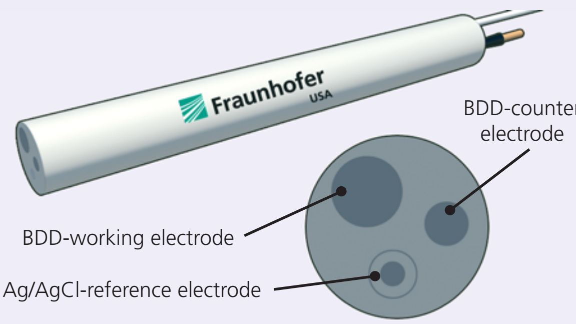
PORTABLE BORON-DOPED DIAMOND SENSOR FOR ANALYSIS OF TOXIC HEAVY METALS

THE TASK

Boron-doped diamond (BDD) has the largest electrochemical potential range of all electrode materials and, as a result, is considered an excellent sensor and electrode material. BDD has a wide range of application – from water treatment techniques to chemical syntheses and electrochemical analyses. Its extreme mechanical and chemical stability, the low background current and the low double layer capacitance make the BDD material particularly useful to detect traces of toxic heavy metals in water.

The increasing occurrence of toxic heavy metals in potable water is a growing problem. Continuous exposure to heavy metals, such as lead, cadmium and mercury is carcinogenic and results in physical damages including renal failure, massive nerve damage and lower IQ. Children's bodies absorb these poisons more quickly, so that these hazardous effects can be observed in children to an increased extent. The World Health Organization (WHO) reports in Europe indicate that the IQ of children drops even at blood lead values of less than 10 µg dl^{-1} or 1 ppm.

Portable BDD sensor, configuration with three electrodes



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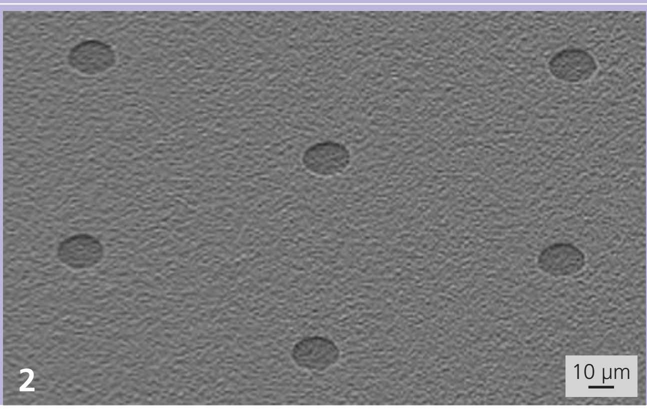
It is necessary to detect these metallic poisons before they enter the human body to avoid potential lifelong suffering. For this reason, it is very important to develop a simple and user-friendly sensor.

OUR SOLUTION

Researchers at the Fraunhofer Center for Coatings and Diamond Technologies CCD in Michigan, USA, engineered a portable electrochemical sensor for universal use, based on the boron-doped diamond technology. The sensor makes it possible to reliably measure even minimal heavy metal concentrations in potable water, for instance in the municipal water treatment station or at home. The sensor (Fig. 1) consists of a BDD working electrode, an Ag/AgCl reference electrode and a BDD counter electrode.

The development of a suitable BDD working electrode calls for investigations of microelectrode arrays (MEA) and macroelectrodes. Several geometry variants (diameter and center point-to-center point distances) of the MEAs were analyzed in detail to optimize sensitivity and detection limit. Figure 2 shows images of an individual microelectrode and the hexagonal configuration of the BDD-MEA.

The CCD researchers developed a miniaturized low-cost potentiostat to set up a complete measuring system. The potentiostat can control and measure the voltage curves required and resultant currents for a wide variety of electrochemical measuring techniques. Square-wave-stripping voltammetry (SWSV), in which the measured current is proportional to the concentration of the analyte in the solution, is a sensitive measuring technique that may also be used.



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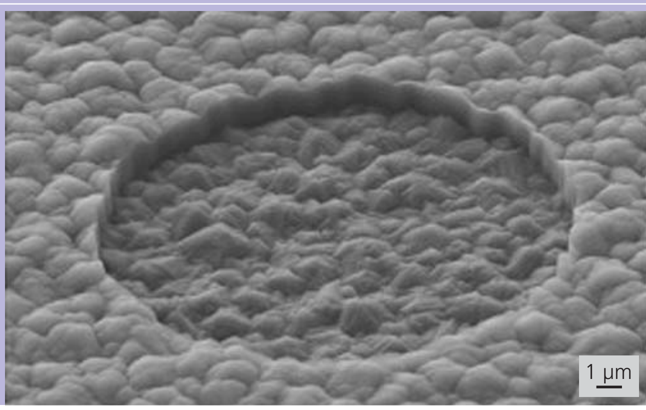
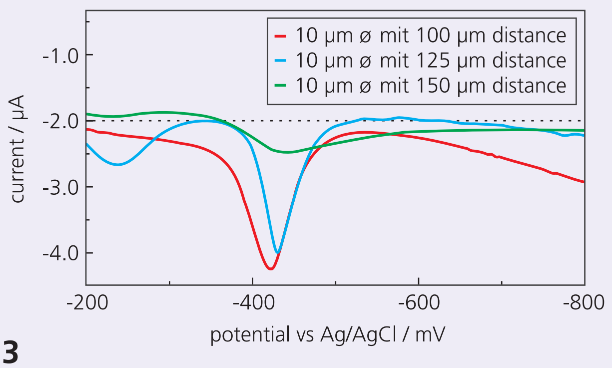


RESULTS

With SWSV, trace elements can be detected in heavy metal ions by eliminating the capacitive background currents. Thus the measured current only consists of faradaic current or current, which is caused by the analyte. Figure 3 lists the SWS voltammograms of lead, which were measured by various MEA geometries. Each electrode shows a clearly quantifiable reaction at a trace concentration of only 5 ppb (25 nM) lead in the solution. A 10 µm individual electrode diameter and a center point-to-center point distance of 100 µm proved to be the best option.

Square-wave-stripping voltammograms of a lead concentration of 5 ppb (25 nM) in PBS solution (pH 4.0), recorded by means of BDD-MEA electrodes of different geometries.



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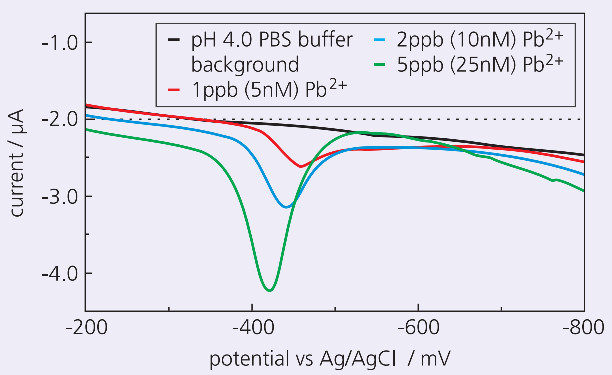
Square-wave-stripping voltammograms of several Pb^{2+} concentrations at a BDD-MEA with 10 µm diameter and 100 µm distance in PBS solution.



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Further examinations using the 10 µm x 100 µm BDD-MEA are summarized in Figure 4. In this case, a series of different lead concentrations from 1 to 5 ppb (5 to 25 nM) was analyzed. These concentrations were chosen to determine whether the BDD sensor was able to reliably measure concentrations below the maximum permissible values for potable water. For lead, for instance, these values are 10 ppb (50 nM) according to the German Federal environmental agency (German abbrev.: UAB) in Germany and 15 ppb (75 nM) according to the Environmental Protection Agency (EPA) in the USA.

As can be seen in the Figures 3 and 4, it is possible to obtain clearly quantifiable current measurements even for 1 ppb of lead. A linear correlation between the growing lead concentration and the current deflection obtained demonstrates that the BDD-MEA sensor created by Fraunhofer reaches a detection limit of 0.2 ppb (1 nM), which is 50 times or 75 times less than the permissible value for potable water according to the German UAB and the US EPA, respectively.

The CCD researchers also engineered optically transparent BDD electrodes for spectral-electrochemical measurements (such as to investigate polycyclic aromatic hydrocarbons), as well as BDD arrays for ozone generation, and flexible diamond electrodes – packed in polymer – to analyze neurotransmitters.

2 *Scanning electron microscopic image of a boron-doped micro-electrode array (BDD-MEA)*

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