Research Networking Programmes

Short Visit Grant ☐ **or Exchange Visit Grant** ☒

(please tick the relevant box)

Scientific Report

The scientific report (WORD or PDF file – maximum of eight A4 pages) should be submitted online within one month of the event. It will be published on the ESF website.

Proposal Title: Implementation of integrated optics backbone and coupling techniques for plasmon-based biosensors at the single-molecule and single-photon level

Application Reference N°: 4633

1) Purpose of the visit

To develop theoretical and experimental techniques that allow coupling of light from single molecules into integrated waveguides chips, and the coupling between distant molecules deposited on these photonic structures. Due to the discrete nature of light emitted by single emitters, new experimental techniques need to be developed. First, to measure faint light coupled from the emission of single emitters (single photons) into waveguide modes. Second, to extract photon statistics from the light coupled into the photonic structures. Furthermore, a numerical method should be developed, that allows us to which quantify the expected number of photons interchanged between distant emitters in an arbitrary inhomogeneous environment. In this way, we can perform a priori design of the best candidate photonic structures.

2) Description of the work carried out during the visit

First part of the visit was devoted to develop a robust and general method to quantify photon exchange rate between distant emitters. We make use of a readily available electromagnetic equation solver based on a vectorial 3D finite differences on the time domain (FDTD) [1]. The classical approach we follow gives results that can be mapped to the quantum case via an equivalence principle [2]. The model takes into account retardation effects present in arbitrary inhomogeneous environments, as well as the full vectorial polarization of the environment. The developed technique allows us to obtain both the dyadic Green functions and the acceptor induced polarizabilities for a broad range of frequencies.

In particular, we found that the presence of optical antennas tuned to their dipolar resonance enhances the energy transfer (between two emitters sepparated by 1μm) more than 7 orders of magnitude when compared with two emitters interacting in vacuum, and more than 5 orders of magnitude when compared to a bare-waveguide case [Fig.1]

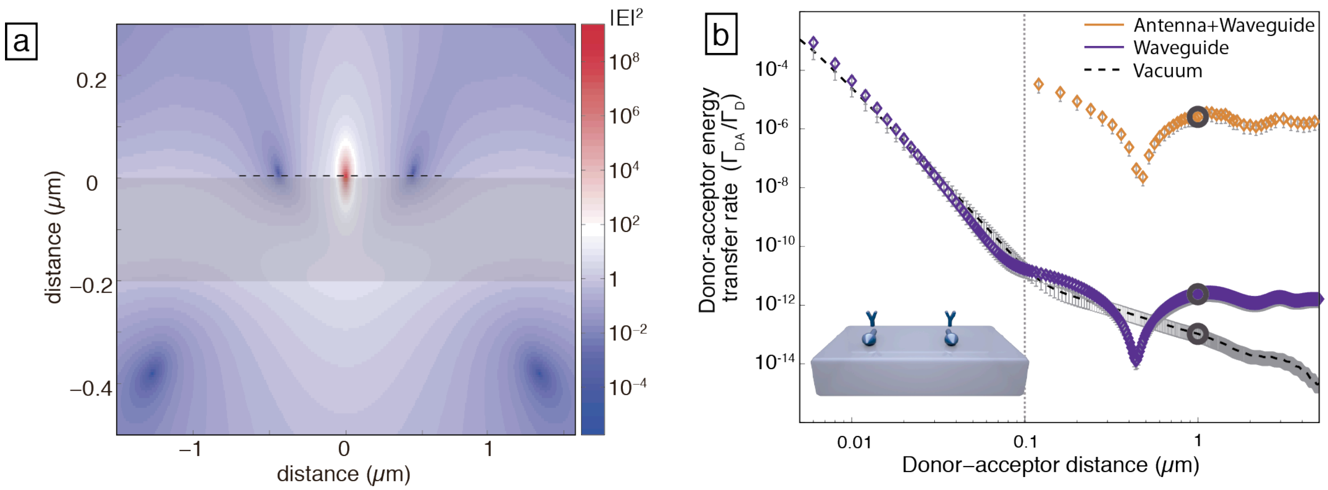

Fig.1: Inhomogeneous environments modify energy transfer rate between a donor and an acceptor. Panel a: Integrated electric field intensity (arbitrary units) created by a dipole 10nm on top of a 200 nm-thick and 400 nm-wide dielectric membrane (n=2). Dashed line represents the line at which quantities in Panel b are calculated. Panel b: Energy transfer rate per donor emis- sion event (Γ_{DA}/Γ_D) for two parallel dipoles placed in vacuum (dashed line), the same two dipoles placed over a waveguide and two emitters whose energy transfer is mediated by metallic antennas.

Second part was (and is still being) devoted to develop the experimental techniques required to study coupling of single-photon emitters into integrated waveguides. Single photon emitters deposited on dielectric photonic structures couple more efficiently to waveguides presenting evanenscent fields[3]. Dielectric waveguides need to be thin in order to present evanenscent fields extending outside of them (of the order of a tenth of a wavelength at optical frequencies). These small dimensions translate into poor coupling in(out) to the optical fibers used to inject excitation lasers and to collect Stokes shifted fluorescent photons. To minimize this drawback, an optical chip composed of tapered waveguides was designed. A fiber-coupling waveguide set-up was also developed mainly by Alex Clark, post-doctoral researcher at Imperial College [Fig.2].

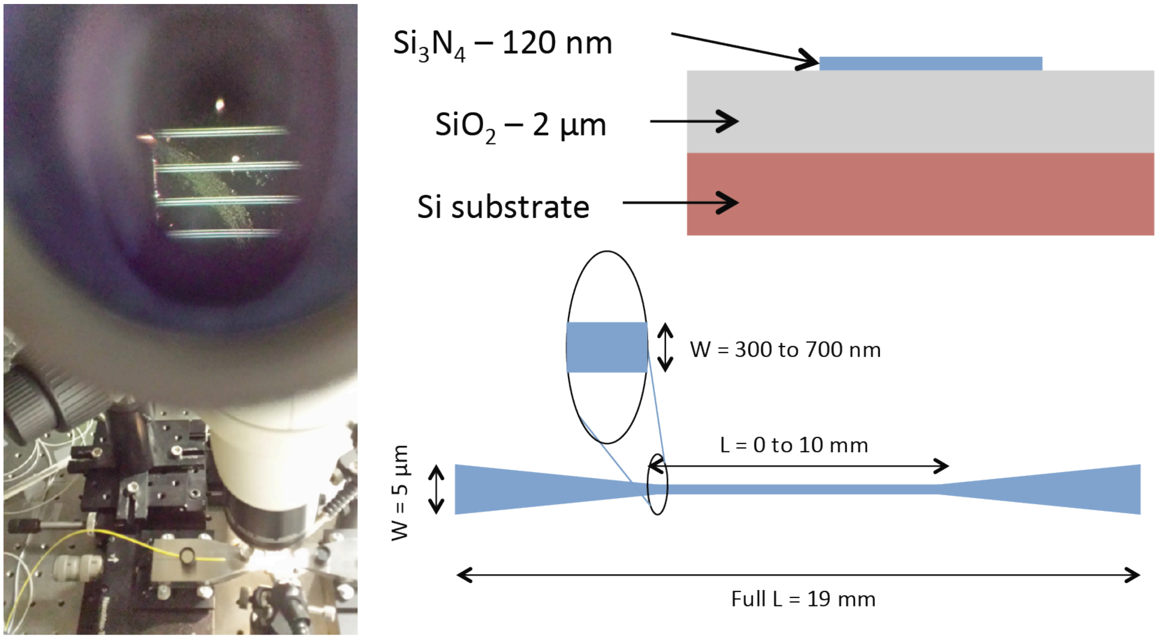

Fig.2: Left panel: Fiber coupling optical set up. Under white light illumination, the waveguide scatters green light radiation (as seen through a magnifying glass). Right panel: Dimensions of one typical photonic structures tested in the experiments.

In order to study single-photon statistics and coupling into the waveguides, candidate emitters were tested by Samuele Grandi (PhD candidate at Imperial College) and myself. Among them, colloidal quantum dots acting as dummy emitters embedded in thin (<100 nm) polymer films. The studied CdSe/CdS quantum dots show small absorption cross-sections at excitation wavelengths close to their emission (~780nm), which translates into photon emission rates <10kCounts s^{-1}. This means that the collection of photon statistics is tedious and slow. We are currently studying better emitter candidates (substituted terrylene molecules) which show larger absorption cross sections at 780nm wavelength. They should deliver increased emission rates, making possible to make straightforward statistical analysis of emitted photons using photon counters and correlator cards. Much of the work in these studies is devoted to find a thin-film deposition method which is compatible with the photonic chips, and does not introduce scattering defects either allong the waveguides or at the coupling facets.

Kyle Major and Claudio Polisseni (PhD candidates), devoted valuable time developing techniques to grow thick and thin crystals of

DBT molecules embedded in anthracene crystals which can be incorporated into the photonic chips. These molecules will be studied under low temperature (2K) conditions once a new closed-cycle He cryostat microscope is intalled in September 2014. These techniques will allow to study photonic coupling at low temperatures, using the chip methods developed during the present Exchange Visit.

The research project presented in this manuscript was supervised by Ed Hinds and Jaesuk Hwang.

References:

[1] A. Taflove and S.C. Hagness, Computational Electrodynamics: The Finite-Difference Time-Domain Method (Artech House, Boston, 2005), 3rd ed.

[2] L. Novotny, B. Hecht, Principles of Nano-Optics, Cambridge University Press.

[3] J. Hwang, E.A. Hinds, New J. Phys. **13**, 085009 (2011)

3) Description of the main results obtained

1.- Generalized numerical technique to quantify the photon exchange rate between dipolar emitters. The technique is based on the widely used FDTD method, which means there are a moderate number of researcher which can benefit from it.
2.- Development of a fibre-waveguide coupling set-up.
3.- Development of thin-film deposition techniques compatible with photonic chips.
4.- (Currently ongoing) Experimental techniques to quantify the fraction of single photons coupled into dielectric waveguides using photon statistics.

4) Future collaboration with host institution (if applicable)

The project is currently ongoing, and is being extended until 15th of October 2014. During this extended period, single DBT molecules at cryogenic temperatures will be tested as quantum emitters. These molecules present a narrow absorption linewidth, which translates into large scattering cross-sections. Further collaboration is expected in the near future.

5) Projected publications / articles resulting or to result from the grant *(ESF must be acknowledged in publications resulting from the grantee's work in relation with the grant)*

6) Other comments (if any)