

Efficient Förster Resonant Energy Transfer in Hybrid Structures Combining Polyfluorenes and III-Nitride Quantum Wells



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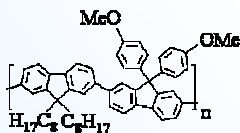


Summary

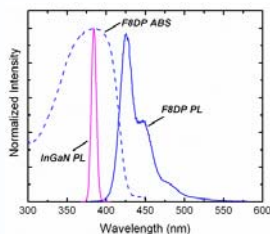
Our work has demonstrated for the first time non-radiative energy transfer between inorganic quantum wells (QWs), and overlayers of light-emitting polymer, mediated by dipole-dipole interactions. This process is a form of Förster resonant energy transfer (FRET), and it allows energy stored within a QW to be transferred into the polymer *without* emission of a photon, a key distinction from radiative energy transfer used within this project for colour conversion. The experimental methodology involves photopumping at ~360 nm of hybrid structures made by applying an overlayer of a polyfluorene to InGaN single QW structures. The thickness of the GaN cap layer above the QW has been varied between measured values of 1.9 and 11.8 nm, to investigate the distance dependence of the effect. Time-resolved photoluminescence (PL) experiments on the different structures indicate a separation dependence close to the form predicted theoretically for two 2D sheets of interacting dipoles. The non-radiative energy transfer process offers the exciting prospect of producing new forms of hybrid electrical injection device, in which carrier injection into an inorganic QW generates excitations transferred with high efficiency into an organic light emitting medium, the properties of which are widely tuneable.

Fabrication of the hybrid structures and initial PL results

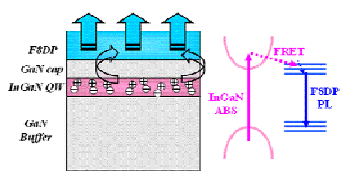
Hybrid structures were fabricated from InGaN/GaN QWs designed to emit at ~390 nm, and grown using metal organic chemical vapour deposition at Strathclyde Institute of Photonics. The QW thickness is ~2.2 nm, and the InN fraction ~7%. Polymer overlayers ~5 nm in thickness were made by spin coating at Imperial College EXSS. The polyfluorene F8DP was chosen for initial work because of two very convenient photophysical properties: temperature-insensitive PL properties, and minimal spectral overlap in emission with the QWs. The latter point is critical when we use time-resolved PL to examine lifetimes of excitations within the QW.



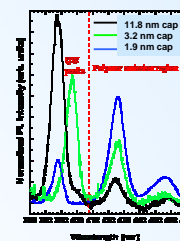
Molecular structure of the F8DP alternating copolymer: poly(9,9-dioctylfluorene-co-9,9-di(4-methoxy)phenylfluorene)



Plots above illustrate the match between the QW emission and F8DP absorption spectra; also the conveniently large Stokes' shift exhibited by the polymer



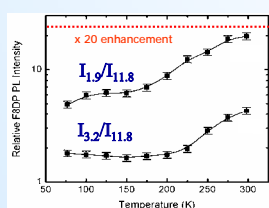
Left-hand side of the schematic above shows the physical structure of the hybrid samples. The right-hand side is a representation of the FRET process: fast relaxation within the polymer makes the process basically unidirectional.



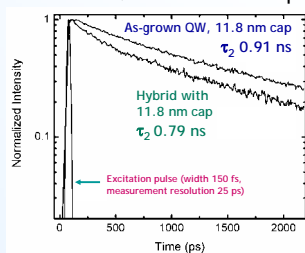
Time-integrated PL spectra at 15 K of hybrid structures with three cap layer thicknesses. Note the inverse relation between peak intensity in the two emission regions.

Variable-temperature and time-resolved PL results on hybrid structures

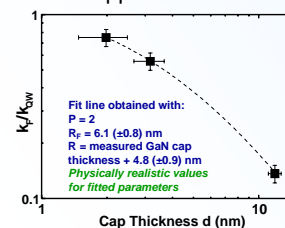
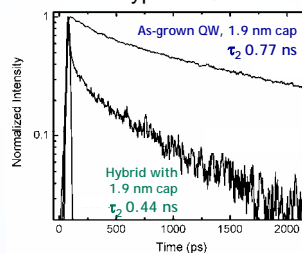
Definitive evidence for the FRET process comes both from time-integrated measurements at a range of temperatures, plus more recent time-resolved PL measurements, reported in references 1 and 2 respectively. Variable-temperature measurements sample the different regimes in which QW excitations can exist: unbound e-h pairs at higher temperatures, free Mott-Wannier excitons at intermediate temperatures, and excitons localised by potential fluctuations in the QWs at lower temperatures. Each type of QW excitation appears to support FRET effectively.



Plots of integrated intensity in the polymer emission region versus temperature, divided by the equivalent intensity from the thick-cap sample, which supports predominantly radiative energy transfer.



Time-resolved PL data acquired at 15 K in the QW emission region, from thin- and thick-cap structures, with and without the F8DP overlayer. In the case of the thin-cap structure, addition of the polymer opens a new non-radiative decay channel for excitations in the QW: energy flows into the polymer layer.



Rates for the FRET process (k_F) and the radiative decay of the QW excitation (k_{QW}) can be extracted from the TR-PL data. The ratio $k_F/k_{QW} = [R_F/R]^P$, where R is the effective exciton separation, R_F is the Förster radius, and P is an integer exponent. The plot shows agreement between the model and experiment, obtained with $P=2$: the model for sheet-sheet dipole interaction.

Future research plans

- Demonstrations of energy transfer into polymer blends for emission of white light, by analogy with previous work within the project on radiative energy transfer.
- Studies to elucidate the detailed mechanisms of the FRET process, eg. via measurements at different excitation powers.
- Longer-term development of electrical-injection hybrid devices. The close proximity required between the inorganic QW and the organic layer poses the obvious challenge in this effort. However, the timeliness of such research is illustrated by recent work from US national laboratories using an 'inverted' n-i-p nitride LED structure to demonstrate FRET into an overlayer of inorganic quantum dots [3].

References and acknowledgements

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- [2] G. Itskos, G. Heliotis, P.G. Lagoudakis, J. Lupton, N.P. Barradas, E. Alves, S. Pereira, I.M. Watson, M.D. Dawson, J. Feldmann, R. Murray & D.D.C. Bradley, submitted to *Physical Review B*.
- [3] M. Achermann, M.A. Petruska, D.D. Koleske, M.H. Crawford & V.I. Klimov, *Nanoletters*, **6**, 1396-1400 (2006).

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