Optical Antennas Based on Segmented Metal-Nanotube Structures

Xudong Cui, Daniel Erni
General and Theoretical Electrical Engineering (ATE), Faculty of Engineering, University of Duisburg-Essen, D-47048, Duisburg, Germany. Tel: +49(0)203/379-3213, Fax: +49(0)203/379-3499, xudong.cui@uni-due.de,

Lixin Dong
Institute of Robtics and Intelligent Systems, ETH Zurich, CH-8092 Zurich, Switzerland, Tel: +41-44-6322539, Fax: +41-44-6321078, ldong@ethz.ch

Weihua Zhang
Nanophotonics and Metrology Laboratory, EPFL Lausanne, CH-1015, Lausanne, Switzerland Tel: +41-21-6933968, weihua.zhang@epfl.ch

Abstract: We have fabricated two-segment carbon nanotube (CNT) based structures. We prove their ability to operate as optical antennas, where the field enhancement, distinct resonances, as well as radiation patterns are thoroughly investigated.

Optical antennas are capable of coupling far-field radiation to the near-field in the sub-wavelength range. They can be used to tailor light-matter interactions in the nanoscale, leading to various applications (like nano-scale lithography, field-enhanced microscopy etc.) [1]. The optical responses of an optical antenna heavily depend on the surface plasmon resonances [2] in the structure, which are quite sensitive to the material properties, the geometry and the operating environment. Based on a full-wave electromagnetic analysis we propose a two-segment CNT based nanostructure [3] to operate as a “fat” dipole-type optical antenna. The field enhancement, the resonances, and the radiation patterns are thoroughly investigated. Our study reveals that the advantages of pure metallic antennas and CNT antennas could be combined, providing additional degrees of freedom in tailoring both the material properties and the wavelength response, and, hence, the overall emission characteristics. Segmented composite nano-antennas turned out to carry a great potential for engineering nanoscale emitters and receivers, for e.g. biosensing applications or within advanced nanophotonic circuit topologies.

[1] P. Muhlschlegel, H. J. Eisler, O. J. F. Martin, B. Hecht, and D. W. Pohl, “Resonant Optical Antennas, ” Science 308, 1607-1609 (2005).
[2] W. L. Barnes, A. Dereux, and T. W. Ebbesen, “Surface plasmon subwavelength optics, ” Nature 424, 824-830 (2003).
[3] L. X. Dong, X. Y. Tao, L. Zhang, B. J. Nelson, X. B. Zhang, “Nanorobotic spot welding: Controlled metal deposition with attogram precision from copper-filled carbon nanotubes, ” Nano Lett. 7, 58-63 (2007).

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Lixin Dong

Institute of Robtics and Intelligent Systems, ETH Zurich, CH-8092 Zurich, Switzerland

Department of Electrical and Computer Engineering, Michigan State University, U.S.A

Weihua Zhang

Nanophotonics and Metrology Laboratory, EPFL Lausanne, CH-1015, Lausanne, Switzerland

Optical antennas are capable of coupling far-field radiation to the near-field in the sub-wavelength range. They can be used to tailor light-matter interactions in the nanoscale, leading to various applications (like nano-scale lithography, field-enhanced microscopy etc.) [1]. The optical responses of an optical antenna heavily depend on the surface plasmon resonances in the structure, which are quite sensitive to the material properties, the geometry and the operating environment. Based on a full-wave electromagnetic analysis we propose a two-segment CNT based nanostructure [2] to operate as a "fat" dipole-type optical antenna. The field enhancement, the resonances, and the radiation patterns are thoroughly investigated. Our study reveals that the advantages of pure metallic antennas and CNT antennas could be combined, providing additional degrees of freedom in tailoring both the material properties and the wavelength response, and, hence, the overall emission characteristics. Segmented composite nano-antennas turned out to carry a great potential for engineering nanoscale emitters and receivers, for e.g. biosensing applications or within advanced nanophotonic circuit topologies.

1. Segmented Structure based on Nanotube

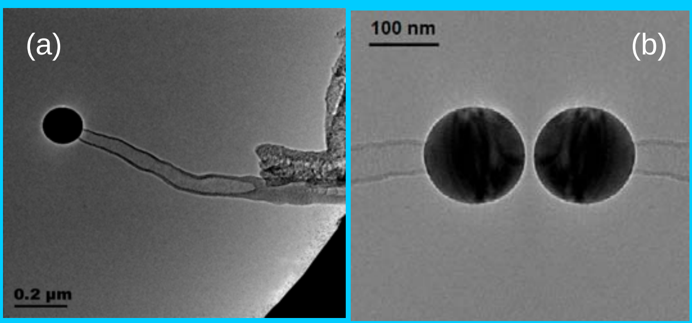

Fig. 1 TEM images of our fabricated structures based on the methods shown in [2].

2. Optical Properties of the Paired Structures

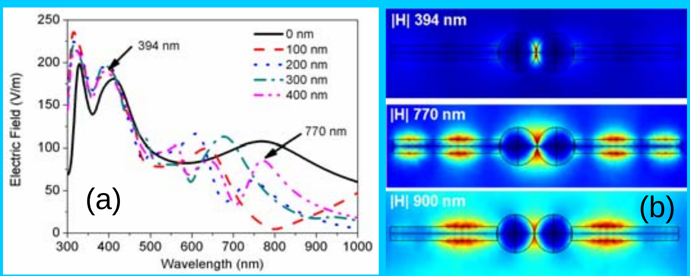

Fig. 2 (a) The electric field strength in the center of the gap as a function of the wavelength for various lengths of the metallic nanotubes, the gap size *g*=2nm. The geometry of the structure corresponds to the one shown in Fig. 1(b). Some resonances for the structure with a 400 nm long nanotube are labeled in the figure. (b) The magnetic field strength at different wavelengths for a nanotube length of 400nm, where red - bright colors indicate high field values. See [3].

1. P.Muhlschlegel et al, "Resonant Optical Antennas," *Science* 308, 1607-1609 (2005).
2. L.Dong et al., "Nanorobotic spot welding: Controlled metal deposition with attogram precision from copper-filled carbon nanotubes," *Nano Lett*. 7, 58-63 (2007).
3. X.Cui et al., *Optics Express*, 2009, Submitted.

3. Radiation Properties of the Paired Structures

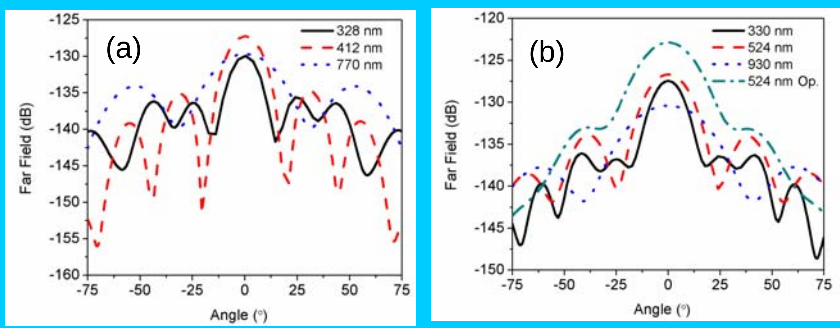

Fig. 3 Far-field radiation characteristics of the structure with respect to the *x*-*y*-plane (*E*-plane): (a) Spheres without CNTs at resonance wavelengths of 328nm, 412nm, and 770nm, respectively. (b) Spheres with two 100nm long semiconductor CNTs at the resonant wavelengths of 330nm, 524nm and 930nm, respectively. The optimized emission pattern at 524nm is also shown for comparison. The relevant dimensions of the two spheres are *R*=70nm and *g*=2nm, where for the optimized structure *R*=25nm. See [3].

4. Tailoring the Emitter Lifetime by the Paired Structures

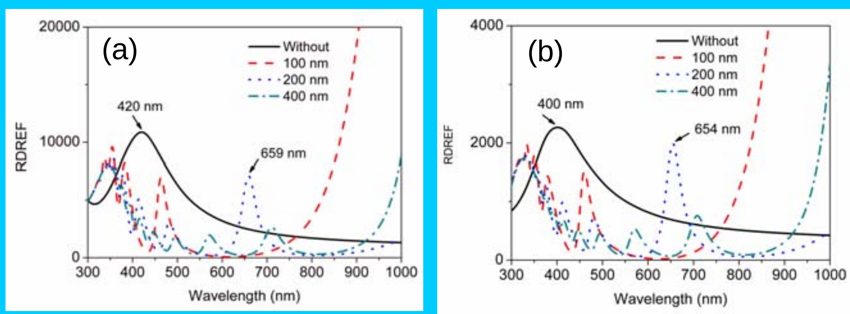

Fig. 4 The radiative decay rate enhancement factor (RDREF) as a function of CNT length. The wavelengths with large RDREF for the structure without CNT and with two 200nm CNTs are marked in the figure. (a) For a structure with a sphere radius of *R*=70nm and a gap width of *g*=10nm. (b) For a structure with a sphere radius of *R*=70nm and a gap width of *g*=20nm. See [3].

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xudong.cui@uni-due.de, daniel.erni@uni-due.de

UNIVERSITÄT DUISBURG ESSEN