

Enhanced Light-to-Electron Conversion in Photoconducting Nanostructured Multilayers by Optical Field Confinement Effects

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Herein we show experimental evidence of resonant photocurrent generation in dye sensitized periodically nanostructured photoconductors, which is achieved by spectral matching of the sensitizer absorption band to different types of localized photon modes present in either periodical or broken symmetry structures. Results are explained in terms of the calculated spatial distribution of the electric field intensity within the configurations under analysis.

Photo-electro-chemical devices may largely benefit from the electromagnetic field localization occurring within periodic photonic nanostructures [1]. Different studies show that both photocatalytic and photovoltaic cells improve their efficiency when such materials, capable of enhancing radiation-matter interactions at specific locations and wavelengths, are introduced [2-6]. However, proofs of concept so far reported are based on the observation of performance parameters whose improvement cannot be unambiguously linked to increased electron photogeneration resulting from optical field confinement [7-9]. The reason for this lies in the sort of materials that have been employed so far for these experiments. In some cases, the modulation of the refractive index can be realized employing different stacks of nanostructures of similar composition but with different porosity [10-14]. Such ensembles preserve the intensive properties of the bulk material and at the same time present new optical properties of structural origin. When the molded material is photoconducting, as it is the case of TiO_2 or SnO_2 , then the possibility opens up to modify the spectral response of the photocurrent by means of the optical design of the multilayer. However, in lattices of uniform chemical composition and alternated porosity, the refractive index contrast is usually low, large number of periods being required in order to observe strong scattering phenomena. This has prevented the observation of clear field confinement effects on the photocurrent spectrum of photoconducting multilayers so far. Alternative approaches based on inverse opal photoconducting structures lead to photonic crystal lattices with larger dielectric contrast but high density of intrinsic defects, as the low intensity scattering related to order indicates [2, 3, 5, 15], again being difficult to relate the observed enhancement with specific photon resonances.

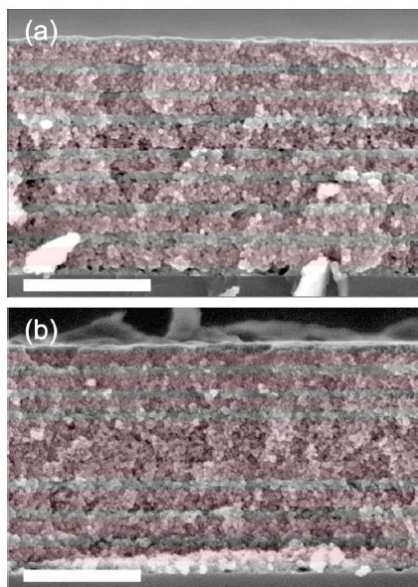


Figure 1: FESEM images of cross sections of (a) a periodic multilayer and (b) a multilayer in which a thicker middle layer has been deposited. Each type of layer has been shaded with a different color for the sake of clarity (grey, thinner lower porosity layer; purple, thicker higher porosity layer). The scale bar is 500nm in both (a) and (b).

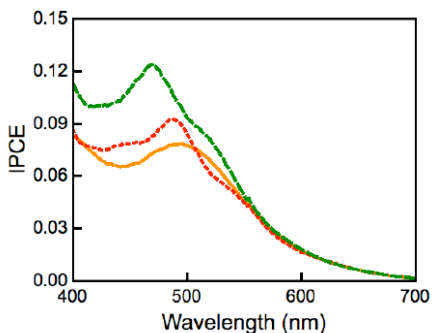


Figure 2: Incident photon to collected electron efficiency measured for a dye sensitized periodic multilayer (green dotted line), a dye sensitized multilayer in which a thicker middle layer has been deposited (red dashed line) and a nanostructured TiO₂ reference cell with no photonic properties (orange solid line).

References

- [1] Chen, J.I.L.; von Freymann, G.; Choi, S.Y.; Kitaev, V.; Ozin, G.A. *Adv. Mater.* 2006, 18, 1915–1919.
- [2] Nishimura, S.; Abrams, N.; Lewis, B.A.; Halaoui, L.I.; Mallouk, T.E.; Benkstein, K.D.; van de Lagemaat, J.; Frank, A.J.; J. Am. Chem. Soc. 2003, 125, 6306–6310.
- [3] Li, Y.; Kunitake, T.; Fujikawa, S. *J. Phys. Chem. B* 2006, 110, 13000–13004.
- [4] Ramiro-Manzano, F.; Atienzar, P.; Rodriguez, I.; Mesguera, F.; Garcia, H.; Corma, A. *Chem. Commun.* 2007, 242–244.
- [5] Chen, H.; Chen, S.; Quan, X.; Zhang, Y. *Environ. Sci. Technol.* 2010, 44, 451–455.
- [6] Sordello, F.; Duca, C.; Maurino, V.; Minero, C. *Chem. Commun.* 2011, 47, 6147–6149.
- [7] Mihi, A.; Míguez, H. *J. Phys. Chem. B* 2005, 109, 15968–15976.
- [8] Halaoui, L.I.; Abrams, N.M.; Mallouk, T.E. *J. Phys. Chem. B* 2005, 109, 6334–6342.
- [9] Chen, J.I.L.; von Freymann, G.; Kitaev, V.; Ozin, G.A. *J. Amer. Chem. Soc.* 2007, 129, 1196–1202.
- [10] Steele, J.J.; van Popta, A.C.; Hawkeye, M.M.; Sit, J.C.; Brett, M.J. *Sens. Actuators B* 2006, 120, 213–219.
- [11] Guo, D.L.; Fan, L.X.; Wang, F.H.; Huang, S.Y.; Zou, X.W. *J. Phys. Chem. C* 2008, 112, 17952–17956.
- [12] Schubert, M.F.; Xi, J.Q.; Kim, J.K.; Schubert, E.F. *Appl. Phys. Lett.* 2007, 90, 141115.
- [13] Calvo, M.E.; Colodrero, S.; Rojas, T.C.; Anta, J.A.; Ocaña, M.; Míguez, H. *Adv. Func. Mater.* 2008, 18, 2708–2715.
- [14] Guldin, S.; Kolle, M.; Stefik, M.; Langford, R.; Eder, D.; Wiesner, U.; Steiner, U. *Adv. Mater.* 2011, 23, 3664–3668.
- [15] Chen, X.; Ye, J.; Ouyang, S.; Kako, T.; Li, Z.; Zou, Z. *ACS Nano* 2011, 5, 4310–4318.