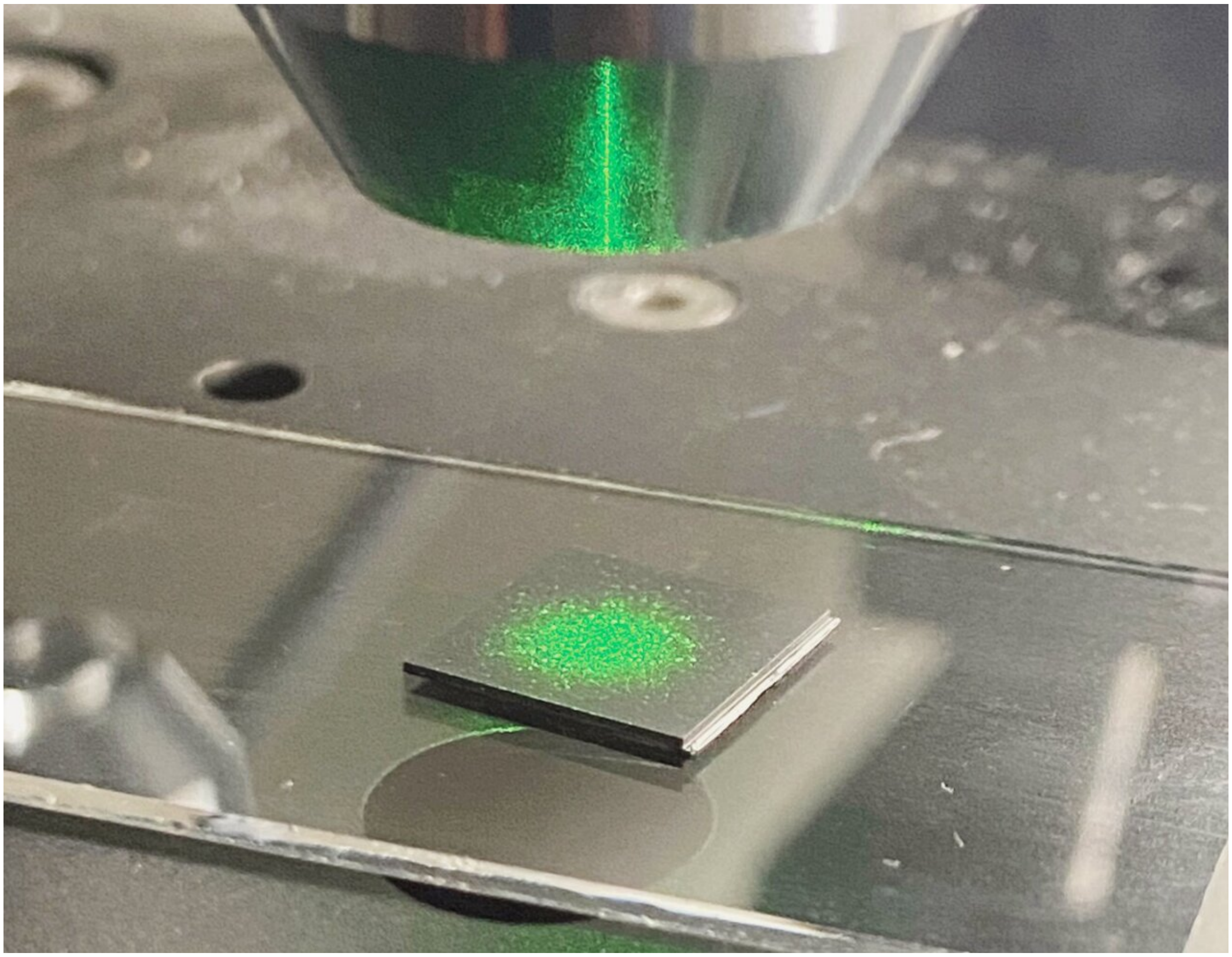
Nano-structured, reusable substrate for ultra-sensitive detection of pollutants

March 28 2023



With laser light and the so-called Raman effect, small material samples can be analysed and show whether, for example, traces of pollutants are contained. The substrate on which the sample lies plays a decisive role here. Credit: Cenk Aktas / Josiah Shondo

Surface-enhanced Raman scattering (or spectroscopy), known as SERS, is an advanced analysis method that extends the range of Raman applications to trace analysis, such as part-per-million-level detection of a pollutant in water or different liquids. SERS has a high potential to be used in the fields of biochemistry, forensics, food safety, threat detection and medical diagnostics.

But before the method can be applied at industrial and clinical levels, there is still a need for inexpensive and reliable SERS substrates that will allow reproducible spectral signals. Material Scientists from Kiel University carried the SERS approach to an advanced level by developing a new substrate with plasmonic and photocatalytic nanostructures. It increases the sensitivity, spatial and temporal resolution and leads to 50 times more powerful analyses than classical SERS.

Researchers designed this new substrate to be reusable, which significantly reduces the cost. Their results have been published in the journal *Small*.

The substrate plays a crucial role

Raman spectroscopy—named after physicist and Nobel Prize winner Chandrasekhara Venkata Raman—is a method of determining the chemical composition of materials. Therefore it can also detect harmful substances. For this purpose, a material sample is irradiated with a laser. Based on the reflected Raman signal, conclusions can be drawn about the properties of the material.

"The substrate plays the most critical role in the performance of this analytic technique, because of interactions with the laser light influence the Raman signal," explains Josiah Ngenev Shondo. As a doctoral researcher at the Chair for Multicomponent Materials, he works to improve the detection and photocatalytic clean-up of pollutants in water.

By combining materials with different properties, the researchers have now succeeded in producing a novel substrate for SERS analysis that enhanced the Raman signal by a factor of 50 in comparison to classical SERS.

"That's more than has ever been reported before for this method," says Professor Oral Cenk Aktas. That enormously increases the sensitivity, spatial, and temporal resolution in analysis of materials at trace amounts. As a result, even very small amounts of material can now be analyzed in a short time. Before and after the material analysis the researchers irradiate the substrate with UV light for activation and clean-up, respectively.

"This way the analyte is decomposed and the substrate, which is quite costly, can be re-used several times now. We showed that our substrate can be reused at least twenty times without any loss of its Raman activity," Aktas continues.

Substrate carries SERS approach to an advanced level

The researchers created the novel surface with a composition of nanocolumnar structures, a nanocrack network, nanoscale mixed oxide phases, and nanometallic structures ("4N-in-1"). This surface enhances the Raman signal and provides a high detection sensitivity. Recently PIERS (Photo Induced Enhanced Raman Spectroscopy), a new extension of SERS method, has been proposed.

With their novel PIERS substrate "4N-in-1" the research team combines plasmonic and photocatalysis concepts to achieve high resolution and signal enhancement in SERS analysis. "Our substrate brings various superior properties together on the same substrate. In addition to the plasmonic nanostructures, it is composed of extremely active titanium dioxide layer," says Dr. Salih Veziroglu.

Further plans: Spin-off and combination with AI methods

"This substrate is the result of many years of long-standing experience and various expertise in our Chair. Now we want to transfer our findings from fundamental research into an application," says Professor Franz Faupel, head of the Chair. Their substrate can easily be combined with any type of Raman spectroscopy, and this may trigger various new applications.

To bring their advanced method of Raman spectroscopy to the market, they are looking for other research groups and companies in laboratory and analytical technology. They also plan to combine their method with artificial intelligence (AI) to create a comprehensive data basis for materials analysis. This could enable faster and more precise detection of individual molecules.

One idea for a concrete application was already investigated by Shondo in his doctoral thesis, which is about to be completed. In 2018, the materials scientist came to Kiel University with a scholarship from the German Academic Exchange Service (DAAD) intent to do something about the environmental pollution in his home country of Nigeria. The extraction of the country's large oil deposits contaminates soils, rivers and even drinking water.

With the new substrate Shondo and his colleagues have developed, he sees potential for using it with portable Raman spectroscopy equipment in Nigeria: "Since even small amounts of oil can be detected and even removed, this method could be used at an early stage and prevent worse environmental damage."

More information: Josiah Shondo et al, Nanoscale Synergetic Effects on Ag–TiO_2 Hybrid Substrate for Photoinduced Enhanced Raman Spectroscopy (PIERS) with Ultra-Sensitivity and Reusability, *Small* (2022). DOI: 10.1002/smll.202270271

Provided by Kiel University