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14. ABSTRACT
Princeton University has carried out research to investigate the physics of surface-enhanced Raman scattering (SERS), develop new nanostructure designs to control and increase SERS sensitivity, and to use innovative high-precision large-area nanopatterning technologies to fabricate SERS nanostructures. Particularly, the research has led to (i) a new SERS substrate architecture, “disk-coupled dots-on-pillar antenna-array” (D2PA), that has a large-area uniform SERS enhancements of several orders of magnitude higher than the highest previously reported, (ii) new nanofabrication technologies for making such SERS substrate over large area with high throughput and low cost; (iii) giant fluorescence enhancement on such substrates, and (iv) applications of such substrates for bio/chemical detections.

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Final Report to Air Force Office of Scientific Research

Project: “Design and Fabrication of Large-Enhancement-Factor, Large-Area SERS Nanostructures”

Award Number: FA9550-08-1-0222

PI: Prof. Stephen Chou

Department of Electrical Engineering, Princeton University

Submitted: July 20, 2012

ABSTRACT

Princeton University has carried out research to investigate the physics of surface-enhanced Raman scattering (SERS), develop new nanostructure designs to control and increase SERS sensitivity, and to use innovative high-precision large-area nanopatterning technologies to fabricate SERS nanostructures. Particularly, the research has led to (i) a new SERS substrate architecture, "disk-coupled dots-on-pillar antenna-array" (D2PA), that has a large-area uniform SERS enhancements of several orders of magnitude higher than the highest previously reported, (ii) new nanofabrication technologies for making such SERS substrate over large area with high throughput and low cost; (iii) giant fluorescence enhancement on such substrates, and (iv) applications of such substrates for bio/chemical detections.

SUMMARY

Princeton University has developed a new SERS substrate architecture, "disk-coupled dots-on-pillar antenna-array" (D2PA), its fabrication, and application in the enhancements in SERS and fluorescence as well as in bio/chemical detections.

1. New SERS Architecture that Changed Landscape. Princeton team has proposed and demonstrated a new surface enhanced Raman scattering (SERS) architecture that has led to unprecedented high SERS enhancement factor and excellent uniformity over large area. Princeton team also has developed new nanofabrication technologies which have produced the new SERS structures precisely and cost-effectively over large area. The unprecedented high and uniform enhancement plus the easy fabrication over large area have opened up many great opportunities for SERS applications in ultra-sensitive detections of explosive, chemical and biological weapons, to name just a few.

The new SERS architecture developed by Princeton team, termed "disk-coupled dots-on-pillar antenna-array" (D2PA), uniquely combines a dense three-dimensional (3-D) cavity nanoantenna array, dense plasmonic nanodots, and dense nano-gaps. The architecture is able to maximize several important but conflicting and competing factors to SERS enhancement.

2. New Nanofabrication Process for D2PA. The new nanofabrication developed by Princeton combines nanoimprint, guided self-assembly and self-alignment to fabricate the architecture precisely, simply, inexpensively and over large area (4-inch wafer).

3. High (1.7×10^9) and Uniform (22.4% variation) SERS Enhancement over Large Area. Princeton team has achieved experimentally not only high area-average SERS enhancement (1.7×10^9) but also excellent uniformity (22.4% variation) at the same time over large-area.

The area-average SERS enhancement is over 1,000 fold (100,000%) higher and the uniformity is over 3 fold (300%) better than the best commercial SERS substrate.

Princeton team fabricated the new SERS substrates on 4" wafers. The fabrication technologies can scale to 12" wafers.

4. Giant Fluorescence Enhancement. By adding certain refinements to the new SERS architecture, Princeton team has achieved area-average fluorescence enhancement over 5,000 folds (500,000%) and single molecule fluorescence enhancement at a hot spot over 1,000,000 folds, which is 100X and 1,000X, respectively, higher than the highest previously reported. Princeton advances open up many applications of fluorescence in bio, chemical and medical detection and imaging.

5. New Application Exploration for the New SERS Substrate. Princeton team has explored various applications of the new SERS and fluorescence enhancement architecture in bio, chemical, and medical detections. The application includes explosive detections, chemical identifications, and immunoassay.

More details are described in the published papers on the list below.

PUBLICATIONS

[1] W. Li, F. Ding, J. Hu, and S. Y. Chou, "Three-dimensional cavity nanoantenna coupled plasmonic nanodots for ultrahigh and uniform surface-enhanced Raman scattering over large area," Optics Express, 19 (5) 3925-3936 (2011).

[2] W. Li, J. Hu, and S. Y. Chou, "Extraordinary light transmission through opaque thin metal film with subwavelength holes blocked by metal disks," Optics Express, Vol. 19 Issue 21, pp.21098-21108 (2011).

[3] W. Zhang, F. Ding, W. Li, Y. Wang, J. Hu and S. Y. Chou, "Giant and uniform fluorescence enhancement over large areas using plasmonic nanodots in 3D resonant cavity nanoantenna by nanoimprinting," Nanotechnology 23, 225301 (2012).

[4] L. Zhou, F. Ding, H. Chen, W. Ding, W. Zhang, and S. Y. Chou, "Enhancement of Immunoassay's Fluorescence and Detection Sensitivity Using Three-Dimensional Plasmonic Nano-Antenna-Dots Array," Anal. Chem. 84, 4489−4495 (2012).