The study of *p*-Si/Al_2O_3/*n*-Si (100) sandwiches structures deposited by KrF excimer laser ablation

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Abstract: Laser ablation is a versatile technique for deposition of metals, semiconductors as well as dielectrics. Our pulsed laser deposition (PLD) system is set up into an ultra-high vacuum (UHV) machine with working pressure of $1.5*10^{-10}$ Torr. In this work we report the successfully deposition of sandwiches structures *p*-Si/Al2O3/*n*-Si (100) substrate. The obtained thin layers were characterized by atomic force microscopy (AFM), scanning electron microscopy (SEM) and composition was investigated by energy dispersive X-ray (EDX). Also micro Raman spectroscopy was involved for measurement of the stress in *n*-Si (100) substrates as well as top deposited *p*-Si. Depositions were performed at three different values for: distance between target and substrate (3, 4, 5 [cm]), temperature of substrate (400, 500, 600 [°C]), laser pulse energy (400, 500, 580 [mJ]) and laser pulse repetition rate (20, 30, 40 [Hz]). We conclude that the optimally conditions for Al_2O_3 layer are: 5 cm, 500°C, 580 mJ, 20 Hz and for top *p*-Si same values except the pulse repetition rate, which is 30 Hz.

1 Introduction

The market demand for thinner field effect transistor (FET), such is now the available 14 nm technology, increased the interest of scientists for buried oxides layers. Following this trend we test our ability to deposed successive layers Al_2O_3 and *p*-Si type over a Si *n* (100) substrate by laser ablation and to find the proper parameters for uniform surfaces.

Laser ablation is a versatile technique for deposition of: metals, semiconductors as well as dielectrics.[1,2]

The alumina (Al_2O_3) is well known as one of the best insulator with resistivity $1x10^{14}$ Ωcm and is chemical stabile even at high temperature, being suitable for thin buried oxide layer.

2 Experimental and results

Pulsed laser Deposition (PLD) system is a unique versatile research tool. The system offers a broad range of materials and applications. The ability to extend the vacuum capabilities to ultra high vacuum base pressures allows the control of unwanted film impurities. Up to now, our best vacuum level is $1.5*10^{-10}$ Torr. The laser target manipulator accommodates up to four 2" diameter in vacuum which are selectable through the controlling computer. Each of the individual targets can be rotated about its axis, which together with the laser scanning provides a uniform ablation of the target. Using this flexibility, a multitude of thin film structures deposition are possible.

The system consist of three chambers, load lock, growth and the RHEED gun, which serve for: load/unload the targets and samples, deposition and *in-situ* analysis respectively.

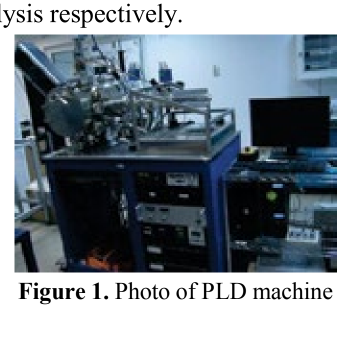


Figure 1. Photo of PLD machine

The ablations were performed with Coherent Compex pro 205 F KrF excimer laser: $\lambda = 248$ nm and pulse duration of 20ns.

First step is the substrate preparation prior to deposition. The commercial (Sigma Aldrich) Si wafer *n* type (100) oriented surface was treated by HF 10% for 10 minutes to eliminate the native oxide on surface, after was cleaned by acetone and dried in nitrogen flow.

The (100) surface orientation was proved by RHEED investigation (not shown here).

For studying *p*-Si/Al_2O_3/*n*-Si (100) sandwiches structures we must have the possibility to investigate both deposed surfaces, therefore after the alumina deposition the samples were taked out and a Ti foil masck was used for partial covering the surface before the deposition of *p*-Si layer (Fig. 2).

Depositions were performed at three different values for: distance between target and substrate (3, 4, 5 [cm]), temperature of substrate (400, 500, 600 [°C]), laser pulse energy (400, 500, 580 [mJ]) and laser pulse repetition rate (20, 30, 40 [Hz]).

The rotation speed of the substrate and the time for ablation were kept constant at 10 Rpm and 10 minutes respectively.

In figure 2 we can observe the macroscopic diferences of surfaces obtained at 4, 5 and 6 cm. The left and right parts of samples are uncovered *n*-Si (100) substrates. Bottom is alumina layer and top is *p*-Si over alumina.

a) b) c)

Figure 2. Macroscopic differences of deposition performed at 4 (a); 5 (b); 6 (c) cm respectively

Alumina and *p*-Si layers show different colours and shining as function of distance between target and substrate.

Nano scale investigations were carried out by AFM (Solver Next) and reveal that optimal value of distance is 5 cm for both deposed layers (Fig. 3). [3]

The surfaces were further analysed by SEM (Fig. 4). Composition and stoichiometry of alumina and Si *p* layers were proved by EDX (Table 1).

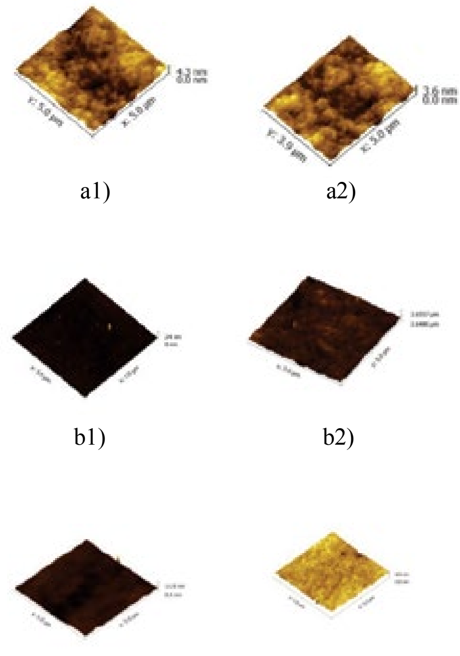
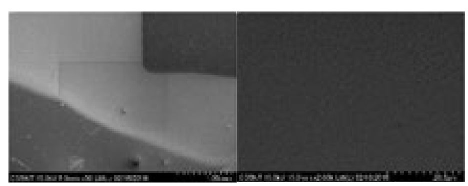


Figure 3. 3D topography images of alumina (1) and top *p*-Si (2) for: 4 cm a); 5 cm b) and 6 cm c)



a) b)

Figure 4. SEM images of all layers a); alumina layer b)

Table 1. The atomic percentages as resulting from EDX analysis proving stoichiometry of alumina layer

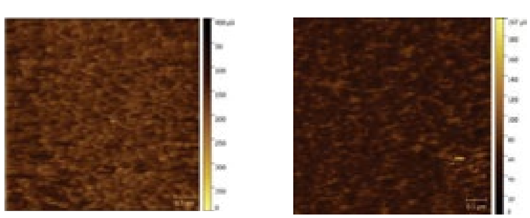
	Atomic (%)		
Statistics	O	Al	*p*-Si
Max	61.96	38.04	98.36
Min	1.57	0.07	81.97
Average	26.43	13.46	

Table 2 show the roughness indicators (RA and RMS) for all the parameters investigated.

Table 2. The first line is corresponding to alumina deposition and second one to top *p*-Si. The values in the table correspond to: index of sample, distance between target and substrate, pressure before ablation, pressure during ablation, substrates temperature, laser pulses energy, repetition rate of laser pulses and the surface roughness indicators RMS and RA. With yellow are highlighted the optimal values.

No	D (T-S) cm	P_i Torr	P_a Torr	T ° C	E mJ	RR Hz	RMS nm	RA nm
4	4	$7.7*10^{-7}$	$4*10^{-6}$	500	580	30	1.125	0.782
		$7*10^{-7}$	$4.8*10^{-6}$	500	580	30	0.524	0.413
8	5	$2*10^{-7}$	$2.8*10^{-6}$	500	580	30	0.7000	0.4239
		$4.7*10^{-7}$	$1.2*10^{-5}$	500	580	30	0.4484	0.3475
5	6	$6.5*10^{-7}$	$2.1*10^{-6}$	500	580	30	0.6159	0.4837
		$5.7*10^{-7}$	$5*10^{-6}$	500	580	30	0.8015	0.6208
7	5	$1.3*10^{-6}$	9*10-6	600	580	30	0.799	0.57
		$1.1*10^{-6}$	1*10-5	600	580	30	0.449	0.3437
8	5	$2*10^{-7}$	$2.8*10^{-6}$	500	580	30	0.7000	0.4239
		$4.7*10^{-7}$	$1.2*10^{-5}$	500	580	30	0.4484	0.3475
6	5	$8*10^{-7}$	$3*10^{-6}$	400	580	30	1.125	0.782
		$7*10^{-7}$	$1.8*10^{-6}$	400	580	30	0.498	0.397
9	5	$6.4*10^{-7}$	$3.6*10^{-6}$	500	580	20	0.3639	0.2889
		$9*10^{-7}$	$1*10^{-6}$	500	580	20	0.8544	0.6729
8	5	$2*10^{-7}$	$2.8*10^{-6}$	500	580	30	0.7000	0.4239
		$4.7*10^{-7}$	$1.2*10^{-5}$	500	580	30	0.4484	0.3475
10	5	$2.6*10^{-6}$	$2.8*10^{-7}$	500	580	40	0.63	1.06
		$4.1*10^{-7}$	$4.6*10^{-6}$	500	580	40	1.09	0.55
12	5	$1*10^{-6}$	$5.8*10^{-6}$	500	400	30	2.011	0.961
		$2*10^{-6}$	$2.4*10^{-6}$	500	400	30	0.8544	0.6729
11	5	$2.7*10^{-7}$	$6.5*10^{-7}$	500	500	30	0.83	0.65
		$1*10^{-6}$	$1.6*10^{-6}$	500	500	30	0.99	0.72
8	5	$2*10^{-7}$	$2.8*10^{-6}$	500	580	30	0.7000	0.4239
		$4.7*10^{-7}$	$1.2*10^{-5}$	500	580	30	0.4484	0.3475

To test the quality of ours depositions we performed the friction mapping on surfaces by AFM [4]. As can be seen in figure 5 quite uniform values were found for both layers.



a) b)

Figure 5. Friction mapping: alumina a) and b) top *p*-Si

For investigate the stress of *p*-Si deposed layers we used micro Raman spectroscopy. Figure 6 shows such spectrum and the position of peak at normal value 520.8 cm^{-1} unstressed.

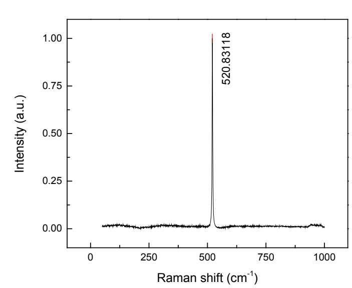


Figure 6. Raman spectrum of top *p*-Si layer

3 Conclusion

By this work we proved our ability to grow uniform layer buried oxide (alumina) on a *n*-Si (100) commercial substrate.

Deposited layers were investigated by AFM in contact mode as well as friction mapping and by SEM.

The composition and stoichiometry of Al_2O_3 and top *p*-Si was proved by EDX analysis.

We conclude that the optimally conditions for Al_2O_3 layer deposition are: 5 cm, 500°C, 580 mJ, 20 Hz and for top *p*-Si same values except the pulse repetition rate, which is 30 Hz.

The top *p*-Si layer shows a Raman peak at 520.8 cm^{-1} indicating unstressed deposition.

Further directions for continuing research is to measure the layers thickness and to control it from experimental parameters.

Acknowledgment

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