

REPORT DOCUMENTATION PAGE					Form Approved OMB No. 0704-0188	
The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to the Department of Defense, Executive Service Directorate (0704-0188). Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ORGANIZATION.						
1. REPORT DATE (DD-MM-YYYY) 07/20/2012		2. REPORT TYPE Final			3. DATES COVERED (From - To) 05/01/2008 - 04/30/2012	
4. TITLE AND SUBTITLE Design and Fabrication of Large-Enhancement-Factor, Large-Area SERS Nanostructures				5a. CONTRACT NUMBER FA9550-08-1-0222		
				5b. GRANT NUMBER		
				5c. PROGRAM ELEMENT NUMBER		
6. AUTHOR(S) Chou, Stephen, Y; Li, Wen-Di; Ding, Fei; Hu, Jonathan; Zhang, Weihua; Wang, Yuxuan; Zhou, Liangcheng; Chen, Hao; and Ding, Wei.				5d. PROJECT NUMBER		
				5e. TASK NUMBER		
				5f. WORK UNIT NUMBER		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) The Trustees of Princeton University Office of Research and Project Administration 1 Nassau Hall Princeton, NJ 08544-0001					8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Air Force Office of Scientific Research 875 N. Randolph St., Room 3112 Arlington, VA 22203					10. SPONSOR/MONITOR'S ACRONYM(S) AFOSR	
					11. SPONSOR/MONITOR'S REPORT NUMBER(S) AFRL-OSR-VA-TR-2012-0869	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release.						
13. SUPPLEMENTARY NOTES						
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.						
15. SUBJECT TERMS Surface-enhanced Raman scattering (SERS); disk-coupled dots-on-pillar antenna-array; nanofabrication; nanoimprint; SERS enhancement; and fluorescence enhancement bio/chemical detection.						
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT UU	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Prof. Stephen Y. Chou	
a. REPORT U	b. ABSTRACT U	c. THIS PAGE U			19b. TELEPHONE NUMBER (Include area code) 609-258-4416	

INSTRUCTIONS FOR COMPLETING SF 298

1. REPORT DATE. Full publication date, including day, month, if available. Must cite at least the year and be Year 2000 compliant, e.g. 30-06-1998; xx-06-1998; xx-xx-1998.

2. REPORT TYPE. State the type of report, such as final, technical, interim, memorandum, master's thesis, progress, quarterly, research, special, group study, etc.

3. DATES COVERED. Indicate the time during which the work was performed and the report was written, e.g., Jun 1997 - Jun 1998; 1-10 Jun 1996; May - Nov 1998; Nov 1998.

4. TITLE. Enter title and subtitle with volume number and part number, if applicable. On classified documents, enter the title classification in parentheses.

5a. CONTRACT NUMBER. Enter all contract numbers as they appear in the report, e.g. F33615-86-C-5169.

5b. GRANT NUMBER. Enter all grant numbers as they appear in the report, e.g. AFOSR-82-1234.

5c. PROGRAM ELEMENT NUMBER. Enter all program element numbers as they appear in the report, e.g. 61101A.

5d. PROJECT NUMBER. Enter all project numbers as they appear in the report, e.g. 1F665702D1257; ILIR.

5e. TASK NUMBER. Enter all task numbers as they appear in the report, e.g. 05; RF0330201; T4112.

5f. WORK UNIT NUMBER. Enter all work unit numbers as they appear in the report, e.g. 001; AFAPL30480105.

6. AUTHOR(S). Enter name(s) of person(s) responsible for writing the report, performing the research, or credited with the content of the report. The form of entry is the last name, first name, middle initial, and additional qualifiers separated by commas, e.g. Smith, Richard, J, Jr.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES). Self-explanatory.

8. PERFORMING ORGANIZATION REPORT NUMBER. Enter all unique alphanumeric report numbers assigned by the performing organization, e.g. BRL-1234; AFWL-TR-85-4017-Vol-21-PT-2.

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES). Enter the name and address of the organization(s) financially responsible for and monitoring the work.

10. SPONSOR/MONITOR'S ACRONYM(S). Enter, if available, e.g. BRL, ARDEC, NADC.

11. SPONSOR/MONITOR'S REPORT NUMBER(S). Enter report number as assigned by the sponsoring/monitoring agency, if available, e.g. BRL-TR-829; -215.

12. DISTRIBUTION/AVAILABILITY STATEMENT. Use agency-mandated availability statements to indicate the public availability or distribution limitations of the report. If additional limitations/ restrictions or special markings are indicated, follow agency authorization procedures, e.g. RD/FRD, PROPIN, ITAR, etc. Include copyright information.

13. SUPPLEMENTARY NOTES. Enter information not included elsewhere such as: prepared in cooperation with; translation of; report supersedes; old edition number, etc.

14. ABSTRACT. A brief (approximately 200 words) factual summary of the most significant information.

15. SUBJECT TERMS. Key words or phrases identifying major concepts in the report.

16. SECURITY CLASSIFICATION. Enter security classification in accordance with security classification regulations, e.g. U, C, S, etc. If this form contains classified information, stamp classification level on the top and bottom of this page.

17. LIMITATION OF ABSTRACT. This block must be completed to assign a distribution limitation to the abstract. Enter UU (Unclassified Unlimited) or SAR (Same as Report). An entry in this block is necessary if the abstract is to be limited.

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).