ABSTRACT

Since the discovery of intense scattered Raman signals from pyridine molecules adsorbed on a roughened silver electrode by Fleischmann's group in 1974, surface-enhanced Raman scattering (SERS) has emerged as one of the promising techniques in chemical and biomolecular sensing applications [1]. Using this technique, Raman signals from an extremely low concentrated analyte molecules can be detected. Depending on the size and pattern of the nanoparticles, the intensity of the scattered signal is enhanced by a factor of 10^8 or even more [2]. Due to the high sensitivity with unique fingerprinting capability, the SERS technique is used in different fields that include environmental analysis [3, 4], food quality analysis [5, 6], medical diagnosis [7], forensic science [8], and pharmaceutical applications [9].

Most common way to fabricate SERS substrates is by depositing noble metal nanostructures on a planar substrate. Substrates fabricated using electron beam lithography, optical beam lithography, ion beam lithography, and sputtering techniques offer high enhancement and good degree of reproducibility of the SERS signal, but, the high fabrication cost limits their use in large-scale applications. In an alternative way, to fabricate SERS substrates, plasmonic silver nanoparticles (AgNPs) and gold nanoparticles (AuNPs) have been deposited on the naturally and commercially available, and bio-inspired patterned nanostructured surfaces. These substrates provide high SERS intensity and good reproducibility in a very low fabrication cost and simple fabrication process. Lotus leaf, diatom frustules, printing grade papers, filter paper, polymer nanofibers, bio-polymer, compact discs (CDs) and Blu-ray digital versatile disc (BR-DVD) substrates have been widely used for the fabrication of SERS substrates [10–14].

Pesticides are used to improve the food quality and increase the crop yield by eliminating different insects, fungi, weeds and other pests. Presence of pesticides has been found in the drinking water, fruits, vegetables, and in different packaged food products. Pesticides are harmful to human health leading to various acute and chronic diseases [15]. Conventional pesticide detection techniques such as Gas chromatography combined with mass spectrometry (GC-MS) and liquid chromatography are very expensive, bulky, time-consuming sample preparation and detection process, requires an expert person to carry out the experiment. On-site detection of pesticide residues in

water and food matrices has become one of the important area in SERS-based sensing research. Although, several sensitive and flexible SERS substrates have been reported in the literature, there is a need for transparent, flexible, low-cost SERS substrates which can improve in-situ pesticide detection capability [11].

Infectious diseases caused by virus particles are one of the major concerns to the public health. Rotavirus is one of the main causes of severe gastroenteritis in infants and children worldwide, leading to a high number of hospitalizations and deaths [16, 17]. Rotavirus infection still poses a hazard in low-income nations, although vaccination has decreased the number of fatalities linked to rotavirus illness in recent years. Commonly used rotavirus detection and identification techniques are polymerase chain reaction (PCR) and enzyme-linked immunosorbent assay (ELISA). However, the instruments required for these techniques are very expensive and bulky with time-consuming and complicated sample preparation steps making these techniques unsuitable for rapid applications. Therefore, there is a requirement for reliable, cost-effective and sensitive SERS sensing platform that can be used as an alternative technique to detect the aforementioned analytes.

Present thesis focuses on the detection of two important pesticides in trace concentrations namely profenofos and cypermethrin that are widely used in farm land, and two biomolecular samples- rotavirus RNA and rotavirus particles using SERS sensing technique. Different SERS platforms fabricated through different routes is the center of the present thesis, and by using the developed SERS substrates the targeted analytes were detected reliably.

In the first chapter, the Introduction part of the thesis has been discussed. The chapter starts with the principle of Raman scattering process and SERS as molecular sensing tool. Then, two enhancement mechanisms- the electromagnetic enhancement mechanism and the chemical enhancement mechanism of SERS have been discussed. Then, enhancement factor and reproducibility of the SERS substrates, and SERS probes have been discussed. The thesis problem, scope and contribution of the thesis have been discussed in the end.

In the second chapter, different SERS substrates and their fabrication methods have been discussed. The usability of SERS substrates in different sensing applications has been discussed in this chapter. In the third chapter, functionality of a Raman spectrometer instrumentation that have been involved in the present research study has been discussed. A brief overview of few other compact Raman instruments which are used for rapid and portable SERS sensing applications have been discussed.

In the fourth chapter, the AgNPs has been synthesized and drop-casted on a flexible and transparent polyethylene terephthalate (PET) sheet to fabricate a sensitive, flexible and transparent SERS substrates. It has been found that the SERS signal of the Raman active molecule malachite green (MG) collected from the rear side of the transparent substrate scatters more intense SERS signal compared to the normal SERS signal collection. This observation was verified using the COMSOL Multiphysics simulation software. Proposed SERS platform has been utilized in sensitive detection of profenofos and cypermethrin pesticides.

In the fifth chapter, AuNPs have been deposited in the nanochannels of the commercially available BR-DVD by drop-casting and drying in a vacuum desiccator. For MG as an analyte, the substrates provide an average enhancement factor 3.2×10^6 and signal reproducibility is 94% with a relatively low fabrication cost INR 16 ($\sim$ \$0.2) per substrate. SERS spectra of rotavirus RNA samples are collected using these fabricated substrates. The experimental results have been compared with commercial-grade SERS substrate.

In the sixth chapter, AgNPs have been drop-casted over the commercially available 85 and 100 grams per square meter (GSM) paper to fabricate the sensitive, reproducible, and disposable SERS substrates. The 85 GSM paper SERS substrates have average enhancement factor of 5×10^6 and signal reproducibility is 90% with a relatively low fabrication cost INR 5 ($\sim$ \$0.06) per substrate. The substrates were utilized to detect rotavirus particles in clinical stool samples. The experimental results have been compared with commercial-grade SERS substrate.

The last chapter addresses the conclusion remarks of all the chapters and the future prospect of the research work.

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KEYWORDS

1. SERS
2. Surface-enhanced Raman scattering
3. SERS sensing
4. Electromagnetic enhancement simulation
5. Flexible SERS substrate
6. Blu-ray DVD SERS substrate
7. Paper-based SERS substrate
8. SERS pesticide
9. SERS RNA
10. SERS rotavirus