctoral position in Scuola Normale Superiore (winner of a public international competition with first position)
- **Others:** Reviewer of American Physical Society Journals (Phys. Rev. Lett., Phys. Rev. A, Phys. Rev. B), and American Institute of Physics Journals (Appl. Phys. Lett.)

Skills

- **Semiconductor nanofabrication process and implementation:** Lithography (uv and e-beam), chemical dry-etching techniques (ICP, RIE), Scanning Electron Microscopy (SEM); metal thin-film deposition (thermal as well as electron-gun deposition) and wire bonding of nanofabricated samples. Experience in the nano-fabrication of GaAs/AlGaAs, and InAs/AlSb based semiconductor heterostructures
- **Optical and electrical characterization:** Room temperature and low-temperature linear optical reponse measurements of intersubband resonators using Fourier transform infrared spectroscopy (FTIR). Electrical characterization of nanofabricated intersubband devices.
- **Electrochemical impedence spectroscopy:** Non-destructive electrical characterization of nanocomposites. Experience in alumina-silver nanocomposities, sol-gel derived low-dielectric constant silica aerogels.
- **Numerical simulation:** Design of intersubband microcavities employing optical transfer-matrix formalism. Simulation of band profile of semiconductor heterostructures using Schodinger-Poisson solver. Modelling of equivalent electrical circuits of nanocomposites as well as intrinsic aerogel samples.

Professional Experience

- **Assistant Professor:** Nov '10 – present, Department of Physics, National Institute of Technology, Calicut, Kerala, India.
- **Alexander von Humboldt Fellow:** Oct '08 – Oct '10, Department of Physics and Applied Photonics, University of Konstanz, Germany.
- **Independent Researcher:** Jan '07- June '08: National Enterprise for nanoScience and nanoTechnology (NEST CNR-INFM) center of Scuola Normale Superiore (SNS), Pisa (Italy). Financially supported by SNS under the scheme Assegni di ricerca 2008.

Scientific Output

Book Chapter:

- A. A. Anappara, L. Sorba, A. Tredicucci, G. Günter, A. Sell, A. Leitenstorfer, R. Huber, S. De Liberato, C. Ciuti, G. Biasiol, ***Future Trends in Microelectronics: from nanophotonics to sensors and energy***, Wiley-IEEE Press, ISBN=978-0-4 (2010)

International Journals:

- R. Huber, **A. A. Anappara**, G. Günter. A. Sell, S. De Liberato, C. Ciuti, G. Biasiol, L. Sorba, A. Tredicucci, A. Leitenstorfer, *Switching ultrastrong light–matter coupling on a subcycle scale*, J. Appl. Phys. 109, 102418 (2011)
- A. Sell, **A. A. Anappara**, T. Kampfrath, K. von Volkmann, M. Wolf, J. T. Steiner, M. Kira, G. Biasiol, L. Sorba, A. Tredicucci, A. Leitenstorfer, R. Huber, *Extreme THz nonlinearities in bulk and nanostructured semiconductors*, Ultrafast Phenomena in Semiconductors and Nanostructure Materials XIV, Proc. SPIE, Vol. 7600, 76001S (2010)
- **A. A. Anappara**, G. Günter, J. Hees, G. Biasiol, L. Sorba, A. Tredicucci,, A. Leitenstorfer, R. Huber, *Switch-on of ultrastrong light-matter interaction faster than a cycle of light*, Conference on Lasers and Electro-Optics/International Quantum Electronics Conference, Optical Society of America, Optics Infobase (2010)
- **A. A. Anappara**, S. De. Liberato, A. Tredicucci, C. Ciuti, G. Biasiol, L. Sorba, F. Beltram, *Signatures of the ultrastrong light-matter coupling*, Phys. Rev. B (Rapid communication), 79, 201303 (2009)
- G. Günter, **A. A. Anappara**, J. Hees, A. Sell, G. Biasiol, L. Sorba, S. De Liberato, C. Ciuti, A. Tredicucci, A. Leitenstorfer, R. Huber Sub-cycle switch-on of ultrastrong light-matter interaction, **Nature**, 458, 178 (2009)
- R Huber, **A. A. Anappara**, G. Günter, A. Sell, G. Biasiol, L. Sorba, A. Tredicucci, S. De Liberato, C. Ciuti, A. Leitenstorfer, *How fast electrons and photons mix: sub-cycle switching of intersubband cavity polaritons*, Electron Dynamics in Semiconductors, Optoelectronics and Nanostructures (Edision 16), J. Phys.: Conf. Ser., 193, 012060 (2009)
- S. D George, **A. A. Anappara**, K. G. K. Warrier, P. R. S. Warrier, P. Radhakrishnan, V. P. N. Nampoori, C. P. G. Vallabhan, *Photoacoustic thermal characterization of* $Al_2O_3 - Ag$ *ceramic nanocomposites*, Materials Chemistry and Physics, 111 (1), 38 (2008)
- **A. A. Anappara**, A. Tredicucci, F. Beltram, G. Biasiol, L. Sorba, *Tailoring light-matter interaction in intersubband microcavities*, Physica E, 40 (6), 1906 (2008)
- **A. A. Anappara**, A. Tredicucci, F. Beltram, G. Biasiol, L. Sorba, S. De Liberato, C. Ciuti, *Cavity polaritons from excited-subband transitions*, Appl. Phys. Lett., 91, 231118 (2007)
- **A. A. Anappara**, D. Barate, A. Tredicucci, J. Devenson, R. Teissier, A. Baranov, *Giant intersubband polariton splitting in InAs/AlSb microcavities*, Solid State Communications, 142 (6), 311 (2007)
- **A. A. Anappara**, A.Tredicucci, F. Beltram, G. Biasiol, L. Sorba, *Controlling polariton coupling in intersubband microcavities*, Superlattices and Microstructures, 41, 308 (2007)
- **A. A. Anappara**, D Barate, A Tredicucci, G Biasiol, L Sorba, J Devenson, R Teissier, A Baranov, *Controlling polariton coupling in intersubband microcavities*, AIP Conf. Proc., 893, 523 (2007)
- **A. A. Anappara**, A. Tredicucci, F. Beltram, G. Biasiol, L. Sorba, *Tunnel-assisted manipulation of intersubband polaritons in asymmetric coupled quantum wells*, Appl. Phys. Lett. 89 (17), 171109 (2006)
- **A. A. Anappara**, A. Tredicucci, G. Biasiol, L. Sorba, *Electrical control of polariton coupling in intersubband microcavities*, Appl. Phys. Lett. 87 (5), 51105 (2005)
- **A. A. Anappara**, S. Rajeshkumar, P. Mukundan, P. R. S. Warrier, S. K. Ghosh, K. G. K. Warrier, *Impedance spectroscopic studies of sol-gel derived subcritically dried silica aerogels*, Acta Materialia, 52 (2), 369 (2004)

- **A. A. Anappara**, S. K. Ghosh, P. R. S. Warrier, K. G. K. Warrier, W. Wunderlich, *Impedance spectral studies of sol-gel alumina-silver nanocomposites*, Acta Materialia, 51 (12), 3511 (2003)
- S. D. George, **A. A. Anappar**a, K. G. K. Warrier, P. Radhakrishnan, C. P. G. Vallabhan, V. P. N. Nampoori, *Laser-induced thermal characterization of nano-Ag metal dispersed ceramic alumina matrix*, Proceedings of SPIE - International Society for Optical Engineering, 5118, 207 (2003)

International Conferences:

Invited Talks:

- *Nonadiabatic control of intersubband cavity polaritons*, 14th International Conference on Modulated Semiconductor Structures (MSS14), to be jointly held with EP2DS18 in Kobe, Japan (July 19-24, 2009)
- *Switch-on of ultrastrong light-matter interaction faster than a cycle of light,* Conference on lasers and electro-optics – European quantum electronics conference (CLEO Europe – EQEC 2009), Munich, Germany (June 14-19, 2009)
- *Ultra-intense THz source and extreme THz nonlinearities in condensed matter,* Conference on lasers and electro-optics CLEO/IQEC 2009, Baltimore, USA (May 31-June 5, 2009)
- *Terahertz nonlinear optics of semiconductor systems*, Trends in Nanoscience 2009, Kloster Irsee, Germany (February 28 - March 4, 2009)
- *Femtosecond solid state physics with ultra-intense THz fields,* International Workshop of the Special Research Program ADLIS (Advanced Light Sources), Munich, Germany (March 2-4, 2009)
- *High-field terahertz physics in the non-perturbative regime,* International Workshop on Nonequilibrium Nanostructures, Dresden, Germany (December 1-6, 2008)
- *Femtosecond solid state physics with ultrabroadband THz pulses,* EOS Topical Meeting on Terahertz Science and Technology, Paris, France (September 29 - October 2, 2008)
- *THz coherent control and cavity QED in semiconductors*, International Conference on Correlation Effects in Radiation Fields, Rostock, Germany (September 8 – 10, 2008)
- *Harnessing light-matter interaction in intersubband microcavities,* The Ninth International Conference on Intersubband Transitions in Quantum Wells, Cumbria, U.K. (September 9-14, 2007)

Contributed talks:

- **A. A. Anappara et. al.**, *Femtosecond build-up of ultrastrong light-matter interaction*, International Quantum Cascade Lasers School & Workshop (IQCLSW), Monte Verita, Switzerland (September 14-19, 2008)
- **A. A. Anappara et. al.**, *Femtosecond build-up of ultrastrong light-matter interaction,* XVI International Conference on Ultrafast Phenomena (UP 2008), Stresa, Italy (9-13 June 2008)
- **A. A. Anappara et. al.**,*Tailoring light-matter interaction in intersubband microcavities,* 17th International Conference on Electronic Properties of Two-Dimensional Systems (EP2DS 17)Genova, Italy (15 - 20 July, 2007)
- **A. A. Anappara et. al.**, *Giant cavity-polariton splitting in intersubband microcavities,* 7th International Conference on Physics of Light-Matter Coupling in Nanostructures (PLMCN2007) Havana, Cuba (12-17 April, 2007)
- **A. A. Anappara et. al.**, *Controlling polariton coupling in intersubband microcavities,* 6th International Conference on Physics of Light-Matter Coupling in Nanostructures (PLMCN2006) Magdeburg, Germany (25-29 September 2006)
- **A. A. Anappara et. al.**, *Controlling Polariton Coupling in Intersubband Microcavities,* 28th International Conference of the Physics of Semiconductors (ICPS 28) Vienna, Austria (24-28 July, 2006)
- **A. A. Anappara et. al.**, *Controlling polariton coupling in intersubband microcavities,* Physics of Intersubband Semiconductor Emitters (POISE 2006), Palazzone di Cortona, Italy (26-30 June 2006)

- **A. A. Anappara et. al.**, *Electrical control of polariton coupling in intersubband microcavities,* Intersubband Transitions in Quantum wells (ITQW2005) Cape Cod, USA (11-16 September 2005)

Abstract of my doctoral thesis:

Title: Light-matter Interaction in Intersubband Microcavities

Cavity quantum electrodynamics is a research field which has attracted considerable interest both from a fundamental point of view, because of the possibility it gives to come into contact with quantum properties of physical properties, and in the scope of applications. Historically, the first investigations were devoted to the study of the modification of spontaneous emission of atoms in metallic cavities [1]: the interaction between atoms and confined photon modes are responsible of strong modifications in the properties of the system, with the possibility of an enhancement or a reduction of the emission rate. A very important breakthrough in the field was realized in systems where the photonic and electronic degrees of freedom are simultaneously reduced. Such a soild state replica of an atomic system was realized in embedding semiconductor quantum wells in a monolithic Fabry-Perot resonator [2]. In a semiconductor quantum well the motion of the electrons is confined in one direction, resulting in the formation of electronic subbands within the conduction and valence bands. When the quantum wells are embedded in a resonator the fundamental electronic excitations (interband excitons) interacts resonantly with a discrete cavity mode. A strong-coupling regime arises if the interaction strength of the electron-photon system (vacuum-field Rabi energy) is larger than the damping rates. The strong coupling results in the formation of mixed quasi-particles called cavity polaritons, which are the linear superposition of light and matter excitations [2]. If the quantum well is doped with electrons to have the Fermi level between two subbands, optical excitations between the subbands in the conduction band are possible. These optical transitions are termed as intersubband transitions. In 2003, the strong coupling of intersubband transitions in doped quantum wells with confined photons, and the corresponding formation of intersubband cavity polaritons were experimentally observed up to room temperature [3].

The strong coupling regime of light-matter interaction has been demonstrated in diverse research fields: from atomic physics to organic/semiconductor excitons coupled to a planar microcavity, to superconductor qubits coupled to microwave transmission lines [4]. In contrast to other strongly coupled systems, intersubband microcavities are more appealing due to the unique possibility of externally controlling light-matter interaction. The manipulation of polariton coupling hinges on the principle that the intensity of intersubband absorption in the active region can be controlled either through the carrier density modulation or by altering the oscillator strength of the transition. Owing to the large oscillator strength and relatively low-energy of the transition, in intersubband microcavities the vacuum-field Rabi splitting can be a significant fraction of the intersubband transition energy. Such a regime of light-matter interaction was predicted theoretically and termed as the ultrastrong coupling regime [4].

The research work presented in my thesis is focused on the study of the optoelectronic coupling between the intersubband excitation in doped quantum wells and the resonant photonic mode of a planar semiconductor microcavity, in which the wells are embedded. The investigation of the optoelectronic coupling is here conducted in two different directions: (i) exploring suitable means for the external manipulation of intersubband cavity polaritons and (ii) realizing the conditions for observing the ultrastrong coupling regime of light-matter interaction. The devices employed in the investigation are multiple quantum well active structures embedded in intersubband microcavities - based either on dielectric mirrors or on plasmon mode resonators. The results presented in this thesis contain various experimental realizations of the external control of polariton coupling in a solid-state device, with unprecedented modulation depth and speed. External controls of polaritons are realized in devices employing electrical depletion of carriers, injection of charge carriers by tunnel coupling and also by optical activation of intersubband oscillators. The manipulation of light-matter strong coupling by tuning of oscillator strength is demonstrated. Moreover the first experimental observation of the ultrastrong coupling of light-matter interaction is also reported. These are fundamental steps towards the generation of the photon pairs from vacuum fluctuations in a quantum electrodynamical scheme analogous to the well known dynamic Casimir effect, which is yet to be realized experimentally [4, 5].

References

[1] E. M. Purcell, Phys. Rev. 69, 681 (1946)
[2] C. Weisbuch, M. Nishioka, A. Ishikawa, Y. Arakawa, Phys. Rev. Lett. 69, 3314 (1992)
[3] D. Dini, R. Kohler, A. Tredicucci, G. Biasiol, L. Sorba, Phys. Rev. Lett. 90, 116401 (2003)
[4] C. Ciuti, G. Bastard and I. Carusotto, Phys. Rev. B 72, 115303 (2005)
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