SURFACE-ENHANCED RAMAN SCATTERING IN PICOLITER DROPLETS: TOWARDS HIGHLY SENSITIVE AND SELECTIVE DETECTION OF MERCURY IONS

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ABSTRACT

We report a new method for the trace analysis of mercury ions in water using the droplet-based microfluidics combined with surface–enhanced Raman scattering detection. Specifically, mercury ion detection is performed by using silver nanoparticles labeled with aptamers and Raman reporters. To allow both reproducible and quantitative analysis, a microdroplet channel was used. The manipulation of aqueous droplets through winding microfluidic channels affords rapid and efficient mixing of the contents. This novel combination provides both fast and selective detection of mercury ions in water.

KEYWORDS: SERS, Microdroplet, Aptamer, Trace analysis, Lab on a Chip

INTRODUCTION

Environmental pollution by heavy metals and the resulting adverse effects on human health are problems of increasing concern. In particular, mercury ion is broadly considered to be one of the most toxic pollutants. Accordingly, it is highly necessary to develop a fast and sensitive method for the trace analysis of mercury ion in the water. Herein, we report a unique SERS aptasensor for mercury ion detection using a 21-mer aptamer. For SERS detection of mercury ions, the Raman reporter TAMRA was attached to the 5'-terminus of the synthetic aptamer. The reporter-labeled aptamers were subsequently adsorbed on the surface of silver nanoparticles via electrostatic interactions. Importantly, silver nanoparticles are stabilized against aggregation by the electrostatic repulsion, since highly negatively charged ssDNA spontaneously binds to silver nanoparticles through interactions between silver and nitrogen-containing bases. In the presence of mercury ions, nanoparticles start to aggregate since aptamers capture the mercury ions and form tertiary structures. As a result, SERS signal intensities are increased by the electromagnetic enhancement of aggregated hot spots with the increase in mercury concentration. However, quantitative trace analysis using SERS.has been hampered due to the difficulties associated with reproducing experimental parameters and thus great attention has been focused on the implementation of droplet-based microfluidic systems to SERS. The localizations of reagents within discrete and encapsulated droplets enhance mixing, avoid nanoparticle adsorption and afford highly reproducible conditions [1]. Herein, we demonstrate aptamer-based SERS detection in a droplet-based microfludic system.

EXPERIMENTAL

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Microfluidic devices were fabricated in polydimethylsiloxane (PDMS) using standard soft lithographic techniques. Silver colloids were prepared by recucing silver nitrate using hydroxylamine hydrochloride. An aptamer designed to specifically bind to Hg^{2+} has a sequence of 5`-TTCTTTCTTCCCTTGTTTGTT-3`,and TAMRA moiety at the 5` end is used as a Raman reporter. Spermine promotes surface adsorption of the negatively charged oligonucleotide probe and also aggregates the nanoparticles to provide the higher surface enhancement (Figure 1(a)). Raman measurements were performed using a Renishaw 2000 Raman microscope system. A Spectra Physics argon ion laser operating at 514.5nm was used as the excitation source with a laser power of 25mW. Raman scattering was detected using a CCD camera at a spectral resolution 4 cm $^{-1}$. The laser beam is focused in the middle of the microdroplet channel and the integration time is 10s.

RESULTS AND DISCUSSION

Figures 1(b) and 1(c) show a concept of mercury detection based on aptamer-conjugated silver nanoparticles. In the presence of spermine, ssDNA aptamer molecules are adsorbed onto silver nanoparticles via electrostatic attraction. Here, spermine interacts with the DNA backbone and thereby neutralizes the negative charge. Consequently, spermine solution aids DNA molecules to adsorb onto the metal surface. It also acts as as an aggretating agents for the Raman enhancement. When mercury ions are added, the aptamer changes its conformational structure to capture mercury ions and it results in the reduction of electrostatic interaction. As a result, the folded DNA structures induce a close proximity of nanoparticles and SERS signals are increased along the concentration of mercury ion. To improve system robustness for trace analysis, a droplet-based microfluidic system was used for reagent mixing and fluid control. A schematic illustration of the device structure and operation is provided in Fig. 2. Microdroplets were made to spontaneously form by injecting laminar streams of aqueous reagents into an immisicible carrier fluid. Here, the merging of two droplets, one is aptamer-conjugated silver nanoparticle solution and the other is a mercury ion solution (of varying concentration), has been achieved by passive merging by geometry modification of a channel width. The droplet size was controlled by varying the ratio of the aqueous-to-oil flow rates. As droplets pass through the winding channels, efficient mixing was achieved by chaotic advection. Figure 3 displays the change of characteristic Raman peaks from aqueous droplets containing various concentrations of mercury ions and corresponding calibration curve. The SERS signal concomitantly decreases with the decrease in mercury ion concentration. Figure 2(b) shows the change in the characteristic Raman peak of TAMRA at 1651 cm^{-1} resulting from the presence of mercury ions. Compared with fluorescence-based methods for the trace analysis of mercury (II) ions, the detection sensitivities were enhanced by approximately one order of magnitude.

CONCLUSIONS

Int this study, we demonstrate a highly sensitive and selective method for the trace analysis of mercury ions in drinkable water using the droplet-based microfluidic syatem combined with SERS detection. Here, aptamer-conjugated silver nanoparticles have been successfully used for the highly selective

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detection of mercury ions in water. We expect that our apporoach is applicable to the fast and sensitive trace analyses of other metal ions.

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REFERENCES

[1] G. Wang, C. Lim, L. Chen, H. Chon, J. Choo, J. Hong and A. J. deMello, *Anal. Bioanal. Chem.*, in press.
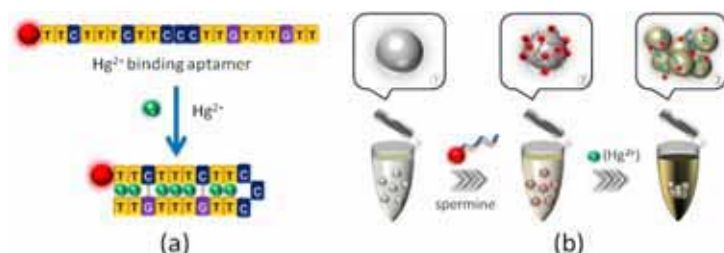

Figure 1 Schematic representation of aptamer-conjugated metal nano probes andits aggregation process by mercury ions.
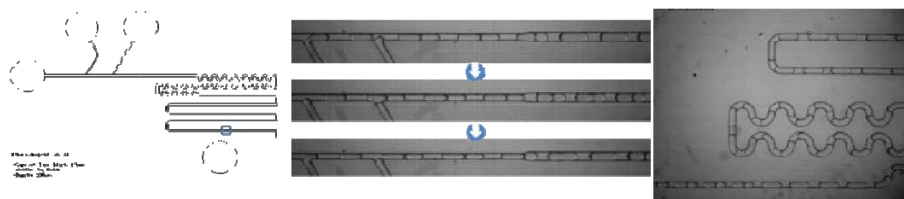

Figure 2 Fabricated PDMS microfluidc devices for the generation of alternating droplets.

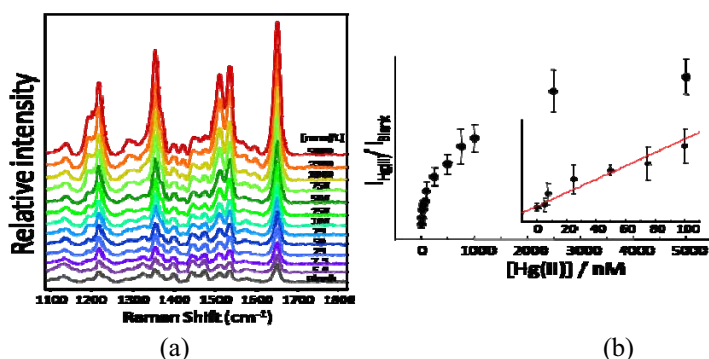(a)   (b)

Figure 3 (a) Variation of SERS Intensities as a function of mercury ion cnocentration and (b) corresponding calibration curve.

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