Fabrication and Characterization of Zinc Oxide (ZnO) Thin Film on Silicon using Pulsed Laser Deposition for Channel Application in MOS Devices

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Abstract - We report a highly crystalline zinc oxide (ZnO) nanorods deposited on silicon using pulsed laser deposition (PLD) method. Multiple experiments carried out to engineer the best condition for the channel engineering in replacement of Si channel in the MOS transistor through the thin film of ZnO using PLD and then analysed using the SEM, EDX, XRD and PL Spectroscopy. The deposition of ZnO thin film carried out at various temperatures with O_2 gas as the partial pressure at the rate of 2 millitorr, which results in the growth of approximately 35nm to 40nm range diameter ZnO nanorods visible in the SEM morphology analysis. XRD shows the pure hexagonal wurtzite with plane 002 orientation for the crystalline ZnO nanorods, where samples are initiated with heating the substrates. It also shows amorphous for the films deposited at room temperature, where no heating involved. PL spectra shows that the ZnO thin film have a good crystalline structure with excellent optical properties.

Keywords: Zinc Oxide (ZnO) nanorods; channel engineering; thin film; Pulsed Laser Deposition (PLD); SEM-EDX; XRD; PL Spectroscopy.

I. INTRODUCTION

Zinc oxide is an II-VI wide band gap semiconductor [1] and is widely used in various scientific research and applications. It is the promising candidate in electronics applications because of its low cost [2], wide band gap [3], high dielectricity [4], highly transparent [5-7], eco-friendly [8], bio-compatible [9] and CMOS compatible electron rich n-type semiconductor [10, 11].

Few recent reports on ZnO include: Kumar, R. et.al. reported ZnO as an excellent material for fabrication of highly sensitive and selective gas sensors [12]. Baruah S. et.al. reported ZnO used in antibacterial tests revealed that the photocatalytic paper stops the growth of Escherichia coli under room lighting conditions [13]. Sirelkhatim, A. et.al., reported that ZnO acts a bio-safe material that possesses photo-oxidizing and photocatalysis impacts on chemical and biological species [14]. Kim et. al., reported in his paper that ZnO is a suitable candidate for supercapacitor applications because of its good electrochemical activity, low cost as a raw material, and environmental friendliness among the various metal oxide materials [15]. For material science applications [16], zinc oxide exhibits high refractive index [17], high thermal conductivity [18], excellent material-binding peptides [19, 20], a very good antibacterial [21, 22] and UV-protection [23] properties.

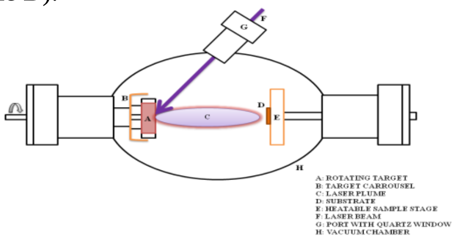
There are various methods to deposit ZnO thin film on the Silicon substrate. It includes physical vapor deposition [24, 25], chemical vapor deposition [26], sol-gel/dip-coating/doctor blade thin film deposition [27-30], sputtering deposition [31-33] techniques and pulsed laser deposition [34-36]. Among all these deposition processes, pulsed laser deposition (PLD) process stands unique because of its sophisticated working phenomena [37] and fast deposition [38] process unlike any other deposition technique, which consumes more time.

Pulsed Laser Deposition is a unique tool which helps us to grow high-quality films [39, 40] of any chemical compounds. It is conceptually simple [41], versatile [42], cost-effective [43], fast [44] and scalable [45].

In this research work, we demonstrate preparing high-quality thin films of ZnO with nanorod arrays deposited on a silicon wafer using pulsed laser deposition technique.

II. EXPERIMENTAL

The ZnO pellet is taken as the precursor target material. Silicon wafer (n-type or p-type) is kept in the sonicate bath containing H_2SO_4 and H_2O_2 mixture taken in 3:1 ratio in order to remove organic matter (piranha cleaning process). Then the thoroughly washed Si substrate is placed on the heatable sample stage of the Pulsed Laser Deposition System – 12 – 100 (Excel Instruments). We use Nd-YAG laser (130mJ converted at the rate of 3ω and 2ω) using the Solid State Pulsed Laser Source (Quantel Laser System – Qsmart 450mJ). The principle of the pulsed laser deposition is schematically shown in figure 1 (a). ZnO pellet is placed on the target carousel as shown in figure 1(b) and the instrument setup is shown in figure 1(c). The laser from the source hits the target ZnO pellet, laser plume produced, which helps in the atom by atom deposition of the ZnO on the Si substrate. The substrate can be heated at various temperatures. In this work, we used at four different heating conditions. Condition I samples involve deposition on the substrate without heating (sample A), condition II samples are deposited while the substrate is heated to 300ºC (sample B), whereas condition III samples include resultant samples of condition II, in which further deposition of ZnO taken place where the substrate heated to 200ºC (sample C) and condition IV samples are deposited while the substrate is heated to the maximum of 600ºC (sample D).



(a)

(b)

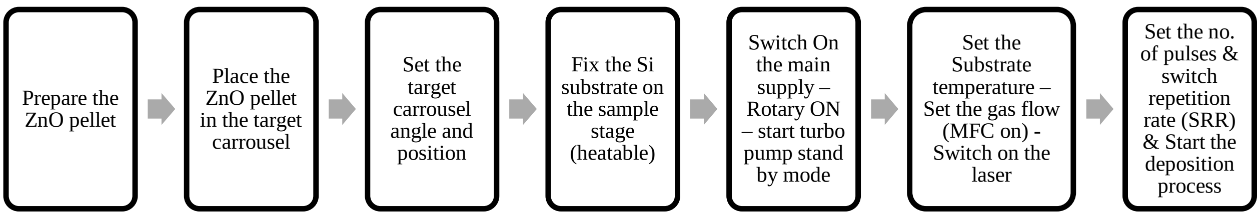
(c)

Figure 1(a) Schematic working of Pulsed Laser Deposition (b) ZnO pellet placed in the target and (c) Instrument setup: Pulsed Laser Deposition System – 12 – 100 (Excel Instruments) and Solid State Pulsed Laser Source (Quantel Laser System – Qsmart 450mJ).

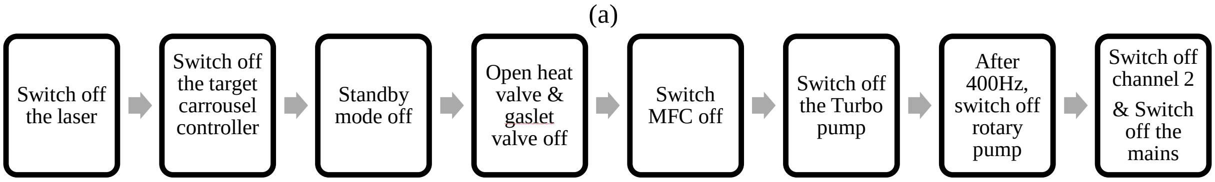
Table 1: Parameters used for various samples in PLD

Sample No.	**Target**	**Substrate**	**Tsub. (°C)**	**Base pressure (torr)**	**Process gas**	**Deposition pressure (torr)**	**Laser Energy (mJ)**	**No. Of pulses**	**Switch Repetition Rate**
A	ZnO	Si	No heating	9.7×10^{-6}	O_2	2×10^{-3}	130	1500	5 Hz
B	ZnO	Si	300	9.7×10^{-6}	O_2	2×10^{-3}	130	750	5 Hz
C	ZnO	Sample B	200	9.6×10^{-6}	O_2	2×10^{-3}	130	750	5 Hz
D	ZnO	Si	600	9.6×10^{-6}	O_2	2×10^{-3}	130	600	5 Hz

Table 1 shows the various parameters used for the different samples (sample A, B, C & D) using PLD. Here ZnO is the target used in all the samples. Silicon is used as the substrate in sample A, B and D. The resultant sample B is used as a substrate for sample C. Substrate can be heatable, as they are placed on the heatable sample stage. Sample A is not heated, sample B is heated to 300 °C, sample C is heated to 200 °C and sample D is heated to 600 °C respectively. Oxygen (O_2) gas is used as the process gas for all the samples and a base pressure is always maintained. The deposition pressure of the O_2 gas is maintained to 2 millitorrs. After multiple experiments, the no. of pulses are reduced to 600 from 1500 as the temperature of the substrate increases. Switch repetition rate is maintained at 5Hz for all the samples. Figure 2 (a) and (b) shows the flowchart of the experiments to be carried out in a standard procedure before and after the deposition process using the pulsed laser deposition system [46-50].



(a)



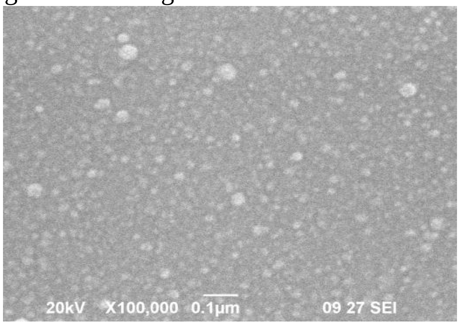
(b)

Figure 2: Operation of PLD instrument (a) before deposition (b) after deposition

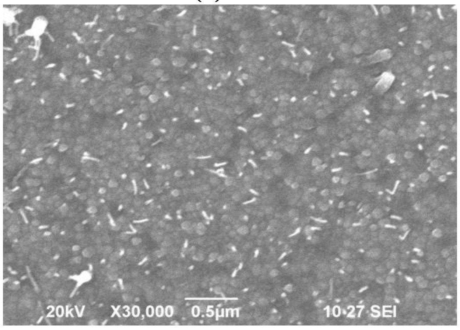
1. Results and discussion:

3.1. SEM Morphology:

Figure 3 (a-d) shows that due to the change in the temperature, there is a change in the quality of the thin film deposition [51] recorded at 20kV with magnification ranges from 30K to 100K.



(a)



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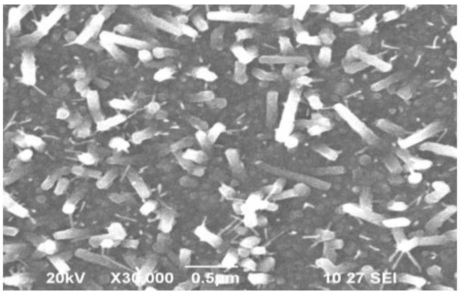

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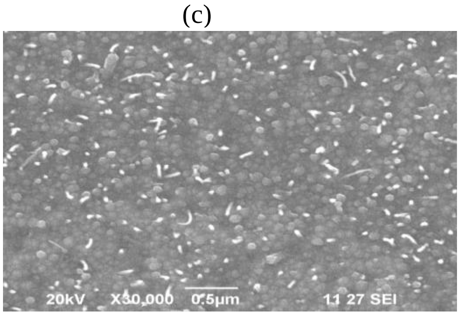


(d)

Figure 3: SEM images of the deposited thin film (a) Sample A (b) Sample B (c) Sample C (d) Sample D

1.2. Energy Dispersive X-Ray (EDX) Spectroscopy Analysis:

Figure 4 shows the EDX spectrum of the deposited ZnO thin film on Silicon (sample C). It helps us to identify the elemental composition of the thin film. It confirms the fabricated thin film ZnO nanorod arrays on a silicon substrate were composed of silicon (Si), zinc (Zn) and oxygen (O) respectively [52].

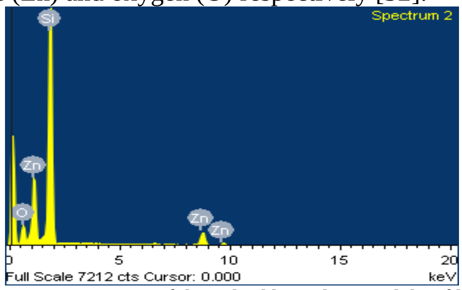


Figure 4: EDX spectrum of the pulsed laser deposited thin film ZnO

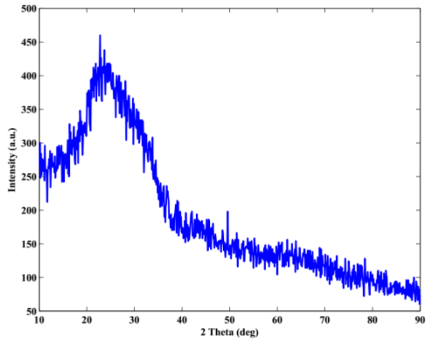
Table 2 shows the tabulation of the elemental composition of the thin film sample C.

Table 2: Composition of elements analysed through EDX

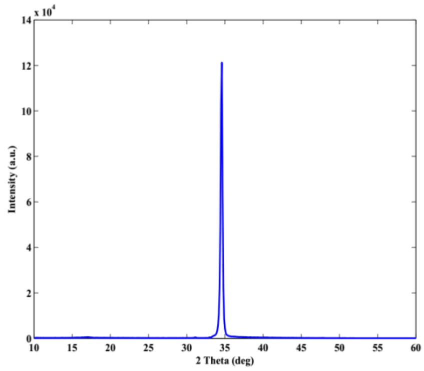
Element	App. Conc.	Intensity Correlation	Weight %	Atomic %
O (b)	30.32	0.7162	24.30	39.21
Zn	24.30	0.8311	16.78	6.63
Si	91.87	0.8949	58.92	54.16

1.3. X-ray diffraction (XRD) analysis:

ZnO films deposited without heating does not show the (002) preferred orientation, although a temperature increase as in sample C brings about a reorientation and the (002) peak becomes enhanced. Figure 5(a) shows the amorphous nature of the film. Figure 5(b) shows the crystalline (002) orientation of the ZnO film (sample C).



(a)



(b)

Figure 5: XRD graph (a) Sample A (amorphous film) (b) Sample C (thin film of crystalline ZnO nanorod arrays)

The sharp peak at 34.5° (2Theta) data is confirmed with the JCPDS card no. 75-0576 [53-55] as tabulated in table 3.

Table 3: Thin films of ZnO XRD data confirmation with JCPDS card

	Peak Values	2Theta (deg)	d(A)	Observance
Sample C	Experimental Value	34.5252	2.59577	Hexagonal (hkl=002) JCPDS card no.: 75-0576
	Theoretical JCPDS Value	34.503	2.5974	

1.4. Photoluminescence (PL) Spectroscopy:

Figure 6 shows the PL spectrum of the thin film ZnO deposited at various conditions (λ_{exc}=325nm) [56]. All the three curves show a short wavelength region with a sharp band located in the ultraviolet region and weak, broad spectral bands in the visible region [57]. Sample A and D's sharp band at 380nm and sample C at 379nm respectively inferred from this PL spectroscopy analysis. As seen in the PL spectra, the sharp and strong UV emission appearance and a very weak deep-level emission indicate that the ZnO nanorods (refer Sample C - PL Spectrum) have a good crystalline structure with excellent optical properties [58].

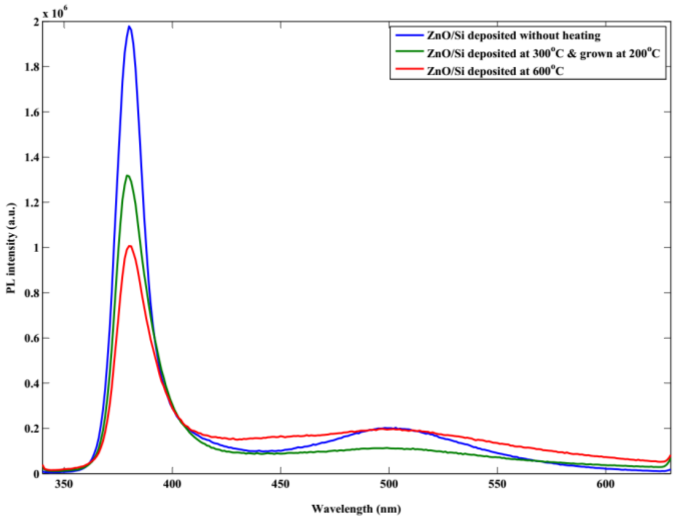


Figure 6: PL spectra of thin film ZnO deposited at various conditions (λ_{exc}=325nm)

2. CONCLUSIONS:

Thus, ZnO nanorods are deposited on silicon film using PLD and the various characteristics of the deposited ZnO are studied through SEM, EDX, XRD and PL spectroscopy analysis. As a future scope, the prepared ZnO nanorod arrays can be used as the channel material for the thin film transistor for excellent switching application as believed in the replacement of Si channel material.

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