Journal of Physics: Conference Series

PAPER • **OPEN ACCESS**

Reactive ion etching of indium-tin oxide films by CCl_4-based Inductivity Coupled Plasma

To cite this article: Sucheta Juneja *et al* 2016 *J. Phys.: Conf. Ser.* **741** 012105

Journal of Physics: Conference Series **741** (2016) 012105 doi:10.1088/1742-6596/741/1/012105

Reactive ion etching of indium-tin oxide films by CCl_4-based Inductivity Coupled Plasma

Sucheta Juneja [1,3], Sergey D Poletayev[1,2], Sergey Fomchenkov[1,2], Svetlana N Khonina[1,2], Roman V Skidanov[1,2], Nikolay L Kazanskiy[1,2]

[1] Samara State Aerospace University, 443086 Samara, Russia.

[2] Image Processing Systems Institute of the Russian Academy of Sciences, 443086 Samara, Russia.

[3]Physics of Energy Harvesting Division, CSIR – National Physical Laboratory, Dr. K.S. Krishnan Marg, New Delhi, India, 110012.

Abstract. Indium tin oxide (ITO) films have been a subject of extensive studies in fabrication of micro-electronic devices for opto-electronic applications ranging from anti-reflection coatings to transparent contacts in photovoltaic devices. In this paper, a new and effective way of reactive ion etching of a conducting indium-tin oxide (ITO) film with Carbon tetrachloride (CCl_4) has been investigated. CCl_4 plasma containing an addition of gases mixture of dissociated argon and oxygen were used. Oxygen is added to increase the etchant percentage whereas argon was used for stabilization of plasma. The etching characteristics obtained with these gaseous mixtures were explained based on plasma etch chemistry and etching regime of ITO films. An etch rate as high as ~20 nm/min can be achieved with a controlled process parameter such as power density, total flow rate, composition of reactive gases gas and pressure. Our Investigation represents some of the extensive work in this area.

1. Introduction

Thin films with high electrical conductivity and optical transparency have been the subject of extensive studies by material scientists and engineers for many applications, such as transparent electrodes in liquid crystal displays or electroluminescent displays, [1] Photovoltaic devices [2]. The most employed thin films are Flat Panel Displays (FPDs) are made from transparent conducting oxide (TCO) materials [3-4]. Among various materials, Indium tin oxide (ITO, 90% wt.% In_2O_3/10Wt. % SnO_2) is one of the most widely investigated and useful transparent conducting oxide, because of its relatively low resistivity and high visible transmittance as compared with other (TCO) materials such as SnO_2 or ZnO [5-10]. It has been known that ITO has both excellent and optical properties [11, 12]. The theoretical understanding of ITO has been limited because of the complex crystal structure of ITO thin film. Indium Tin Oxide is essentially formed by subsititutional doping of In_2O_3 with Sn which replaces the In^{3+} atoms from the cubic bixbyte structure with a unit cell containing 40 atoms and two non-equivalent cation sites [13] .For the applications mentioned above, their etching characteristics and the availability of patterning for the films become an important factor and are directly linked with the productivity. The growths of anisotropic dry etch process for ITO films are an important task to be resolved. Conventionally, wet chemical etching process is used. However, this process requires multiple process steps, large expensive equipment's and geometry patterning [14]. To overcome these problems, dry etching processes have been developed using fluorine–based and hydrogen based chemistries [15-16]. The main concern with the etching of ITO film using fluorine and hydrogen-based gases (such as CF_4 in plasma methods) has the disadvantage of inducing contamination due to polymerization. Whereas the etching of ITO films by plasma, containing Cl_2 and BCl_3 lead to fast etch rate, films with smooth surface without polymerization [17-19]. The etch selectivity of ITO over photoresist films is also an important factor in many applications [20].

In this work, dry etching characteristics and surface structure of ITO films using $CCl_4/Ar/O_2$ in inductively coupled plasmas (ICP) were studied. At the same time, plasma-etching phenomenon were investigated.

2. Experimental

Research on structures to the substrate was made by ion-reactive etching in an inductively coupled plasma installation (RIE-ICP) “Caroline PE-15”. Figure1 shows schematic of the ICP etching system. Ion energy to the substrate, may influence the physical (ion) etching component controls the RF bias generator with a frequency of 13.56 MHz, is fed through to the chuck power matching device. To generate plasma using RF generator matching network was used to convert the loaded impedance in the plasma chamber. The chamber is evacuated with a turbo molecular pump of 800 L / s capacity.

We investigated the effect of bias power on the rate of etching of ITO glass. Etching was carried out in an environment $CCl_4/O_2/Ar$ under the following conditions: power of coil 500 W, current of electromagnet 2A, flow rate CCl_4 7 sccm, flow rate O_2 3 sccm and flow rate Ar 20 sccm . Power of bias took different modes values from 180 to 250 W. The time of etching for all was only 3 min. Aluminium masks was used with approximately 40 nm thickness deposited by magnetron sputtering method on market TCO glass with surface roughness of rms = 1 nm. The choice of aluminum masks determines their relative chemical inertness with respect to the chlorine-containing plasma. Carbon tetrachloride was poured into the flask and connected to a channel flow rate of gases. When the channel is turned on by the action of the vacuum chamber is a partial evaporation of CCl_4 and the formation of the gas stream of vapors and etching was done with these CCl_4 vapors. After etching mask residues are removed by chemical means and then etching rate was determined using a profilometer (KLA-Tencor P16+ model). The 3-D images was taken with Interferometer (ZYGO 7600 model), Field emission scanning electron microscopy (ZEISS SUPRA 25) was used to take surface images.

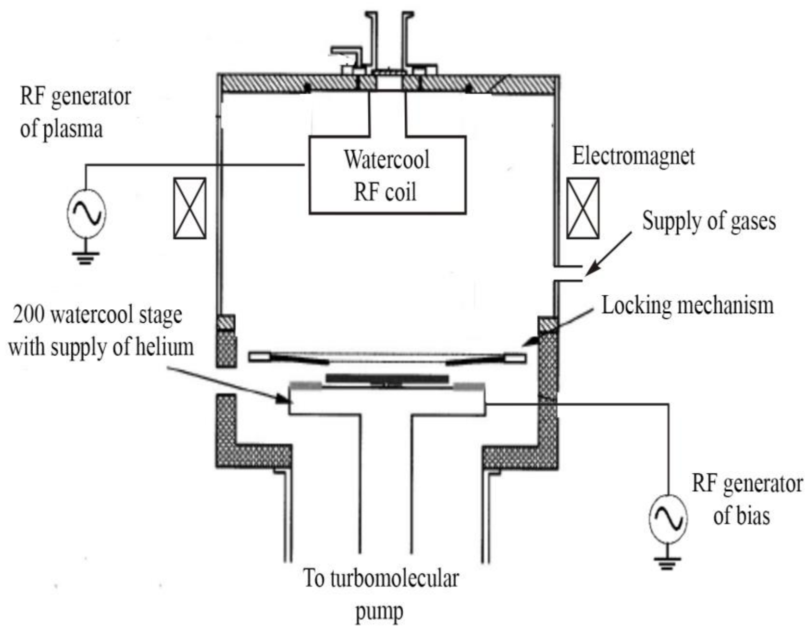

Figure 1. Schematic of ICP etching system [21]

3. Results and discussion

3.1 Etching characteristics of ITO films

Figure 2 shows the etch rate of ITO thin films with CCl_4 /Ar/O_2 gas mixing ratio at bias power of 250W. The etch rate were found to be 5nm/min, 12nm/min and ~20nm/min respectively with different bias power applied.

We may consider that the maximum etch rate is related to the effects of surface chemistry and that can be explained by chemical processes. This etching behavior shows that the inert gas (Ar) results in ion assisted chemical etching and consequently the etch rate is increased. The argon species are ionized in the plasma and accelerate towards the surface of the ITO owing to the DC bias, which could provide energy for the reaction to take place between the etchant and ITO films. The etch reaction in plasma with argon take via sputter deposition mechanism due to energetic ion bombardment [22]. The decreased etch rate obtained at low power is due to the lowering of physical bombardment effect and rate of chemical reaction. Oxygen was added to plasma to increase the etchant percentage by converting unsaturates to etchants. There was lesser reaction between the In and oxygen atoms due to the chemical reactions of In and Sn atoms. It is assume that the plasma containing argon or inert gas broke the chlorine bonding with In_2O_3 in the tetrahedral interstices of the face-centered-cubic In^{3+} lattice. Therefore, the inert gas transported the reaction products such as $InCl_x$ [23,24].

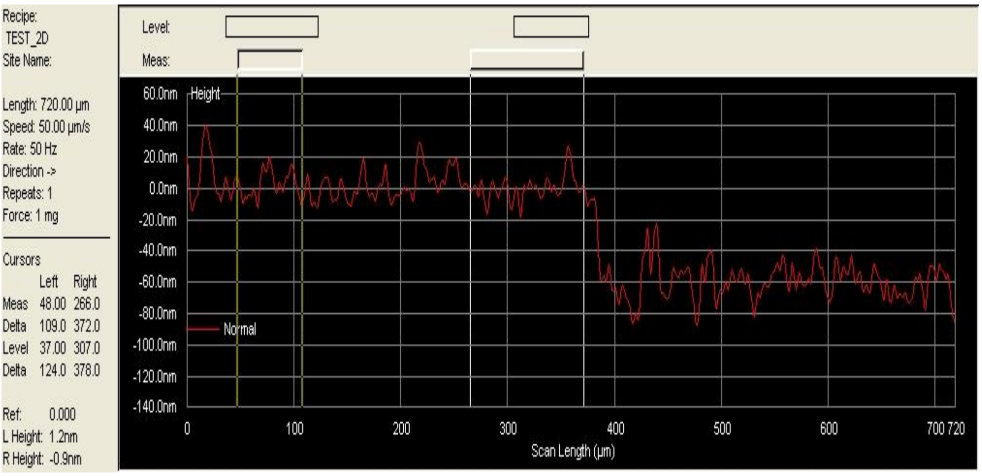

Figure 2. Etch rate of ITO films at bias power of 250W

3.2 Interferometer result

Figure 3 shows the 3-D images obtained from Interferometer. The surface of ITO film is change with etching. It is observed that the average roughness increases after etching unsignificantly. Root mean square remains the same. The smoothest surface of ITO film obtained using CCl_4/Ar/O_2 plasma with high etch rate at bias power of 250W was obtained.

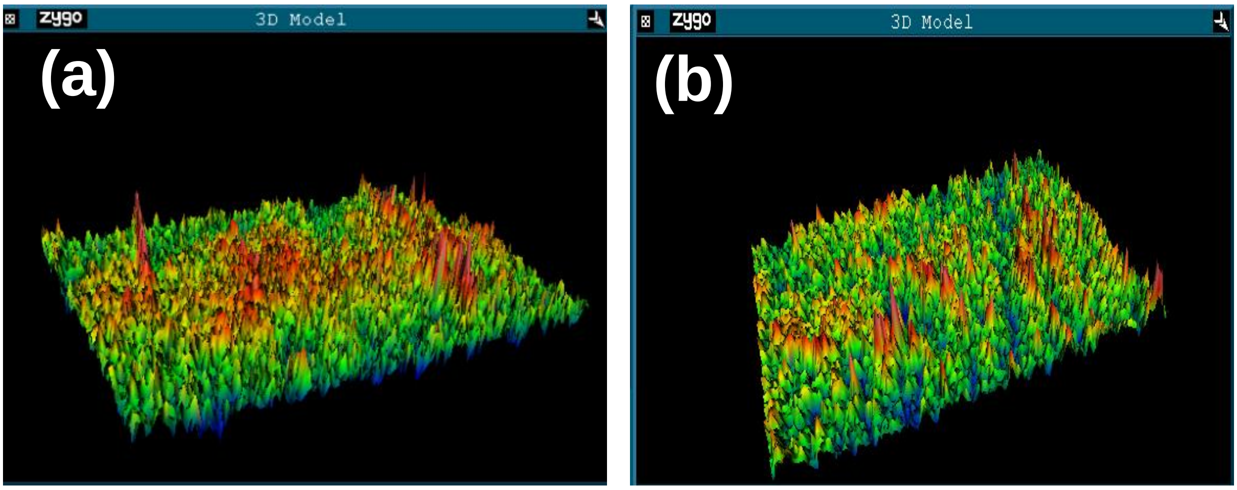

Figure 3. 3-D images of ITO films a) Before etching b) after etching.

3.3 Field emission scanning electron microscopy (FESEM) studies

Figure 4 shows the FESEM images of ITO film at bis power of 250W. The surface of ITO film is change with etching as observed from the images (Figuge 4(a) &(b)). The etching height is also mentioned. This clearly shows the etching of ITO films in gaseous mixture of $CCl_4/Ar/O_2$.

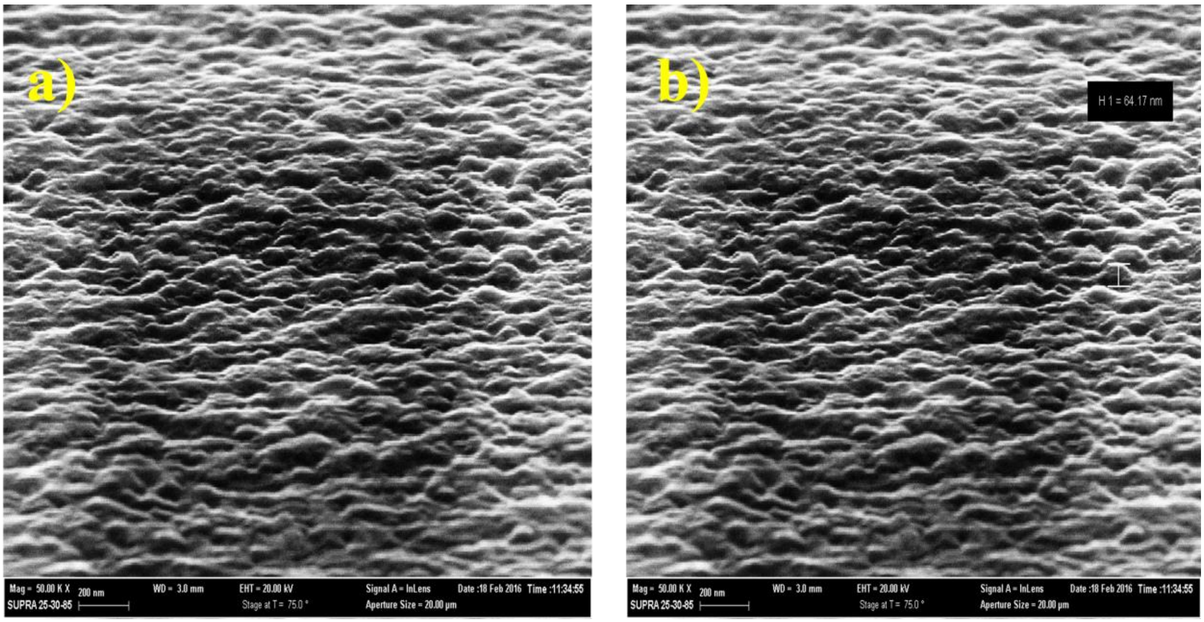

Figure 4. FESEM images of a) before etching and b) after etching

4. Conclusion

ICP etching of ITO has been studied in $CCl_4/Ar/O_2$ plasma. We vary bias power to increase the etch rate in the present investigation. The maximum etch rate of ITO films was ~20 nm/min. When CCl_4 was added to argon, the reaction between ITO and CCl_4 may enhanced by sufficient ion bombardment resulting increase in ITO etch rate. The etching of the ITO thin films in gaseous mixture CCl_4/ O_2 containing inert gas (argon) result in high etch rate and films with smooth surface without any polymerization. Further, more Investigation are needed in detail.

Acknowledgements

This work is financially supported by the Ministry of Education and Science of the Russian Federation.

References

1. Kaneko E 1987. Liquid Crystal TV Displays, chapter 7 (Tokyo: KTK Scientific)
2. Herrero J, Guillen C 2002 Vacuum **67** 611
3. Chou T H, Cheng K Y, Chang T L, Ting C J, Hsu H C, Wu C J, Tsai J H, Huang T Y 2009 Microelec. Eng. **86** 628
4. Lee CS, Cui ZY, Jin HF, Sung SW, Lee HG, Kim NS 2011 Trans. Electr. Electron. Mater. **12** 35
5. Kim YS, Park YC, Ansari SG, Lee JY, Lee BS, Shin HS 2003 Surface and Coatings Technology **173** 299
6. Hwang MS, Lee HJ, Jeong HS, Seo YW, Kwon SJ 2003 Surface and coatings technology **171** 29
7. Keshmiri SH, Rezaee-Roknabadi M, Ashok S 2002 Thin solid films **413** 167
. Chandrasekhar R, Choy KL 2001 Thin solid films **398** 59
9. Fahland M, Karlsson P, Charton C 2001 Thin Solid Films **392** 334
10. Yang ZW, Han SH, Yang TL, Ye L, Zhang DH, Ma HL, Cheng CF 2000 Thin Solid Films **366** 4
11. K.H. Choi, J.Y. Kim, Y.S. Lee, H.J. Kim, Thin Solid Films 341 (1999) 152.
12. A. Klo¨ppel, W. Kriegseis, B.K. Meyer, A. Scharmann, C. Daube, J. Stollenwerk, J. Trube, Thin Solid Films 365 (2000) 139.
13. Ho-Chul Lee Applied Surface Science 252 (2006) 3428–3435
14. Kim JH, Her JH, Lim YJ, Kumar P, Lee SH, Park KH, Lee JH, Kim BK 2010 Transactions on Electrical and Electronic Materials **11**134
15. Shin H, Kim C, Bae C, Lee JS, Lee J, Kim S 2007 Applied Surface Science **253** 8928
16. Kuo Y, Tai TL 1998 Journal of The Electrochemical Society **145** 4313
17 Kuo Y 1997 Japan. J. Appl. Phys. **36** L629
18. Grigonis A, Knizikevičius R, Rutkūnien Ž, Tribandis D 2003 Vacuum **70** 319
19. Andagana HB, Cao XA 2010 Journal of Vacuum Science & Technology A **28** 189
20. S. W. Na, M. H. Shin, Y. M. Jung, J. G. Han, and N.-E. Lee, J. Vac. Sci. Technol. A, **23**, 898 (2005).
21. Berlin, S.Dvinin, L.Seidman , E.Vaccum technology and equipment for coating and etching of thin films M.: Technosphere,2007-172p.
22. Young-Hee Joo, Jong-Chang Woo, Kyung-Rok Choi, Han-Soo Kim, Jae-Hyung Wi, and Chang-Il Kim, TRANSACTIONS ON ELECTRICAL AND ELECTRONIC MATERIALS Vol. 13, No. 3, pp. 157-161, June 25, 2012
23. D. Y. Kim, J. H. Ko, M. S. Park, N. E. Lee, Thin Solid Films 516, 3512 (2008) [DOI:10.1016/j.tsf.2007.08.021].
24. W. R. Salaneck, N. Johansson, K. Z. Xing, F. Cacialli, R. H. Friend, G. Beamson, D. T. Clark, Synth. Met. 92, 207 (1998) [DOI:10.1016/S0379-6779(98)80088-X].