

FINAL REPORT AFOSR FA9550-04-1-0197
(Robert Armstrong, Principal Investigator)

This report describes the results of an experimental investigation of a coupled resonance detection scheme with intended applications to optical sensors (in particular bio-sensors). The work exploits recent advances in resonant sensor and enhanced optical coupling technologies. Multiplicative enhancement of optical gain is achieved through a coupled resonator configuration involving whispering-gallery modes (WGM's) in a dielectric microsphere coupled to Surface-Enhanced-Raman Scattering (SERS) emission from analyte-doped metal nanoparticles. Evanescent coupling of WGM and SERS emissions provides a significant increase in resonator output as compared with conventional far-field sensors.

Brief Statement of Basic Concept:

In many scenarios involving biological or other threat molecules, there is a vital need for a reliable, rapid optical sensor. Exploiting the fingerprint characteristics of Raman scattering, we have developed a Raman-based optical sensor to accomplish this objective. SERS emission from analyte molecules adsorbed on metal nanoparticles provides large optical gain, while simultaneously suppressing the unwanted effects of non-adsorbed species. If the metal nanoparticles are adsorbed on the exterior surface of a dielectric micro-cavity, SERS emissions are efficiently coupled to micro-cavity WGM's, providing further (multiplicative) gain. The resulting total gain can be extremely large. Finally, conventional, far-field coupling the Raman emitters, typically very inefficient, is replaced by near-field evanescent coupling. Benefits of this scheme include far greater coupling efficiency (i.e., signal levels dramatically improved over conventional far-field coupling schemes), and greater simplicity in the coupling and signal collection experimental stages.

Description of Work

Evanescent coupling arises from the same fundamental optical process that is responsible for the well-known phenomenon of total internal reflection. For incident angles greater than the critical angle, the transmitted field becomes exponentially damped, decaying with a characteristic length scale of the order of the optical wavelength; for visible light, this scale is of the order of a few hundred nm. Evanescent light may be produced by several

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 Services and Communications 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)		2. REPORT TYPE		3. DATES COVERED (From - To)		
4. TITLE AND SUBTITLE				5a. CONTRACT NUMBER		
				5b. GRANT NUMBER		
				5c. PROGRAM ELEMENT NUMBER		
6. AUTHOR(S)				5d. PROJECT NUMBER		
				5e. TASK NUMBER		
				5f. WORK UNIT NUMBER		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)				8. PERFORMING ORGANIZATION REPORT NUMBER		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)		
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)		
12. DISTRIBUTION/AVAILABILITY STATEMENT						
13. SUPPLEMENTARY NOTES						
14. ABSTRACT						
15. SUBJECT TERMS						
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON	
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER (Include area code)	

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.

techniques including prism and tapered fiber coupling schemes. In the experiments described here, we employ a prism coupler. Although tapered fiber couplers provide somewhat greater coupling efficiency (by a factor of approximately 2), the simplicity of prism couplers makes them preferable in these initial experiments.

The experimental arrangement is sketched in **Fig. 1**; light from a cw laser (a 3 mW HeNe is used in the experiments reported here) is focused through the interior of a glass prism onto its hypotenuse face at an angle greater than the critical angle, thereby emerging as evanescent light in the region beyond. A 50 micron radius glass microsphere is positioned in the evanescent region by an x-y micro-positioning translator (parallel to the hypotenuse face) and by a z nano-positioning translator (perpendicular to the hypotenuse face). For values of z in the few-hundred nm range and x-y positioning accuracy of a few microns, evanescent coupling occurs, signaled by the presence of strong WGM resonant emissions visible in light directly emitted by the microcavity. The emitted light is analyzed by a grating spectrograph and detected with a CCD detector.

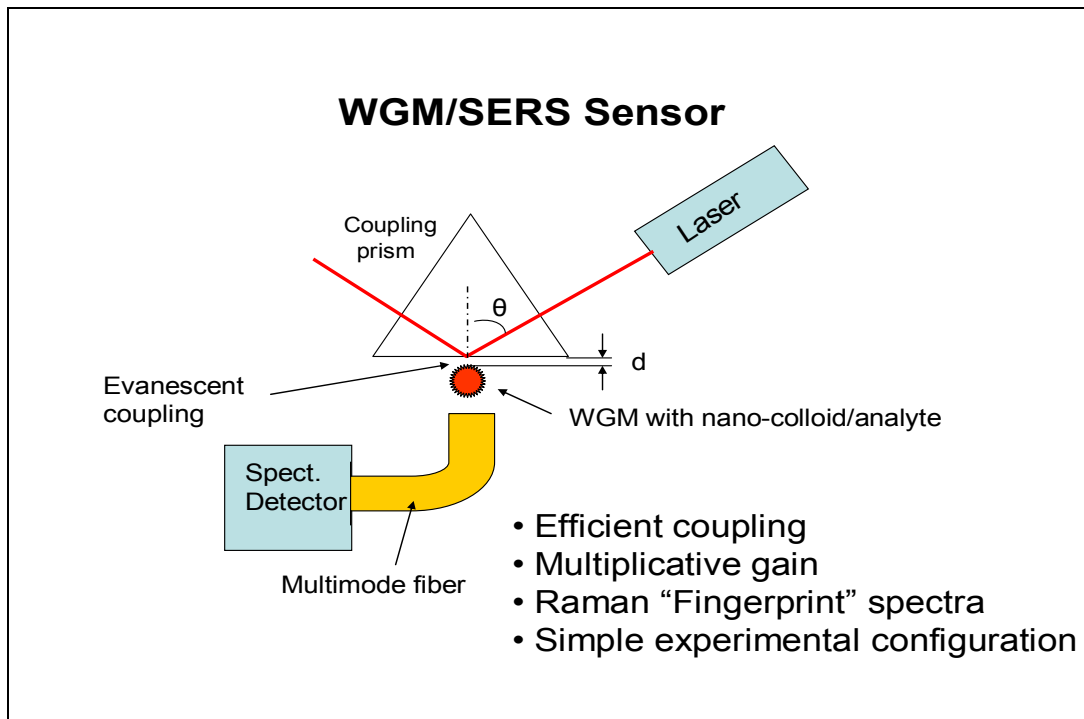


FIGURE 1

In order to investigate coupled resonance spectra, the microspheres are prepared with an approximately 20-30 nm layer of silver colloid particles doped with a suitable analyte; the microsphere is initially coated with a thin (monolayer) silane layer to facilitate bonding to the colloid and analyte. Colloid particles are fabricated in our laboratory using the well-known Lee-Meisel method. In this manner, Raman emissions from the analyte are efficiently coupled to both the WGM's of the microsphere and the surface plasmon-enhanced (SERS) oscillations of the analyte, generating greatly enhanced coupled resonant (WGM/SERS) analyte spectra.

Experimental Results

The experimental arrangement illustrated in Fig. 1 was used to obtain WGM/SERS spectra from the well-known organic dye, Rhodamine 6G (R6G) and from a bacterium, E Coli. Spectra of the dye were used primarily as calibration spectra to provide a quantitative description of our spectral detection capability. WGM/SERS spectra depend on several experimental parameters including: (1) the distance s between the sphere and the prism, (2) the angle of incidence, A , of the laser beam (A greater than the critical angle for total internal reflection) and (3) the wavelength of the incident laser beam. Results of varying the first two parameters are presented here; experimental study of the third parameter awaits our acquisition of a tunable laser source. The effect of varying these two parameters on the WGM/SERS signal level are plotted in Figs. 2 and 3. Figure 2 shows the dependence of WGM/SERS signal on distance of the sphere to the coupling prism. Note the total distance traveled is less than 1 micron, consistent with evanescent coupling distances. Figure 3 shows the WGM/SERS signal as a function of the angle in excess of the critical angle. Again, the measured angle dependence in the 0.02-0.09 degree is consistent with the evanescent coupling variation of the angle of incidence. In particular, note the steep increase in signal level beyond the critical angle signifying the onset of highly efficient coupling in the evanescent region. The bar graph provides more quantitative data on the angular dependence of the evanescent coupling.

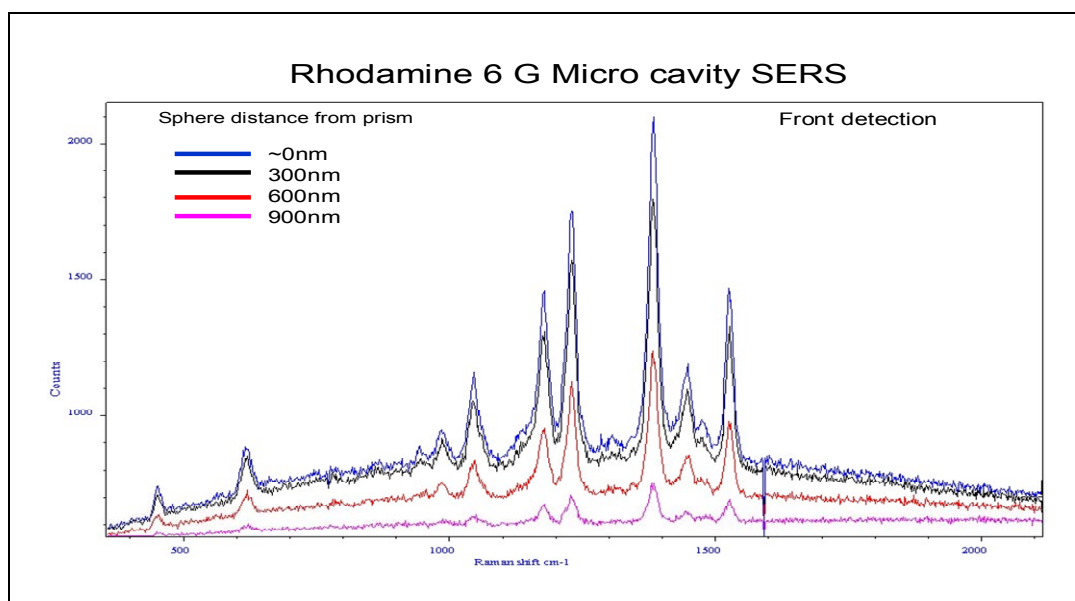


FIGURE 2

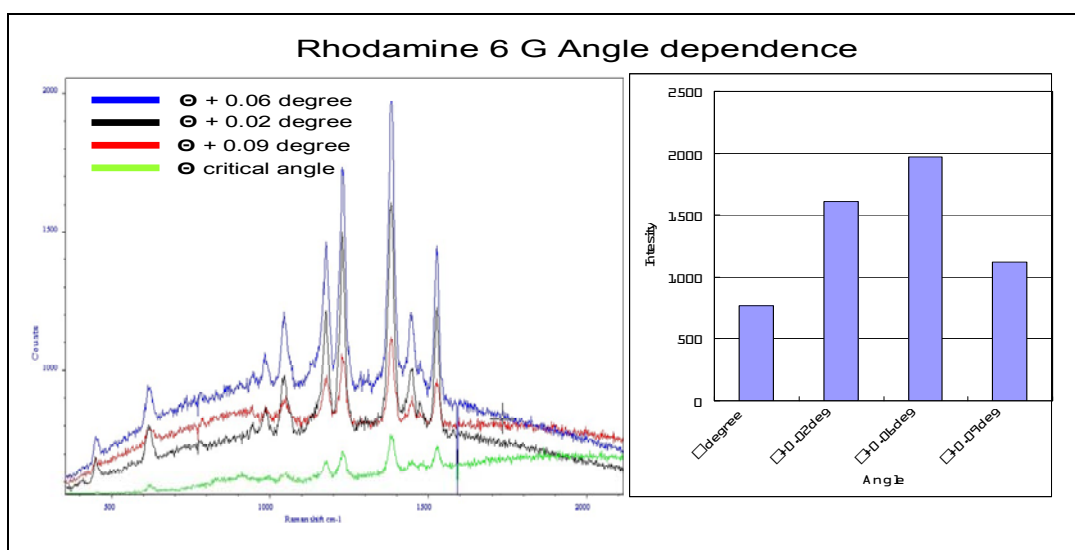


FIGURE 3

Figure 4 is a WGM/SERS spectrum of the e Coli bacterium. The feature of interest in the Figure is the great sensitivity of the measurement, corresponding to a small number of bacteria (1-5) in the pump laser focal volume and the short time to acquire signal (about 5 sec).

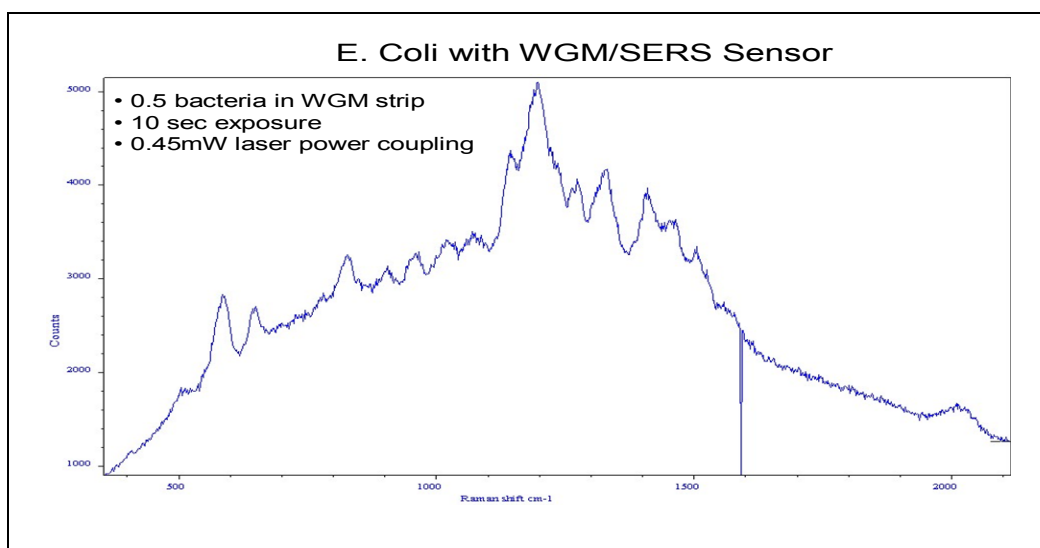


FIGURE 4