Report of scientific progress achieved during visit funded by ESF

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July 11, 2012

1 General

I have completed a period of 20 week visit to the group of Prof. Stefan Maier at Imperial College London. The visit was dedicated to further development and implementation of the technique called Nanoparticle-assisted Stimulated-Emission-Depletion nanoscopy (NP-STED), developed in collaboration with Maier's group in the period preceding the visit [1]. Specifically, the purpose of the visit was to guide the experimental efforts, to deepen our theoretical understanding of the technique and to further simplify the technique by reducing the complexity of the original idea. All three goals were achieved. A description of the work carried out and the results obtained is given below.

2 Description of the work carried out during the visit and the main results

2.1 Theory

1. Further details of the implemenation of NP-STED, namely, the dependence of the improved performance on parameters such as average field and decay rate enhacements as well as STED pulse and time-gating durations were investigated. This work identified the optimal conditions for the implementation of the technique, and the results were applied to nanoparticle s of arbitrary shape. A new manuscript which described these results was submitted and accepted for publication in Applied Physics Letters [2].

2. Further investigations into the theory of field enhancement in the metal core-shell nanoparticles used for NP-STED was performed in collaboration with the group of Prof. Peter Török at Imperial College London. This work resulted in a significantly simpler way to calculate the relevant field enhancement for NP-STED and gave us a deeper understanding of the interaction of the doughnut-shaped beams used in STED (and NP-STED) with the metal nanoparticles. These results are being summarized into a paper that will be submitted soon [3].

2.2 Experiments

1. Unfortunately, the fabrication of nanoparticles required for the experimental test of NP-STED has not gone according to expectation. Specifically, the first two batches of nanoparticles fabricated did not have the required spectral properties. This failure required excessive correspondence with the fabrication companies aimed at improving the problems and enabling the fabrication of proper particles. This effort included also exploring different companies specializing in the required fabrication. Consequently, the third batch of particles seem to satisfy our specifications. Some preliminary measurements give good indications to the potential of the scheme. However, much further experimental work is required.

2. In addition to developing the original NP-STED technique, a novel implementation of the technique for imaging near to surfaces was developed. Specifically, I suggested to exploit the plasmonic near-field enhancement near two-dimensional metal nanoparticles arrays (e.g., periodic arrays of nano-antennae, semicontinuous metal films etc.) in order to improve the performance of the STED nanoscope using the principles of [1]. Whereas the functionality of this technique is limited to imaging near the surface, the fabrication required is by far simpler and cheaper. Some preliminary measurements give good indications to the potential of the scheme and simulation work is currently underway.

3 Future collaboration with host institution

Further experimental tests of NP-STED would be carried out in the next few months based on the nanparticles designed and fabricated during the visit. Furthermore, a grant proposal was written jointly with the host and submitted to the Leverhulme Trust. In case the grant application will be successful, the collaboration with the host would be sustained in the next few years.

The collaboration with the group of Prof. Török is also planned to continue, specifically, investigating further the possibilities to enhance nonlinear effects using nanoparticles.

References

[1] Y. Sivan, Y. Sonnefraud, S. Kéna-Cohen, J. B. Pendry and S. A. Maier, "Nanoparticle-assisted stimulated-emission-depletion nanoscopy", ACS Nano **6**, 5291-5296 (2012).

[2] Y. Sivan, "Performance improvement in nanoparticle-assisted Stimulated-Emission-Depletion nanoscopy", Appl. Phys. Lett., in press (2012).

[3] M.R. Forman, Y. Sivan, S.A. Maier and P. Török, "Illumination-dependence of plasmonic near-field enhancements", to be submitted (2012).