Cadmium Contaminated Water Detection with Interdigitated Electrodes and Microfluidic System

Suroosh Ali, Vishal Rathee, Jayu Kalambe, Suresh Balpande

Abstract*: *In this paper, a sensing mechanism based on Microfluidics, for detection of dangerous heavy metals in liquids has been prepared. A pair of interdigitated electrodes (IDE's) was fabricated on a glass substrate using a silver ink constituting nano-particle size molecules. The impedance between the pair of IDEs was measured for different samples with varied cadmium concentrations. The capability of these IDE's for detecting very low to low concentrations (Picomolar to Millimolar) of Cadmium was explored. The response curve based on Impedance Spectroscopy Analysis of the IDE's with the help of a Digital impedance testing equipment was plotted for detection of Picomolar, Nanomolar, Micromolar and Millimolar concentration levels of Cadmium sulfide compound in water. The averaged out results obtained showed coherently decreasing impedance values with increasing Cadmium sulfide concentrations in water.

Index Terms*: *Impedance Spectroscopy, Interdigitated electrodes, Micro-fluidic sensing mechanism, Water dissolved Cadmium

I. INTRODUCTION

Contamination of Water because of hazardous heavy metals is a widespread concern that needs meticulous attention and awareness to retain the safe and unadulterated water with unharming quality. Millions of children, below the age of five pass away each year as a result of infections and disorders caused by such destructive water intake [1, 2]. Heavy metals in environment are a result of liberation of toxic atomic and nuclear wastes from industries into water-bodies, unintentional spills, farming and mining activities, etc. [3]. While these metals are omnipresent in the surroundings and some are vital nutrients when present in micro level, but all are toxic to biota above some threshold concentrations [4].

Revised Manuscript Received on June 20, 2019

Suroosh Ali, Research Scholar, Department of Electronics Engineering, Shri. Ramdeobaba College Of Engineering and Management, Nagpur, India.

Vishal Rathee, Assistant Professor, Department of Electronics Engineering, Shri. Ramdeobaba College Of Engineering and Management,
Nagpur, India.

Jayu Kalambe, Associate Professor, Department of Electronics Engineering, Shri. Ramdeobaba College Of Engineering and Management, Nagpur, India.

Suresh Balpande, Associate Professor, Department of Electronics Engineering, Shri. Ramdeobaba College Of Engineering and Management, Nagpur, India.

The existing Spectrometric detection methods such as Flame Atomic Absorption Spectrometry (FAAS), Atomic Absorption Spectrometry (AAS) and Graphite Atomic Absorption Spectrometry (GFAAS) are too complex, time-consuming, expensive processes and require hefty setups. This fact accentuates the need to build a system which will have the ability to detect and indicate the concentrations of heavy metals in a portable, savvy and streamlined way.

Group IIB element of the periodic table, 'Cadmium' is a heavy metal and its excessive omnipresence causes callous dangers to the mankind. It is found that universally about 7000 t/year of cadmium is emitted from varied sources [5, 6]. Along with copper, zinc and lead, cadmium coexists in the form of minerals. It finds widespread utilization in manufacturing methods as an operator which is anticorrosive, as an added substance in PVC items, as a color dye, in nuclear power plants as an absorber of neutrons and in manufacturing of NiCd rechargeable batteries [7]. Manures consisting of phosphate too demonstrate enormous cadmium content. . Despite the fact that few cadmium inherent items can be reused, a major share of the basic cadmium contamination is brought about by dumping and burning cadmium-embedded waste [8-10]. Cadmium exists as compounds of Sulfides, Sulphates, Chlorides, etc. in water. The metal itself is insoluble in water, but its compound illustrates varied solubility. Cadmium Sulfide (CdS), has low solubility, with a reported limit of 1.3 mg/L whereas the Sulfate ($CdSO_4$) and Chloride ($CdCl_2$) salts of Cd demonstrate quite high dispersion property in water with reported limit of 608,000 mg/L and 1,680,000 mg/L respectively [11, 12]. Excessive cadmium pesters the neural sensors, human digestive and urinary systems with undesirable physical and mental human wellness. Furthermore, over cadmium consumption causes tumors and cancers to significantly develop because of the solid bonds that the sulfur atoms in the human body make with these metal particles [13, 14]. An Impedance spectroscopy technique is utilized here to detect cadmium which gives the advantage of operations without any labels on the sample, miniaturization friendly and relatively inexpensive for validation and quantitative interpretation of experimental impedances [15]. The sensing mechanism based on IDE's as measuring elements offer vital advantage of requirement of low sample volumes and avoidance to

monotonous polishing of electrodes. The interdigitated form of electrodes in general raises the sensing power and detection limits towards the contaminant and is appropriate for developing analytical devices and for other chemical science studies [16].

In this work, Ag based ink was employed to fabricate two paired (4 teeth) Interdigitated electrodes on a substrate i.e. glass which was then sintered for 10 minutes on a heating mantle at about 280°C to acquire the IDE structure. Polydimethylsiloxane (PDMS) was deposited on the glass substrate around the IDE to create a boundary for the obstruction of the liquid flow. The potential of the IDE mechanism was tested by observing the response based on Impedance Spectroscopy for Cd compound based water samples with the assistance of a handheld LCR meter. Sample concentrations of cadmium sulfide (CDS) in DI water prepared to a tune of Picomolar, Nanomolar, Micromolar and Millimolar were analyzed for impedance variations at a frequency of 100 Hz utilizing digital LCR meter.

II. EXPERIMENTATION

A. Processing of Materials for sample preparation

A translucent glass petri-dish having a thickness of 3 mm was used as the base for development of sensing mechanism. A nano molecular silver conductive ink (TEC-IJ-010) from InkTec Inc. was used for preparing metallic electrodes. Heat curable silicon-based Polydimethylsiloxane (PDMS), an organic polymer was bought as two-part silicone elastomer kit (Sylgard® 184) from Dow Corning and was used to create the boundary of IDEs to obstruct the liquid flow. Difference in the properties of the above two materials (Given in Table 1) ensured efficient isolation and non reactiveness amongst them.

Table 1: Properties of Silver metal and PDMS

	Silver	PDMS
Density	10.50 g/cm^3	965 kg/m^3
Melting Point	962°C	-49.9 – 40°C
Boiling Point	2212°C	200°C
Hardness	25	46
Thermal Conductivity	419 W/mK	0.15 – 0.2 W/mK

Crystallised Cadmium Sulfide (CdS) was bought from the Chemical Company Sigma–Aldrich® to prepare sample and Agilent's U1732C Digital Handheld LCR Meter having maximum frequency range upto 10 kHz was used for its impedance measurement purpose. A J-SIL High Precision Micropipette was used for the preparation of milimolar, micromolar, nanomolar and picomolar CdS solutions. The suspension of CdS was done in DI water to form solutions of 1 to 13 mM, µM, nM and pM concentrations. All the prepared solutions were stored in 100 ml aliquots at 4.44°C before use.

With improved mobility and reduced size of the metal sensing mechanism, its potential users could be the Gram panchayats, NGO's, Local municipal corporation departments, Fertilizer vendors, Water testing agencies, Food manufacturing industries, Hospitals etc. in urban as well as rural areas.

B. Fabrication of Microfluidic Sensing Platform

The Silver ink used to formulate the interdigitated electrodes on the substrate made up of glass was preferred over other metallic pastes like copper/ aluminium for its good reliable electrochemical properties over a wide variety of applications and processes. For the fabrication of the electrodes, Gray resin moulds (shown in Fig. 2) were created using 3D printing process. The sensing area consisted of two pairs of IDEs that were 10 mm (10000 µm) long with spacing and width of 4 mm (4000 µm) and 2 mm (2000 µm) respectively, selected keeping futuristic mobility and space constraints for handheld sensor in mind. The glass substrate was first cleaned with acetone to remove the dirt and fingerprints. A PDMS based solution was prepared by taking the PDMS and curing agent in a ratio of 10:1 and pouring it around the fabricated IDE to create a boundary for the obstruction of the liquid flow. The sensor structure was then kept on a heating mantle at around 150°C for about 15 minutes to cure the PDMS solution [17].

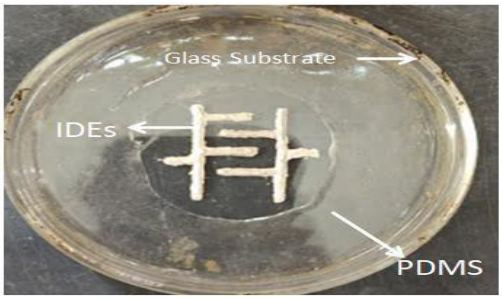

Fig.1: Fabricated IDE on glass substrate

Fig.2: Fabricated Gray resin 3D printed moulds

C. Experimental Setup

The calibration of the wires and probes in the experimental setup (shown in Fig.3) was done before taking measurements with offset null adjusted properly. All the measurements were performed at normal ambient temperature. A simple syringe was used to pour 0.2 ml of the prepared sample drop-wise on the fabricated IDEs. The crocodile clip leads were connected to the handheld digital LCR meter and these leads were connected to the two electrodes of the IDE to measure the impedance values. The magnitude of impedance of the device was measured at a frequency of 100 Hz using LCR meter. The lowest frequency of 100 Hz was selected as it is less likely to show up any stray reactances and higher frequencies may modify the effective value of the impedance. The response of the sensing mechanism was observed and plotted.

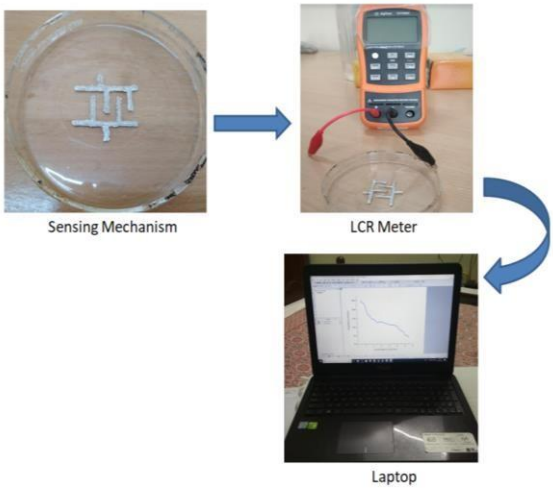

Fig.3. Experimental Setup

III. RESULTS

The fabricated sensing mechanism was tested for different concentrations of CdS in DI water. Figure 4, 5, 6 &

7 show the dynamic impedance response curves of the mechanism for the four different concentrations of CdS (pM to mM) having a step-size of 10^3 determining the cadmium concentration present from 0.187798 x 10^{-9} gm to 0.014446 gm with an impedance variation ranging from 343-163 kΩ, 485-275 kΩ, 1600-750 kΩ and 420-70 kΩ respectively. The decrement in
the value of impedance with linearly increasing sample concentration (CdS dissolved DI water) arises due to the increase in capacitance and decrease in resistance values of the interdigitated electrodes, since impedance is inversely proportional to capacitance and directly proportional to the resistance between the electrodes.

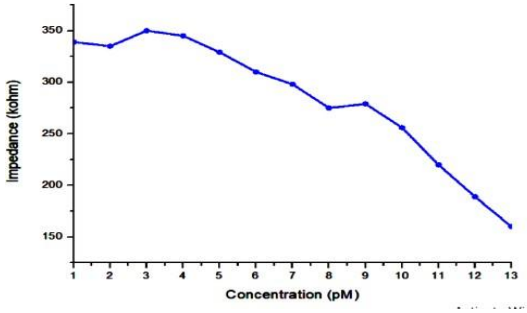

Fig.4: Picomolar CdS concentration

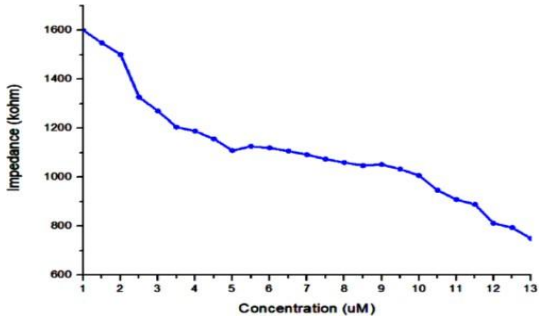

Fig.5: Nanomolar CdS concentration

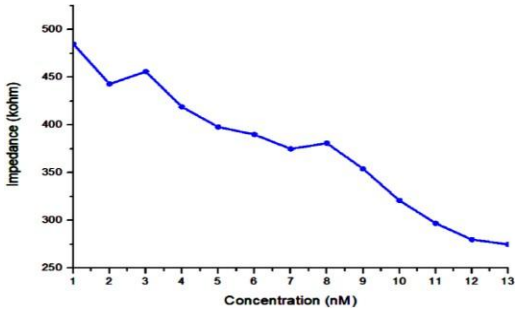

Fig.6: Micromolar CdS concentration

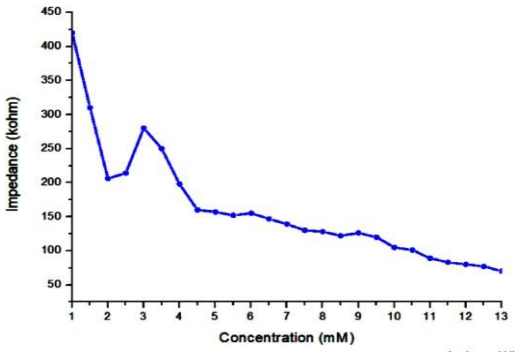

Fig.7: Millimolar CdS concentration

IV. CONCLUSION

In this work, a Microfluidic Sensing mechanism for detection of a standalone suspended heavy metal Cadmium was successfully investigated with the help of Silver ink-based interdigitated electrodes. The mechanism's potential to differentiate between different concentrations of prepared CdS was determined. The mechanism's impedance response curves showed an easily measurable impedance range between 1600 kΩ to 70 kΩ with standard deviations of 61.90, 56.89, 196.41 & 64.18 respectively for increasing concentrations of Cd. The results indicate coherence with study of gradual decrease in impedance with increasing sample concentration while some of the hikes were observed in between measurements due to environmental effects, presence of static electric field and lack of automation in the measurement setup

ACKNOWLEDGMENT

The authors wish to thank Soham Khapre, Bhavishya Waghwani, Rushali Pardhi and Dr. Suraj Butolia, RCOEM, Nagpur for their technical support and guidance. We acknowledge the Grant received from DST (India) under FIST level0 and the Microsystem laboratory in the Electronics Engineering Department at Shri. Ramdeobaba College of Engineering and Management, Nagpur for providing the necessary chemicals, measurement setup and other facilities.

REFERENCES

1. Dinesh Rotakea and A. D. Darjia, "Heavy Metal Ion Detection in Water using MEMS Based Sensor", International Conference on Processing of Materials, Minerals and Energy, Science Direct Journal, 2016
2. Binu Baby Narakathu et al., "Development of a Microfluidic Sensing Platform by Integrating PCB Technology and Inkjet Printing Process", IEEE sensors journal, vol. 15, no. 11, 2015
3. N. Verma and M. Singh, "Biosensors for heavy metals," Biometals, vol. 18, no. 2, pp. 121–129, Apr. 2005.
4. S. Rajindiran et al., " Heavy metal polluted soils in india: status and countermeasures", ResearchGate article, JNKVV Res J 49(3), 2015
5. Johannes Godt et al., "The toxicity of cadmium and resulting hazards for human health", Journal of Occupational Medicine and Toxicology,2006
6. Gaspar Banfalvi, "Removal of insoluble heavy metal sulfides from water", Chemosphere, 2005
7. Shaofang Zou et al., "An Environmental Automatic Monitoring System for Heavy Metals", IEEE International Conference on Control and Automation, CHINA, 2007
8. Terry L. Roberts, "Cadmium and Phosphorous Fertilizers: The Issues and the Science", Procedia Engineering 83, 2014
9. C. H. Williams and D. J. David, "The Accumulation in soil of cadmium residues from phosphate fertilizers and their effect on the cadmium content of plants" , Soil Science, Vol. 121, No. 2
10. Usarat Thawornchaisit and Chongrak Polprasert, "Evaluation of phosphate fertilizers for the stabilization of cadmium in highly contaminated soils", Journal of Hazardous Materials 165, 2009.
11. Jennifer de Livera et al., "Cadmium solubility in paddy soils: Effects of soil oxidation, metal sulfides and competitive ions", Science of the Total Environment 409, 2011
12. G Oberdörster, "Pulmonary deposition, clearance and effects of inhaled soluble and insoluble cadmium compounds", IARC scientific publications.
13. Lars Jarup, "Cadmium overload and Toxicity", Nephrology Dialysis Transplantation 17, 2002
14. Takeya Inaba *et al.*, "Estimation of cumulative cadmium intake causing Itai–itai disease", Toxicology Letters 159, 2005
15. N S Mazlan *et al.*, "Interdigitated electrodes as impedance and capacitance biosensors: A Review", 3rd Electronic and Green Materials International Conference, 2017
16. A.K.M Muaz *et al.*, "Fabrication of Interdigitated Electrodes (IDE's) by Conventional Photolithography Technique for pH Measurement Using Micro-Gap Structure", IEEE Conference on Biomedical Engineering and Sciences, Malaysia, 2014
17. Balpande S.S., Bhaiyya M.L., Pande R.S., "Low-cost fabrication of polymer substrate-based piezoelectric microgenerator with PPE, IDE and ME", Electronics Letters, 2017, 53, (5), p. 341-343.

AUTHORS PROFILE

Suroosh Ali, received her Bachelor's degree in Electronics and Telecommunication Engineering in the year 2017 and is currently pursuing her Master's degree in VLSI Design from Shri. Ramdeobaba college of Engineering and Management, Nagpur.

Vishal Rathee, is an Assistant Professor at Shri Ramdeobaba college of Engineering and Management, Nagpur and he received his Bachelor's degree in Electronics and Telecommunication Engineering in the year 2002. He completed his Master's degree in Electronics Engineering in 2007. His fields of interests are Microsystems and soft computing. He has published more than 10 papers in International Conference /Journal.

Jayu Kalambe, is an Associate Professor at Shri Ramdeobaba College of Engineering and Management, Nagpur. She has received her Master's degree and Ph.D. in Electronics engineering from the Visvesvaraya National Institute of Technology, Nagpur. Her research area includes design and analysis of microcantilever-based sensor. She has authored over 30 papers in national and international conferences, six papers in international journals and one patent. She is a member of ISTE, IEEE and ISSS.

Suresh S. Balpande, is an Associate professor at Shri Ramdeobaba College of Engineering and Management, Nagpur and he has received his Master's degree in Digital Electronics with honors and then carried out his doctoral research in the area of Energy Harvesting Systems. His research interests are MEMS sensors, Industrial Automation and Mechatronics. He is credited with thirty journal publications, International-National conferences and magazine articles. He is a reviewer of Scopus indexed and SCI journals and served as advisory board member for international and national level conferences. He is also associated with ISTE, IETE and ISSS.