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Advanced Functional Materials and Devices

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This book is dedicated to Late Prof. Vinay Gupta

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Foreword

I would like to congratulate the Department of Physics for the successful organization of three-day online International Conference on "*Advanced Functional Materials and Devices (AFMD 2021)*" under the IQAC. The department has been at the forefront in research activities in college, and this new endeavour has proved to highlight their commitment to the same.

Atma Ram Sanatan Dharma College has become synonymous with equity and excellence in the last few years. Established in 1959, the college underwent upheaval and transformation in the post-independence years. Yet, the ability to adapt while holding onto one's cultural identity, built into its foundations early on, has held ARSD in good stead. A NAAC-accredited A-grade institution and holding NIRF All India Rank of 13, the college stands testament to this community's dedication towards creating an educational ecosystem that is holistic and all-embracing. In the last five years, the college has gone from strength to strength, developing existing facilities to maximize their potential and keep pace with rapid shifts in the global economy. ARSD is evolving into an excellent centre for research. The departments of physics, chemistry, biology and mathematics are funded by the Department of Biotechnology, GOI, under the Star College Scheme, attesting to the high quality of work being undertaken at the campus. The establishment of the DBT Science Centre in addition to the Centre for Innovation and Entrepreneurial Leadership (CIEL) in collaboration with M/oMSME, a first for any University of Delhi college, showcases ARSD's commitment to research and innovation. The college has been the recipient of several prestigious grants and is fast emerging as a hub of research. The aim of ARSD College is, therefore, to produce bright young minds in synergy with their ecosystem and maximizing their potential in an ethically sound manner. I wish this institution the very best and hope it continues to light the way towards the creation of a knowledge society.

AFMD 2021 was enriched with 20 invited lectures from eminent researchers and also received 94 abstracts for oral and poster presentations from all over the world. The conference began with the inaugural ceremony by respected Guests of Honour, Prof. Vinay Gupta (Dean, FOT, University of Delhi); Prof. Prem Lal Uniyal, Treasurer, ARSD College; and Chief Guest, Prof. Pradeep Burma, Chairman, ARSD

College followed by a plenary talk by Prof. R. S. Katiyar, University of Pureto Rico, USA. I would like to thank all the invited speakers and participants for sharing their valuable knowledge and research work on this platform. The theme of the conference was very relevant to the present day of technology. Researchers from each and every corner of the globe are working very efficiently in the advancement of the technology for the benefit of the common people.

I am happy to announce that this proceeding book is the outcome of the papers received in AFMD 2021. I would like to congratulate all the authors whose papers have been selected for the publication. My sincere gratitude to the respected reviewers and editors for putting their efforts and time. The editorial board of this proceeding book was led by renowned researchers Prof. Saluru Baba Krupanidhi (Emeritus Scientist, IISc Bangalore) and Late Prof. Vinay Gupta (Professor, University of Delhi). I thank both Prof. Krupanidhi and Prof. Gupta for their valuable cooperation. I really appreciate the hard work of other editors Dr. Anjali Sharma Kaushik and Dr. Anjani Kumar Singh for giving shape to this book. At last, I appreciate the convener of the conference, Dr. Vinita Tuli, and the organizing team for the grand success of AFMD 2021. I wish them all the very best for future endeavours and may many such more feathers of accomplishments be added in their hat of success.

Coming together is a beginning. Keeping together is progress. Working together is success.

June 2021

Gyantosh Kumar Jha
Principal, Atma Ram Sanatan Dharma College
University of Delhi
New Delhi, India

Preface

The book titled *Advances in Functional Materials* presents the selected proceedings of the International Conference on "Advanced Functional Materials and Devices" (AFMD 2021). AFMD 2021 was organized by the Department of Physics and Internal Quality Assurance Cell of Atma Ram Sanatan Dharma College, University of Delhi, New Delhi, India, from 3 to 5 March 2021 via online mode. Papers published in this book highlight the advancements in functional materials which include electronic, magnetic, optical, adaptive, dielectric materials, etc., that are required to develop new functionalities with better performance in the present era based on technology. The topics covered include the knowledge of a wide range of materials for energy harvesting, biomedical applications, environmental monitoring, photonics and opto-electronic devices, strategic applications and high energy physics. This book can be a valuable addition reference for beginners, researchers, and academicians regarding the new functional materials for device applications.

The conference consisted of invited as well as technical sessions along with the discussions with eminent speakers covering a wide range of topics: multifunctional materials, 2D materials, biomaterials, materials for environmental studies, DFT and solar simulation of materials, perovskite and double perovskite materials, luminescent materials, smart materials, materials for energy conversion and storage, smart materials, advanced functional materials, polymeric materials, composites, liquid crystals, materials for sustainable development, nanomaterials and thin films, smart devices and quantum dot synthesis technique, and characterization tools with application in smart devices. On this occasion, one plenary speaker, 2 keynote speakers and 20 invited speakers delivered their outstanding research works in various fields of material science. There were 54 oral presentations and about 40 poster presentations by participants which brought great opportunity to share their recent research work among each other graciously.

A total of 94 abstract submissions were received from all over the world including countries like Singapore, USA, Mexico, Iran, South Korea, Japan, etc., from which 62 full-paper submissions materialized. All papers were reviewed by two experts in the field, and after intense review, only 33 papers were accepted for the publication. This proceeding book mainly focuses on the material science, but few papers are

from nuclear and particle physics also as the scope of the conference. Efforts taken by peer reviewers in the form of constructive critical comments, improvements and corrections to the authors contributed to improve the quality of papers which is gratefully appreciated. Our sincere gratitude to all the authors who submitted papers because of which the conference became a story of success.

We hope the papers published in the proceeding book will not only expand readers' knowledge but also open a new platform for research to grow. Last but not least, we thank the respected editors, International/National Advisory Committees, session chairs, programme committee members and external reviewers, who invested time and effort in the selection process to ensure the scientific quality of the programme. We also thank Springer Nature for their support towards our journey of success. Their support was not only the strength but also an inspiration for organizers.

Bengaluru, India — Saluru Baba Krupanidhi
New Delhi, India — Vinay Gupta
New Delhi, India — Anjali Sharma Kaushik
New Delhi, India — Anjani Kumar Singh

Contents

About the Editors

Prof. Saluru Baba Krupanidhi is a materials scientist who integrates in an exemplary manner fundamental science with engineering of materials and devices. He has worked as Professor at Indian Institute of Science, Bangalore for more than 22 years. At present he is serving as Emeritus Professor at IISc. He is internationally recognized in the areas of integrated ferroelectrics and compound semiconductor technology as evidenced by invited lectures at international meetings and memberships of editorial boards. Professor Krupanidhi's research is focused on developing expitaxial thin films of complex oxides for electro-optic, ferroelectric, and high permittivity dielectric applications and hetero epitaxial compound semiconductors for opto-electronic applications. His major contributions in the area of complex perovskites include ECR plasma assisted development of low temperature epitaxy, rapid thermal processing, modeling of crystallization in perovskite thin films under strong thermal gradients, and engineered properties in the superlattices of ferroelectric peroksites. Professor S. B. Krupanidhi has been honored with many awards and positions like 2 Engineering Invention Awards at Motorola, USA (1986), MRSI Medal, India (1997), Fellow of Indian Academy of Sciences (2003), VASVIK Medal (2004), MRSI Superconductivity-Materials Science Award (2004), Tatachem Chair Professor, Indian Institute of Science (2006), Rustum Choksi medal for research excellence, IISc (2006) J. C. Bose Fellow, DST (2009–2019), Prof. C. N. R. Rao Lecture Prize, MRSI (2010), Fellow of Indian National Science Academy (2012), Fellow of Indian National Academy of Engineering (2012) D. S. Kothari Research Professor (2016–2020), INSA Senior Scientist (Indian Institute of Science) (2018–2021) and MRSI Distinguished Materials Scientist Of The Year Award (2019). He has published more than 600 research papers in journals of high repute. He has also guided more 55 research Scholars who are holding good position in leading institutes.

Prof. Vinay Gupta received the B.Sc., M.Sc., and Ph.D. degrees in physics in 1987, 1989, and 1995, respectively, from the University of Delhi, New Delhi, India. Presently, he is a professor in the Department of Physics and Astrophysics and Dean of Faculty of Science, University of Delhi. His current research area includes semiconductor and surface acoustic wave (SAW) sensors for gas/chemical/radiations/biomolecules, amperiometric/photometric biosensors, surface plasmon resonance (SPR) technique for dielectric studies and sensing applications, micro-fluidics, nanostructured materials, piezoelectric and multiferroic thin films/ceramics for energy harvesting applications, pressure sensors, RF and microwave resonators, photonic devices, non-linear optical studies, SAW devices, MEMS transducers and Microheaters, Molecular Simulations and device modeling. He is engaged towards the development of integrated devices having strategic as well as commercial applications. His research group has successfully integrated piezoelectric ZnO thin film with MEMS structures fabricated by CEERI, India for acoustic sensor as per specification desired by Indian Space Research Organization (ISRO). These Acoustic sensors have been installed in PSLV flights of ISRO from C9—onwards. He has published more than 370 research papers in high impact factor SCI journals. He has been granted one US and 3 Indian patents along with one successful technology transfer of Indigenously developed table top SPR system which is being used in various academic and research institutes. He is an active member of various reputed research societies like IEEE, MRSI, EMSI etc. At present he has project grants of more than Rs. 4 Crores. He is recipient of BOYSCAST fellow, MRSI Medal-2012 presented by Material Research Society of India and also recently received Distinguished Teacher's Award by University of Delhi. Recently he has been ranked amongst top 2% scientists by Stanford Ranking of world's Best Scientist.

Dr. Anjali Sharma Kaushik received her B.Sc., M.Sc. and Ph.D. degrees in Physics in the year 2006, 2008 and 2013, respectively, from University of Delhi. At present, she is serving as Assistant Professor at Atma Ram Sanatan Dharma College, University of Delhi. Her research interests are in gas sensor systems that include sensor characterization and development of metal oxide films for sensor coatings. She is working towards the fabrication of MEMS based electronic-nose for gas sensing applications. Her area of interest also includes the metal oxide based thermoelectric energy harvesters and fabrication of 2D materials like MoS_2 for sensing applications. She is recipient of Dr. G. C. Jain Memorial Award for best Ph.D. thesis by Material Research Society of India in year 2015 and Shri Ram Arora Award at 141st Annual meeting of The Metals, Minerals and Materials Society, Orlando USA in year 2012 for her excellence in Materials and Engineering. She has published more than 55 papers in journals of high repute with h-index of 17 and has published two Indian Patents. She is also working as Co-PI in two DRDO and DST sponsored projects. She is also actively involved in many students and administrative activities of the college.

Dr. Anjani Kumar Singh is an Assistant professorin the Department of Physics, Atma Ram Sanatan Dharma College, University of Delhi. He has done his M.Sc. from UP Autonomous College, Varanasi and Ph.D. from Delhi University in the year 2010. He worked as a Teaching cum Research Fellow at N.S.I.T., New Delhi. During his Ph.D. work and afterwards he has published twenty 22 research papers in peer reviewed international journals and International Conference. He is a life member of The Materials Research Society of India (MRSI). His major research interests are Electrostriction Based Dielectric Materials, Fuel cells.

Electrocatalytic Properties of ZnO Thin Film Based Biosensor for Detection of Uric Acid

Kajal Jindal, Vinay Gupta, and Monika Tomar

Abstract A novel uric acid biosensor employing ZnO thin film as matrix is developed using pulsed laser deposition technique. The dependence of electrocatalytic properties of ZnO thin films on the ZnO processing pressure during growth is studied. It has been observed that the growth kinetics of ZnO matrix play a critical role in governing the electron transfer characteristics of ZnO thin film based biosensors. It is found from the cyclic voltammetric measurements that the peak oxidation current of ZnO/ITO/glass electrode increases with a rise in pressure of ambient gas from 1 to 100 mT and is maximum (548 μA) for ZnO thin film based electrode prepared in an oxygen ambient of 100 mT. The variation in peak current with change in processing pressure is attributed to the change in surface properties, which largely depends on the mean free path and kinetic energy of ablated species arriving at the substrate. The optimized ZnO thin film (100 mT) offers high surface coverage (9.74 $\times$ 10^{-9} mol/cm^2) during immobilization of uric acid resulting in a sensitivity of 122 μA/(mM-cm^2). In addition, the prepared ZnO based biosensor exhibit high affinity towards detection of uric acid (K*m*~0.07 mM), low limit of detection (0.01 mM) along a storage stability of more than 20 weeks. Thus, the present work suggests an important role of plume kinetics for the fabrication of ZnO thin film based biosensors.

Keywords Uric acid · Zinc oxide · Biosensor

1 Introduction

Recent years have witnessed a growing trend in the research on biosensors as the development of biosensors has facilitated a common man to keep track of the levels

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of various metabolites related to his health at home [1]. Out of the various components of biosensors, Matrix forms the most crucial element as it governs the charge transfer characteristics from the enzyme active center to the electrode. Various literature studies suggest that metal oxide based matrices are preferred due to their high stability, excellent electron communication features, and ease of enzyme immobilization via physical adsorption due to their high isoelectric point (IEP) [2]. Out of the various metal oxide matrices, Zinc oxide (ZnO) has been widely employed for applications in biosensing due to its biocompatible nature, low toxicity, ease of deposition, good electron transfer characteristics, and high IEP for binding of enzymes (~9.0) [3]. It has been used for detection of various bio-analytes in human blood including glucose [4], cholesterol [5], H_2O_2 [6], urea [7], DNA [8], etc. Recently, ZnO finds great applications in development of reagentless biosensors by doping [9], forming *p–n* junction heterostructures [1], or making hybrid composites [10]. Wu et al. [11] have reported a photoelectrochemical and self-powered biosensor based on *p–n* junction of ZnO and Cu_2O. Uddin et al. [12] have reported the development of a chemisensor based on GCE modified with ZnO/RuO_2 NPs for detection of 2-nitrophenol in different water samples. Thus, ZnO forms the constituent of most of the biosensors exhibiting high stability and sensitivity. Particularly, ZnO grown by physical deposition techniques such as pulsed laser deposition (PLD) is exploited for biosensing applications due to the stoichiometric, and nanocrystalline growth of thin films, small turnaround time, good reproducibility and high chemical stability [13]. The electron transfer characteristics of a matrix are strongly dependent on the growth parameters and thus, it is important to critically analyze the role of growth parameters of ZnO thin film on its biosensing response [14]. Despite the fact that ZnO is the most widely used matrix for the development of biosensors, an insight into its growth kinetics in governing its electrocatalytic properties has not been provided in literature.

Uric acid (UA) is chosen as a model analyte in the present work to analyze the critical role of processing parameters of ZnO thin film on its electrocatalytic properties. Uric acid is an important constituent of biofluids including urine and blood serum which is released as a consequence of breakdown of purines [15]. Purine is a key constituent of some common foods and drinks that are consumed in our daily life, such as sweet breads, seafood, meat extracts, dried beans, peas, and beer. A major portion of the uric acid (~70%) in human body dissolves in blood and is transported through the bloodstream to the kidneys which is then degraded with the help of urate oxidase (uricase) enzyme into allantoin and excreted out of the body in the form of urine [16]. Nevertheless, UA level in our human serum can become elevated if our body produces in excess or if it doesn't efficiently dispose it. In human blood, men and women should have a reference range of uric acid between 0.214–0.506 mM and 0.137–0.393 mM respectively [1]. UA levels outside the physiological range on either side can be considered as an alarming sign related to several diseases [9]. Therefore, development of sensitive, selective, cost-effective, and reproducible biosensors for detecting the level of uric acid is the concern of research community. Thus, in the present work, role of growth kinetics in Pulsed

laser deposition technique on the electrocatalytic properties of ZnO thin film based electrode has been studied towards the detection of uric acid.

2 Experimental

Preparation of uric acid biosensor mainly involves the following process steps.

2.1 Preparation of Various Reagents

2.1.1 Electrolyte Solution

Firstly, the electrolyte for electrochemical sensing measurements is prepared. 0.2 M stock solutions of NaH_2PO_4 and Na_2HPO_4 were mixed and phosphate buffer saline (PBS) solution (50 mM) was obtained. 5 mM potassium ferrocyanide $[K_4Fe(CN)_6]$ and potassium ferricyanide $[K_3Fe(CN)_6]$ were added as an external mediator in the PBS solution to facilitate the transfer of electrons from the enzyme active sites to the electrode. The pH of the solution was adjusted by adding 0.9% sodium chloride (NaCl).

2.1.2 Enzyme and Analyte Solutions

Uricase (Ur) (*Candida sp.,* 4.9 U) enzyme was employed as receptor for detection of uric acid (analyte). PBS solution was used to prepare (1 mg/ml) enzyme solutions. To prepare different concentrations of uric acid solution in the range of 0.05–1.0 mM, required amounts of uric acid were dissolved in de-ionized water.

2.2 Preparation of ZnO Based Bioelectrode: Ur/ZnO/ITO/Glass

ITO coated glass (ITO/glass) substrates having dimensions of (2 cm × 1 cm) were taken and cleaned thoroughly. ZnO thin film was grown by PLD (fourth harmonic of Nd:YAG laser; 266 nm, repetition rate = 10 Hz) onto cleaned ITO coated glass substrates via a shadow mask over an area of (1 cm × 1 cm) to obtain ZnO/ITO/glass electrode. Electrochemical measurements were carried out by taking electrical connections from the ITO layer which was covered during ZnO thin film deposition (i.e., remaining 1 cm × 1 cm). A one inch dia. ceramic ZnO target prepared by solid state reaction route is used as described in our previous work

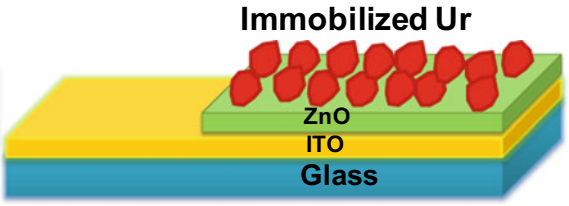

Fig. 1 Schematic of uric acid bioelectrode based on ZnO thin film

[2] to obtain ZnO thin films having a thickness of 90 nm. Ambient pressures (100% O_2) were varied in the range of 1–100 mT to analyze the effect of growth kinetics on biosensing response. In our previous work, it has been reported that the laser fluence influences the defect profile in ZnO films, and native defects are maximum in ZnO thin films deposited at low laser energy density (1.0–1.5 J/cm^2) [17]. Since presence of defects in metal oxide matrix enhanced the electron communication property and are useful for obtaining good biosensing response characteristics [14]; ZnO thin films are grown at low laser fluence (1.2 J/cm^2) in the present work for biosensing applications [17]. Since the ablated species require minimum energy to settle down on the desired nucleating sites on the substrates, ZnO thin films were intentionally deposited without heating the substrates so that large number of defects may be introduced. Uricase is immobilized via physical adsorption by drop casting 10 µl of Ur solution (0.049 Units) on the surface of ZnO/ITO/glass electrode to prepare bioelectrode. Uricase possesses a low IEP $\approx$ 6.06 and is thus easily attached on the surface of ZnO thin film having high IEP (~9.5). The prepared bioelectrode was kept overnight for drying and thereafter rinsed with buffer solution to remove the uricase which was loosely bound. The schematic diagram of the developed bioelectrode is shown in Fig. 1.

3 Results and Discussion

3.1 Characteristics of ZnO Based Uric Acid Bioelectrode

The biosensing response characteristics of all prepared Ur/ZnO/ITO/glass bioelectrodes are investigated using the cyclic voltammetric (CV) measurements which are performed using a Potentiostat/Galvanostat in a three-electrode electrochemical cell configuration (Gamry Inc. 600). Here, Ag/AgCl, Pt foil, and Ur/ZnO/ITO/glass bioelectrode were used as reference, counter, and working electrode respectively. 10 ml PBS solution with a mediator was used as electrolyte (Sect. 2.1).

Developing a matrix is highly critical as it provides the base for the immobilization of enzymes and provides a pathway for the transfer of electrons to the bottom electrode. Since the electron transfer characteristics of the matrix are strongly governed by growth kinetics, it is important to optimize its deposition condition. In the present

work, O_2 gas pressure has been optimized for deposition of ZnO thin film matrix using CV studies.

3.1.1 Effect of Oxygen Gas Pressure for Growth of ZnO Matrix

Different electrodes were prepared for the CV measurements by preparing ZnO thin film at different oxygen gas pressures (1, 10, 50, 100 mT) and under the conditions described in Sect. 2.2. The obtained cyclic voltammograms for ZnO electrodes prepared under different O_2 gas pressures are shown in Fig. 2.

It may be observed from Fig. 2 that CV spectra of ZnO electrodes fabricated at higher pressures (10 to 100 mT) are well defined and exhibit good oxidation and reduction peaks which may be attributed to the presence of $[Fe(CN)_6]^{3-/4-}$ in the buffer solution and serves as a mediating species for the transfer of electrons from enzyme active site to electrode. However, no redox peaks are observed when CV spectra were recorded for ZnO thin film electrode fabricated at an ambient pressure of 1 mT (Fig. 2). The peak oxidation current is found to increase continuously for ZnO/ITO/glass electrodes as ZnO films are fabricated at higher pressure from 10 to 100 mT. The peak value of oxidation current (I_{po}) is plotted by varying processing pressure for ZnO matrix as shown in Fig. 3. The magnitude of I_{po} increases from 160 to 548 μA as the oxygen gas pressure in PLD chamber is raised from 10 to 100 mT (Fig. 3) for deposition of ZnO thin film matrix for electrode.

Since biosensing is a process that predominantly occurs at the surface, roughness of the ZnO matrix surface is important as it provides increased surface area for loading of the enzyme and hence, improved response characteristics. The surface roughness of ZnO thin films grown at different oxygen gas pressures is studied using surface profilometer (Dektak 150A), and its variation is shown in Fig. 4. ZnO thin films grown at lower pressures (1–10 mT) are quite smooth having a low surface roughness of

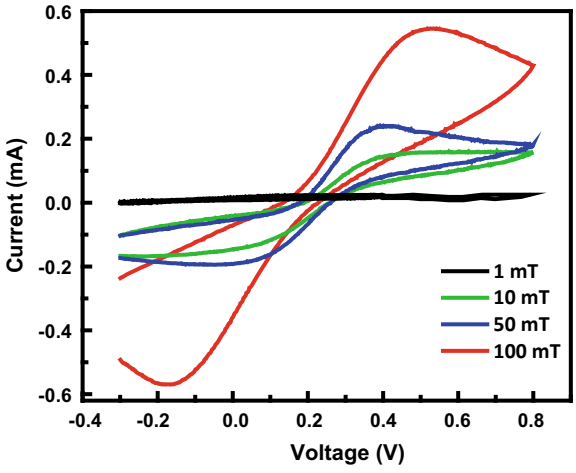

Fig. 2 CV spectra of ZnO based electrodes fabricated at different oxygen gas pressures

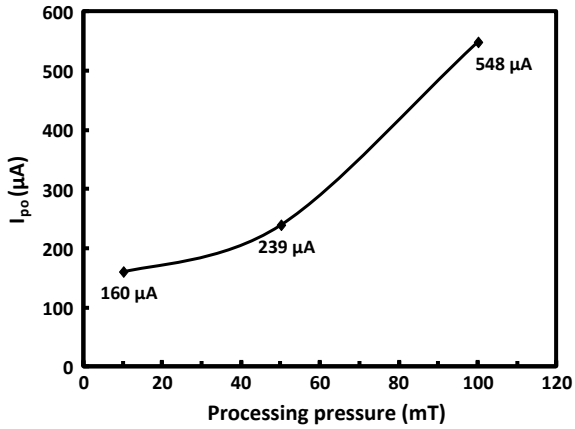

Fig. 3 Variation in peak oxidation current of ZnO/ITO/glass electrode with ZnO thin film prepared at different pressures

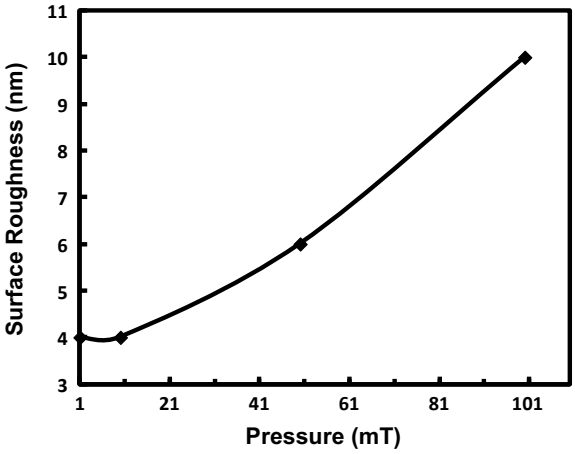

Fig. 4 Variation in surface roughness of ZnO thin film matrix as a function of oxygen pressure

4 nm (Fig. 4) and may be due to large mean free path of species present in plume. Therefore, the ablated species condense on the surface of substrate resulting in the formation of a continuous film with minimal native defects and dense morphology. The dense morphology of the ZnO film at low pressures ($\leq$10 mT) leads to small value of I_{po} with weak CV response (Fig. 2) due to poor electron communication property of ZnO matrix. Surface roughness of ZnO thin film increases significantly to 10 nm as the oxygen gas pressure during film growth is increased to 100 mT (Fig. 4). This is due to the large number of collisions of ablated species with background oxygen gas molecules which results in deposition of ZnO matrix having large amount of native defects and formation of irregular grains with increased surface roughness. The rough microstructure with large defects in ZnO thin film electrode prepared at high processing pressure of 100 mT results in increased value of I_{po} (Fig. 3) due to enhanced charge transfer features, and therefore, it is considered as a suitable matrix

for further study. Thus, it is evident from above studies that growth kinetics of matrix as altered by varying processing pressure play an important role in the development of biosensor and needs to be studied well before the matrix is applied for practical applications.

3.2 Electrochemical Property of Ur/ZnO/ITO/glass Bioelectrode

Uricase (Ur) is immobilized electrostatically over ZnO matrix grown at an optimized processing pressure of 100 mT, and Ur/ZnO/ITO/glass bioelectrode is fabricated as discussed in Sect. 2.2. Figure 5a illustrates the CV spectrums measured for ITO/glass electrode, ZnO/ITO/glass electrode and Ur/ZnO/ITO/glass bioelectrode, and are found to be well defined for all samples. Though the electrical conductivity of ITO is higher than that of ZnO thin film of semiconducting nature, it is important to note from Fig. 5a that the value of I_{po} for ZnO/ITO/glass electrode (548 μA) is much greater as compared to that of bare ITO/glass electrode (178 μA). The obtained high value of I_{po} may be related to the excellent charge conduction taking place through the semiconducting ZnO matrix. The magnitude of I_{po} decreases considerably (Fig. 5a) due to the immobilization of uricase on the electrode (ZnO/ITO/glass) surface (125 μA). The decrease in I_{po} upon immobilization of uricase onto ZnO/ITO/glass electrode (125 μA) is due to the hindrance in the transfer of electrons caused by non-conducting uricase.

3.2.1 pH Studies

pH of buffer solution may largely affect the activity of immobilized enzyme. Thus, the effect of pH of PBS buffer solution on its biosensing response was studied by varying it from 6.0 to 8.0, and the variation in I_{po} for Ur/ZnO/ITO/glass bioelectrode is demonstrated in Fig. 5b. The magnitude of $I_{po} \approx 125$ μA was maximum when pH of buffer solution was set to 7.0 and decreases by reducing and increasing it. Thus, further studies were carried out by maintaining the pH of PBS buffer solution at 7.0.

3.2.2 Effect of Scan Rate

The magnitude of current measured in CV studies for bioelectrodes depends on turnover rate of enzyme, reaction kinetics between redox couple and enzyme, flux of mediator to surface of enzyme, surface coverage of enzyme, and flux of analyte to enzyme surface [18]. Thus, it is important to investigate the kinetics of reaction and surface coverage of uricase on the electrode surface for the development of biosensor.

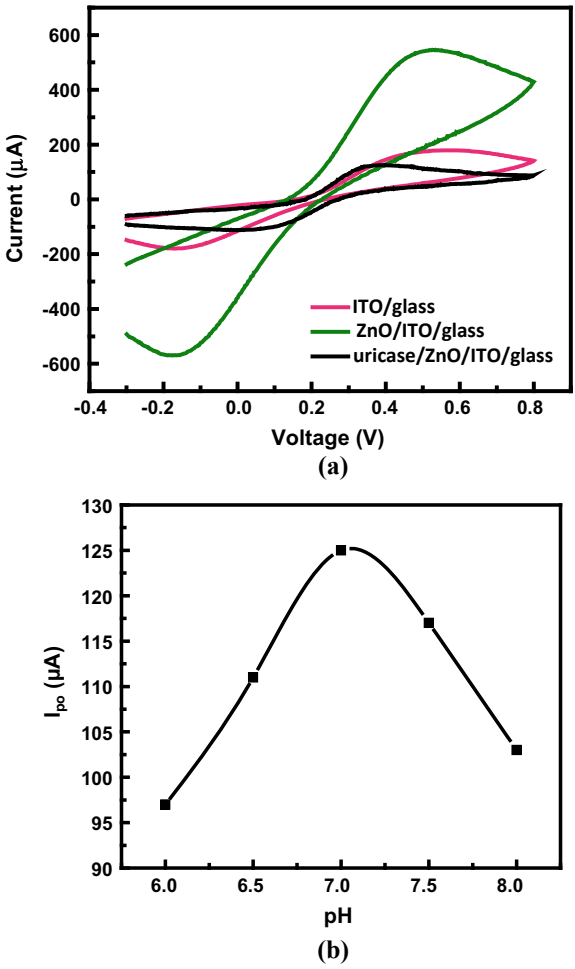

Fig. 5 **a** CV response of ITO/glass electrode, ZnO/ITO/glass electrode before and after uricase immobilization. **b** Influence of pH on the I_{po} for Ur/ZnO/ITO/glass bioelectrode

The CV measurements of Ur/ZnO/ITO/glass bioelectrode were conducted at different scan rates from 90 to 150 mV/s as shown in Fig. 6.

It is interesting to note the quasi-reversibility of system from Fig. 6(a) where the separation between the oxidation (E_{po}) and reduction (E_{pr}) peak potential for the bioelectrode increases due to an increase in scan rate [19]. Figure 6b shows the dependence of peak oxidation (I_{po}) and reduction (I_{pr}) current for the Ur/ZnO/ITO/glass bioelectrode on the scan rate. The peak currents obtained during the oxidation and reduction reactions for ZnO based bioelectrode are found to vary linearly with the scan rate (Fig. 6b). This explains that the electrochemical process at the bioelectrode is surface controlled mechanism [9]. The linear variation of peak currents may be represented in the form of equations given by:

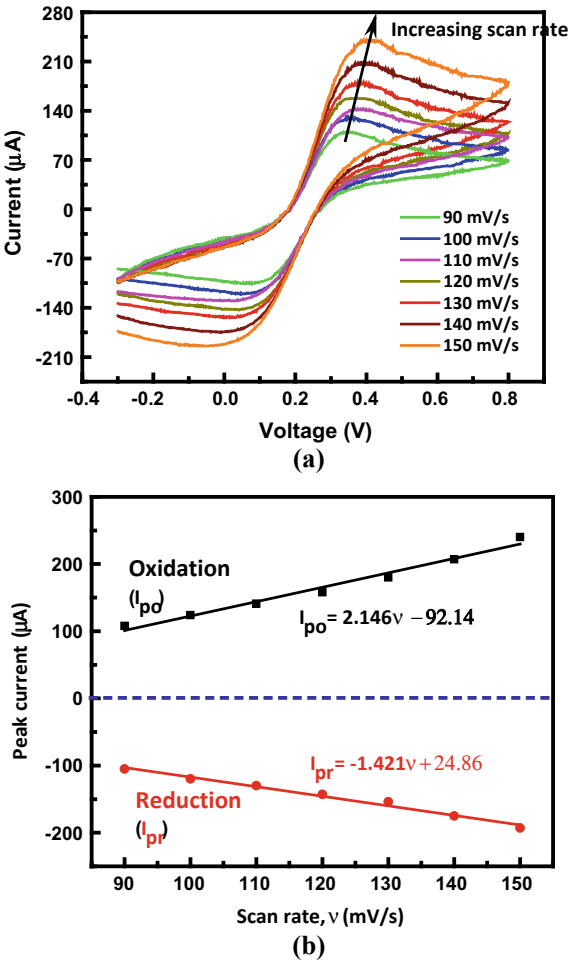

Fig. 6 **a** Scan rate studies showing the cyclic voltammograms of Ur/ZnO/ITO/glass bioelectrode in PBS solution containing $[Fe(CN)_6]^{3-/4-}$. **b** Variation in peak currents obtained by varying scan rate

$$I_{\text{po}}\,(\mu\text{A}) = 2.146v - 92.14\,(r = 0.99, \text{S.D.} = 7.31\,\mu\text{A}) \tag{1}$$

$$I_{\text{pr}}\,(\mu\text{A}) = -1.421v + 24.86\,(r = 0.99, \text{S.D.} = 3.95\,\mu\text{A}) \tag{2}$$

Here, r indicates the coefficient of regression and S.D. corresponds to the standard deviation. Since the value of regression coefficient is found to be close to 1, it indicates a good linear fit of the dependence of peak currents on scan rate. Also, the value of standard deviation is very small.