

Effect of annealing and doping with (Mo , V and Ni) elements
oxides on structural properties of BaTiO₃ thin films
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Abstract

In this work, BaTiO₃ thin films (pure and doped with oxides MoO₃, V₂O₅ and NiO) were deposited using pulsed laser deposition (PLD) technique with thickness equal to (300nm) on glass and Si (111) substrates at temperature equal to (573K). The effects of annealing at temperatures (673K, 773K and 873K) and doping on the structural properties have been investigated. XRD of pure and doped BaTiO₃ pellets shows Polycrystalline structure, and exhibited tetragonal structure, with preferential direction (110). The structural properties of the BaTiO₃ films prepared on glass substrates before and after annealing have been studied by using XRD technique, these tests show that all the films have amorphous structure at substrate temperature (573K) and after annealing at temperatures (673K, 773K and 873K). But in case of Si (111) substrates, the XRD did not detect the crystalline phase before annealing, but annealing at temperature (873K), the XRD detected Polycrystalline structure, and exhibited tetragonal structure of BaTiO₃ film . The same occurs with doping films.

The surface morphology of all the deposited films was studied using atomic force microscope (AFM). The grain size of the nanoparticles observed at the surface depended on the annealing temperature, where annealing at temperature (873K) was the best temperature at the films deposits on Si (111) substrates. BaTiO₃ films with doping ratio (0.1wt%) of NiO has the smallest grain size equal to (44.69nm). RMS roughness increased with increasing annealing temperature.

Keywords: BaTiO₃ thin films, pulsed laser deposition , structural Properties, doping.

تأثير التلدين والتشويب بأكاسيد العناصر (Mo ، V و Ni) على الخصائص التركيبية لأغشية
BaTiO₃ الرقيقة

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الخلاصة

تم في هذا العمل تحضير أغشية الباريوم تيتانيت الرقيقة النقية والمشوبة بأكاسيد (المولبدنيوم، الفناديوم و النيكل) باستخدام تقنية الترسيب بالليزر النبضي بسمك مقداره (300 nm) على قواعد من الزجاج والسليكون (111) بدرجة حرارة أساس مقداره (573K). تم دراسة تأثير التلدين بدرجات حرارة (673K, 773K, 873K) والتشويب على الخصائص التركيبية. إن حيود الأشعة السينية (XRD) لأقراص الباريوم تيتانيت النقية والمشوبة أظهر بأنها متعددة التبلور و ظهور التركيب الرباعي مع هيمنة الاتجاه (110). إن الخصائص التركيبية لأغشية الباريوم تيتانيت المحضرة على قواعد من الزجاج قبل وبعد التلدين قد تمت دراستها باستخدام تقنية حيود الأشعة السينية (XRD)، وأظهرت النتائج بلق جميع

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الأغشية عشوائية التركيب عند درجة حرارة قاعدة (573 K) وبعد التلدين بدرجات حرارة (873K, 773K, 673K). لكن في حالة القواعد السليكونية (111)، فإن حيود الأشعة السينية (XRD) لم يظهر أي طور بلوري قبل التلدين، ولكن عند التلدين بدرجة حرارة (873K)، فإن حيود الأشعة السينية (XRD) أظهر بان غشاء الباريوم تيتانيت متعدد التبلور و ذا تركيب رباعي. وكذلك الحال نفسه بالنسبة للأغشية المشوبة. تم دراسة طبوغرافية السطح لجميع الأغشية المرسبة باستخدام مجهر القوى الذرية (AFM)، أن الحجم الحبيبي للجسيمات النانوية التي ظهرت عند السطح اعتمد على درجة حرارة التلدين، وكانت أفضل درجة حرارة تلدين هي (873K) للأغشية المرسبة على القواعد السليكونية (111). امتلكت أغشية الباريوم تيتانيت المشوب باوكسيد النيكل بنسبة تركيز (0.1wt%) اصغر حجم حبيبي حيث بلغت قيمته (44.69 nm). إن خشونة السطح تزداد بزيادة درجة حرارة التلدين.

الكلمات المفتاحية: الأغشية الرقيقة لباريوم تيتانيت ، الترسيب بالليزر النبضي ، الخصائص التركيبية ، التشويب .

Introduction

Barium titanate (BaTiO₃) was one of the first ferroelectric materials discovered, and also one of the first recognized photorefractive material. It is, to date, the most extensively investigated ferroelectric material [1].

BaTiO₃ is a member of the perovskites family, of which the parent member is the mineral CaTiO₃, called perovskite. The perovskite family includes other well-known materials such as KNbO₃, KTaO₃, PbTiO₃ and SrTiO₃. The general formula of any compound belonging to this family is ABO₃, where A is a monovalent, divalent or trivalent metal and B a pentavalent, tetravalent or trivalent element. From the point of view of practical applications this material is very interesting because it is chemically and mechanically very stable and it exhibits ferroelectric properties at and above room temperature [2]. From the optical applications point of view, BaTiO₃ is very interesting because of its high linear and nonlinear electro optic coefficients. It is, a well-known dielectric material which has been used as an insulating material to fabricate MIS structures. It exhibits several advantages and properties such as high charge storage capacity, good insulating property, low leakage current density and high dielectric breakdown strength [3].

Barium titanate (BaTiO₃) and other perovskite-type materials are being extensively studied for their potential commercial applications in dynamic random access memories (DRAMs) [4, 5]. Ferroelectric thin films attract wide interest due to its good characteristics of dielectricity, piezoelectricity and pyoelectricity. And surface acoustic wave (SAW) device [6,7].

It has become one of the most important electro ceramics since the discovery of its versatility in multilayer ceramic capacitors (MLCC), positive temperature coefficient of resistance (PTCR), thermistors, piezoelectric sensors, transducers, actuators and ferroelectric random access memories (FRAM) and electro-optic devices[8,9]. Its dielectric maximum is shifted towards room temperature by the compositional substitution and its dielectrics were sensitive to temperature, field strength and frequency, especially near the Curie temperature. BaTiO₃ thin films can also be used as dielectrics in an amorphous form, bringing the advantage of a much lower process temperature that is required for crystalline BaTiO₃ films [10,11]. In case of thin films BaTiO₃ have been prepared by sputtering [12] PLD [13] , sol-gel, MOD [14] and MOCVD [15]. PLD is currently the most important method for preparing epitaxial structures for device physics studies.

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Experimental procedure

The BaTiO₃ was prepared by using solid state reaction method by mixing BaO and TiO₂ compounds in [1:1] ratio, BaTiO₃ doped with ratio (0.1wt%) of (Mo,V and Ni oxide) by using solid state reaction method also. After the end of wet mixing and drying process then the mixtures were pressed to form pellets (1.5cm) diameter by using (5ton) pressure. After that, pellets are sintered at (1223K) for (5hr).

BaTiO₃ thin films (pure and doped with oxides MoO₃,V₂O₅ and NiO) were deposited using pulsed laser deposition (PLD) technique.

The pulsed laser deposition experiment was carried out inside a vacuum chamber generally in (10⁻³Torr) vacuum conditions. The focused Nd:YAG SHG Q-switching laser beam incident on the target surface makes an angle of (45°) with it. The films were deposited on glass substrate at temperature (T_s=573K) with rate of deposition equal to (0.5 nm/sec). The deposition was carried out using a Q switched Nd:YAG laser with a frequency second radiation at (532nm) (pulse width (10 nsec) repetition frequency (6 Hz)), for (250) laser pulse.

Films thickness was measured by using optical interferometer method and found to be (300nm), as deposited BaTiO₃ films have been annealed at temperatures (673K,773K and 873K) in air.

In order to study the structural properties, the crystalline structure is analyzed with a SHIMADZU 6000 X-ray diffractometer system which records the intensity as a function of Bragg's angle. The source of radiation is Cu(k_α) with wavelength (λ=1.5406Å), current (30mA) and voltage (40kV). The scanning angle 2θ is varied in the range of (20–60) degree with a speed of (4deg/min).

Where the Bragg condition for diffraction [16]:

$$2d \sin \theta = m\lambda \quad \dots\dots\dots (1)$$

Where (d) is the interplaner distance, (θ) is the diffraction angle (Bragg's angle), (m) is the order of reflection and (λ) is the wavelength.

The observed variation of the crystallization in the thin films is supported by the study of the grain size. The grain size of the thin films was calculated from diffractogram peaks using the Scherrer formula [17]:

$$D = \frac{\lambda}{\beta \cos \theta} \quad \dots\dots\dots (2)$$

Where (D) is the grain size, (β) is the full width at half maximum (FWHM).

Lattice parameters (a) and (c) for tetragonal crystal are calculated from X-ray d-spacing's according to equation:

$$\frac{1}{d^2} = \frac{h^2 + k^2}{a^2} + \frac{l^2}{c^2} \quad \dots\dots\dots (3)$$

Where h, k, and ℓ refer to the Miller indices of individual reflections.

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The morphological surface analysis is carried out employing an atomic force microscope (AFM) (AA3000 Scanning Probe Microscope SPM, tip NSC35/AIBS) from Angstrom Advance Inc.

Results and discussions

Fig. (1) shows the X-Ray diffraction pattern of BaTiO₃ pellet. It can be observed that the pellet has polycrystalline structure in nature and exhibited tetragonal structure. It can be noticed from XRD pattern that the peaks at ($2\theta=22.541^\circ$, 31.949° , 39.291° , 45.708° , 51.31° and 56.585°) referred to (100), (110), (111), (200), (210) and (211) planes direction, respectively. With that the strongest peak occurs for the (110) plane at ($2\theta=31.949^\circ$). Our results are nearly in agreement with Kumar et al [18]. A point of interest is that the preferential orientation is the (110) direction of the powder, this may be due to the layer stability of the (110) plane which reflects the more relaxed bonds with minimum energy. The XRD shows peaks whose positions were shifted slightly from the data of (JCPDS#050626) [19]. Table (1) shows the experiment and the standard peaks from International Centre for Diffraction Data of BaTiO₃.

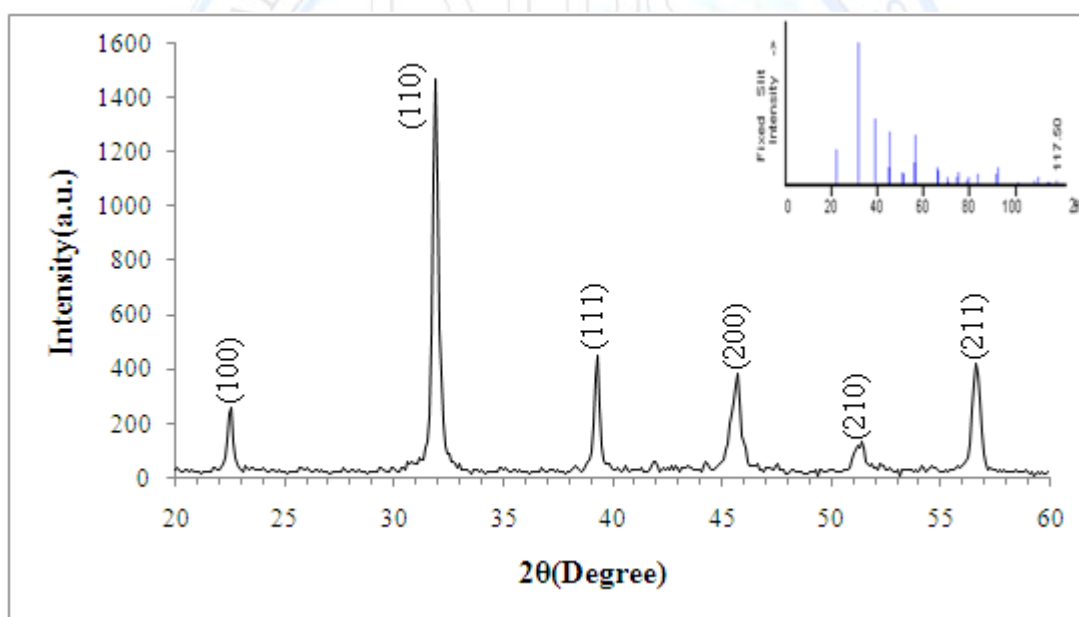


Fig. (1) The XRD pattern of BaTiO₃ pellet.

Table (1) The experimental and the standard peaks of BaTiO₃ pellet.

2θ Exp.	d Exp.(Å)	d Std.(Å)	Hkl
22.541	3.941	3.99	100
31.949	2.798	2.82	110
39.291	2.291	2.314	111
45.708	1.983	1.99	200
51.31	1.777	1.786	210
56.585	1.625	1.634	211

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Figs. (2) to (4) show the X-Ray diffraction pattern of doped BaTiO₃ pellets. The composition BaM_xTiO₃ where M=(NiO,MoO₃ and V₂O₅) and x=(0.1wt%). It can be observed that these pellets have polycrystalline structure nature and exhibited tetragonal structure. Fig. (2) shows the XRD pattern of the Ni⁺² doped BaM_xTiO₃ pellet with the dominant orientation in the (110) direction peak located at ($2\theta=32.112^\circ$). Where as exhibit a prominent reflection angle at ($2\theta=32.112^\circ$) referred to (110) [18]. To form a tetragonal structure according to the International Centre for Diffraction Data (JCPDS#050626) [19]. In Fig. (3) the XRD pattern of the V⁺⁵ doped BaM_xTiO₃ pellet with the dominant orientation in the (110) direction peak located at ($2\theta=32.4^\circ$). A point of interest is that the preferential orientation is the (110) direction of the powder, this may be due to the layer stability of the (110) a plane which reflects the more relaxed bonds with minimum energy. Another interpretation is that this stability originates in the larger density of bond. Also, Fig. (4) shows the XRD pattern of the Mo⁺⁶ doped BaM_xTiO₃ pellet with the dominant orientation in the (110) direction peak located at ($2\theta=32.072^\circ$). We can be noticed that there was little shifting of 2θ location to location other. The shift in peak position is due to the variation of atomic radius of the three doping elements as show (Ba=2.22, Ti=1.47, Ni=1.24, Mo=1.39, V=1.34) atomic radius. We can see from Table (2) the experiment values of 2θ shifting for BaTiO₃ pellets doped with (NiO,MoO₃ and V₂O₅) and (hkl). Also, Table (3) shows the lattice constants values (a,c and c/a) for BaTiO₃ pellets at different doping elements.

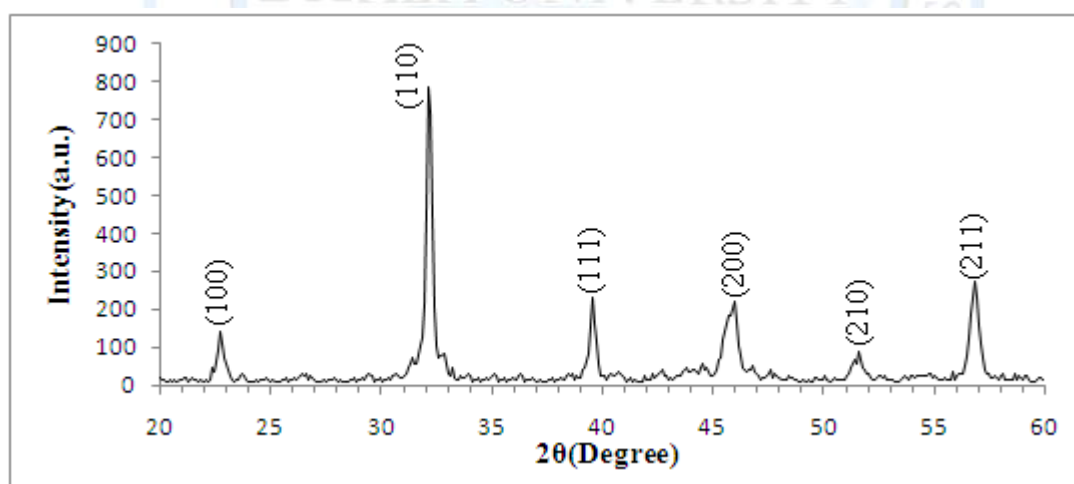


Fig. (2) The XRD pattern of the NiO doped BaTiO₃ pellet.

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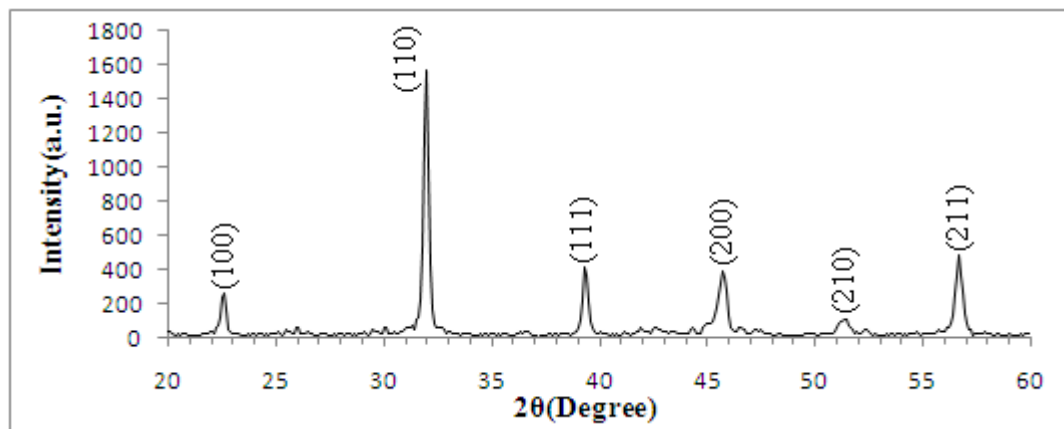


Fig. (3) The XRD pattern of the V₂O₅ doped BaTiO₃ pellet.

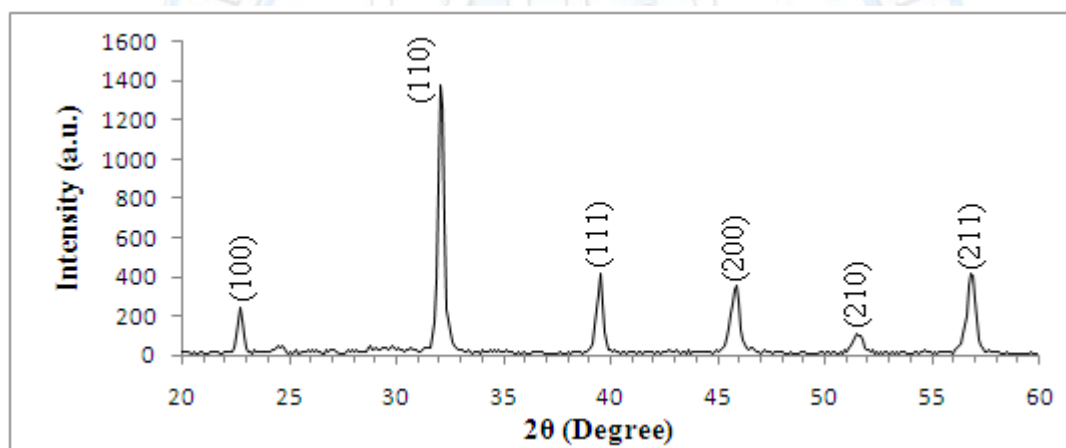


Fig. (4) The XRD pattern of the MoO₃ doped BaTiO₃ pellet.

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Table (2) The experimental values of 2 θ shifting for BaTiO₃ pellets doped with (NiO, MoO₃ and V₂O₅) and (hkl).

Doped BaTiO ₃	2 θ (degree)	Hkl	d Exp.(Å)
NiO 0.1wt %	(22.705)	(100)	3.913
	(32.087)	(110)	2.787
	(39.516)	(111)	2.278
	(45.915)	(200)	1.974
	(51.555)	(210)	1.771
	(56.761)	(211)	1.621
MoO ₃ 0.1wt %	(22.731)	(100)	3.908
	(32.072)	(110)	2.788
	(39.512)	(111)	2.278
	(45.920)	(200)	1.974
	(51.401)	(210)	1.776
	(56.782)	(211)	1.620
V ₂ O ₅ 0.1wt %	(22.617)	(100)	3.928
	(32.400)	(110)	2.761
	(39.352)	(111)	2.287
	(45.742)	(200)	1.981
	(51.321)	(210)	1.778
	(56.682)	(211)	1.622

Table (3) The lattice constants values (a,c and c/a) for BaTiO₃ pellets at different doping elements.

sample	a (Å)	c (Å)	c/a
BaTiO ₃	3.957	3.990	1.0080
BaTiO ₃ :0.1wt%NiO	3.941	3.954	1.0032
BaTiO ₃ :0.1wt%MoO ₃	3.943	3.956	1.0033
BaTiO ₃ :0.1wt%V ₂ O ₅	3.904	4.083	1.0450

Fig. (5) shows the X-Ray diffraction pattern of BaTiO₃ thin films on glass and Si (111) substrates at constant substrate temperature (T_S=573K) and different annealing temperatures

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(673,773K and 873K). No evidence of any phases present on glass substrate or Si (111) substrate for as deposited thin films, that mean the formation of BaTiO₃ phase weak or amorphous that observed from Fig. (5-a,b). Our results are nearly in agreement with Chinchamatpure et al [3] and Park et al [20]. After annealing both samples at temperature (873K), the XRD detected a BaTiO₃ on Si (111) substrate but not for glass substrate. All diffraction peaks can be assigned to BaTiO₃ phase without any indication of other crystalline phase [3]. We can notice from the XRD pattern that the peaks at ($2\theta=22.35^\circ$, 31.75° , 39° , 45.45° and 56.25°) referred to (100), (110), (111), (200) and (211) direction, respectively. A point of interest is that the preferential orientation is the (110) direction of the thin film, this may be due to the layer stability of the (110) plane which reflects the more relaxed bonds with minimum energy. The XRD data of thin film coincides with that of the known tetragonal structure according to the International Centre for Diffraction Data (JCPDS#050626) [19]. Also we can notice from the XRD patterns of the BaTiO₃ thin films grown on Si (111) substrates diffraction peak located at ($2\theta=28^\circ$) which related to Si wafer. Table (4) shows the experiment and the standard peaks from International Centre for Diffraction Data (JCPDS#050626) [19] of BaTiO₃/Si thin film at annealing temperature (873K). The diffraction peaks are broad which indicating the formation of nanocrystalline the average crystal size can calculated as (68nm) from application of Scherer's equation by taking account of the peak broadening at (110) diffraction plane.

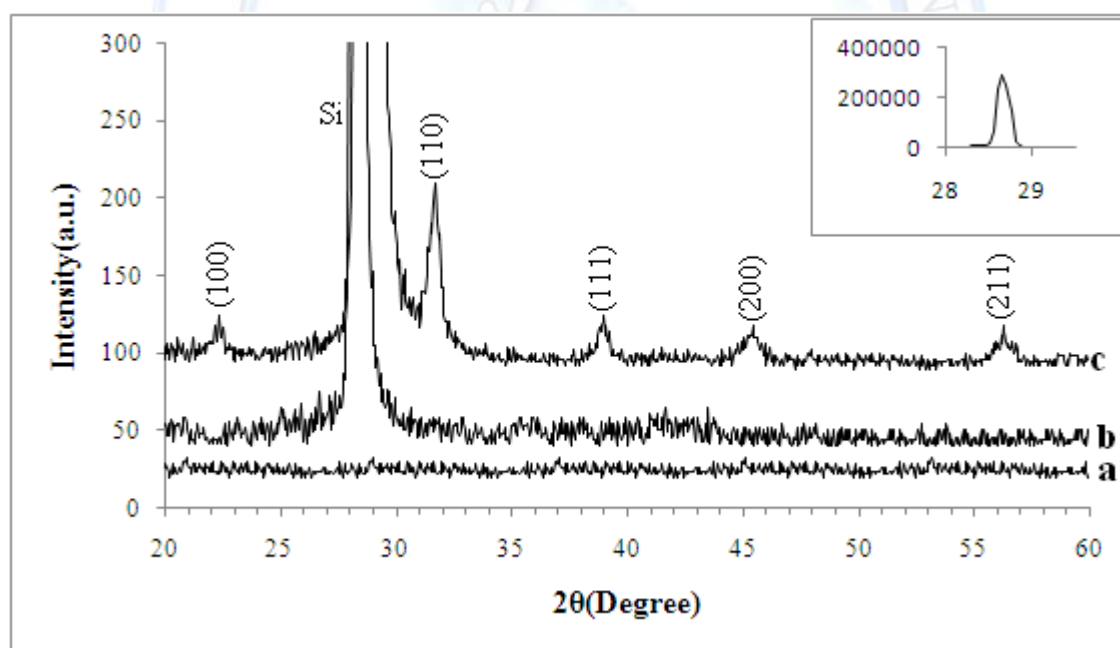


Fig. (5) The XRD pattern of BaTiO₃ thin films at:(a) BaTiO₃/glass thin film deposited at substrate temperature ($T_s=573K$), (b) BaTiO₃/Si thin film deposited at substrate temperature ($T_s=573K$), (c) BaTiO₃/Si thin film at annealing temperature (873K).

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Table (4) The experimental and the standard values of (d,FWHM and Grain size) of BaTiO₃/Si thin film at annealing temperature (873K).

2θ Exp.	d Exp.(Å)	d Std.(Å)	hkl	FWHM	main Grain size (nm)
22.35	3.974	3.99	100	0.1183	68.43
31.75	2.816	2.82	110	0.1843	84.66
39	2.307	2.314	111	0.1140	84.94
45.45	1.994	1.997	200	0.1990	43.27
56.25	1.632	1.634	211	0.1822	49.43

Fig. (6) to (8) show the X-Ray diffraction pattern of BaTiO₃ thin films doped with different oxides. The composition BaM_xTiO₃ where M=(NiO,MoO₃ and V₂O₅) and x=(0.1wt%) on glass and Si (111) substrates at constant substrate temperature (T_S=573K) and different annealing temperatures (673,773K and 873K). No evidence of any phases present on glass substrates or Si (111) substrates for as deposited thin films, that mean the formation of BaTiO₃ phase weak or amorphous. On the other hand, the XRD patterns of doped BaTiO₃ thin films with annealing temperature (873K), the structure of these thin films showed a polycrystalline. Fig. (6) shows the XRD pattern of the Ni⁺² doped BaM_xTiO₃ thin films and exhibited tetragonal structure according to the International Centre for Diffraction Data (JCPDS#050626) [19]. We can be noticed from the XRD pattern that the peaks at (2θ=22.3°, 31.65°, 39.05°, 45.35°, 45.4° and 56.2°) referred to (100), (110), (111), (200) and (211) direction, respectively. We can notice that BaTiO₃ thin films is present in the (110) at (2θ=31.75°), such that high peak intensity in (110) direction. Fig. (7) shows the XRD pattern of the V⁺⁵ doped BaM_xTiO₃ thin films with the dominant orientation in the (110) direction peak located at (2θ=31.76°). Fig (8) shows the XRD pattern of the Mo⁺⁶ doped BaM_xTiO₃ thin films with the dominant orientation in the (110) direction peak located at (2θ=32.7°). The data indicate a lengthening of the c-axis and shortening of the a-axis to produce a more tetragonal structure. Table (5) shows the experiment values of 2θ shifting for BaTiO₃/Si thin films doped with (NiO,MoO₃, and V₂O₅) at annealing temperature (873K) and (hkl). Also, Table (6) shows the lattice constants values (a, c and c/a) for BaTiO₃/Si thin films at different doping elements at annealing temperature (873K).

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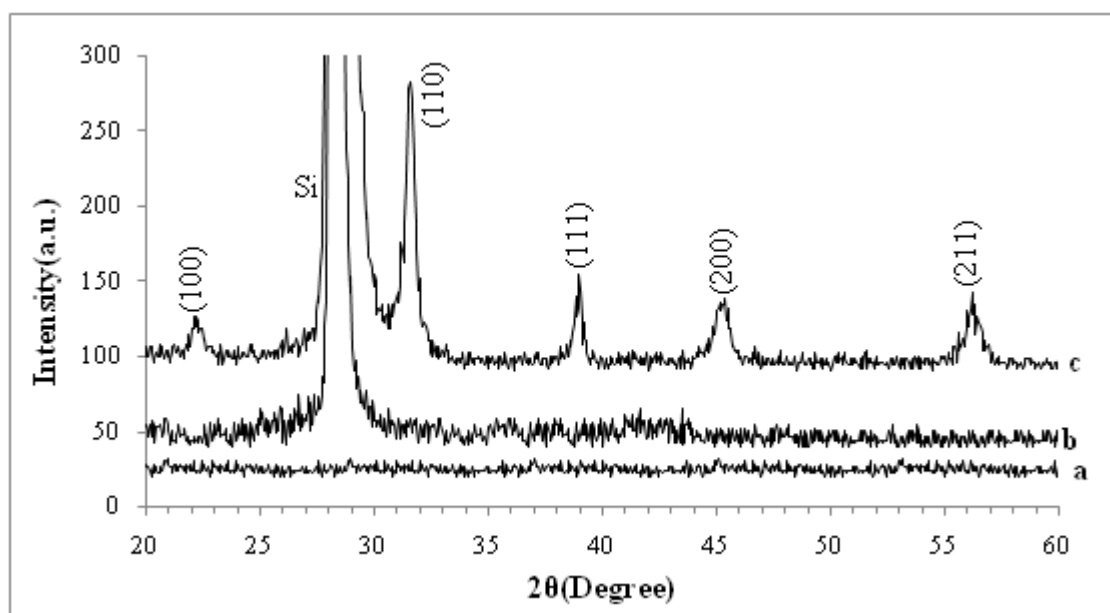


Fig. (6) The XRD pattern at:(a) NiO doped BaTiO₃/glass thin film deposited at substrate temperature ($T_s=573K$), (b) NiO doped BaTiO₃/Si thin film deposited at substrate temperature ($T_s=573K$), (c) NiO doped BaTiO₃/Si at annealing temperature (873K).

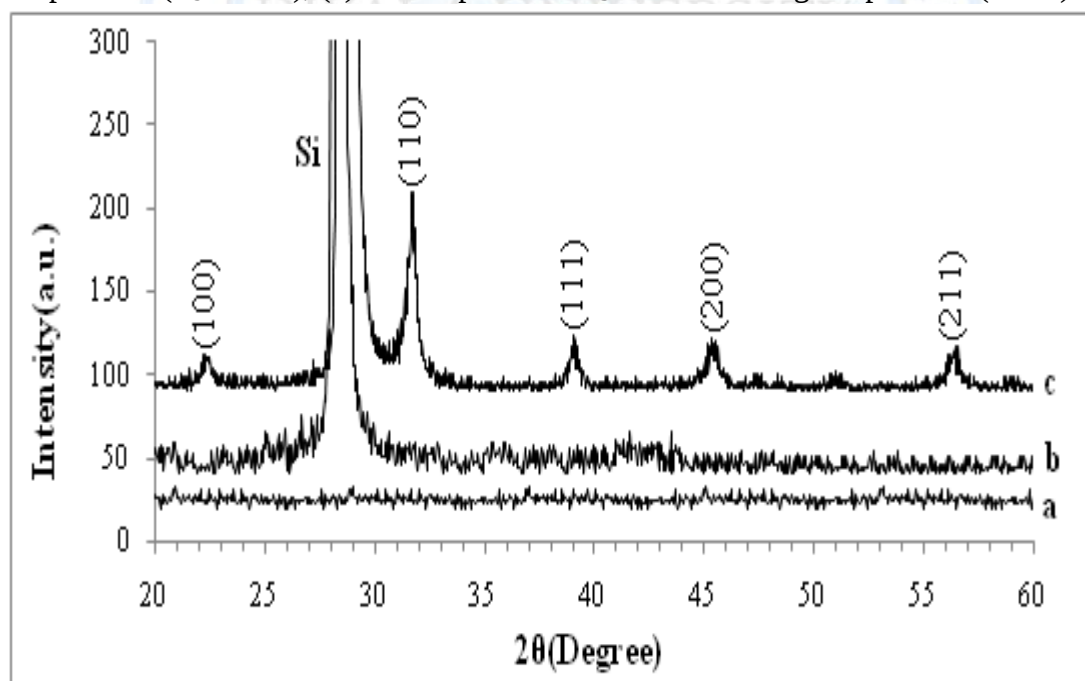


Fig. (7) The XRD pattern at:(a) V₂O₅ doped BaTiO₃/glass thin film deposited at substrate temperature ($T_s=573K$), (b) V₂O₅ doped BaTiO₃/Si thin film deposited at substrate temperature ($T_s=573K$), (c) V₂O₅ doped BaTiO₃/Si at annealing temperature (873K).

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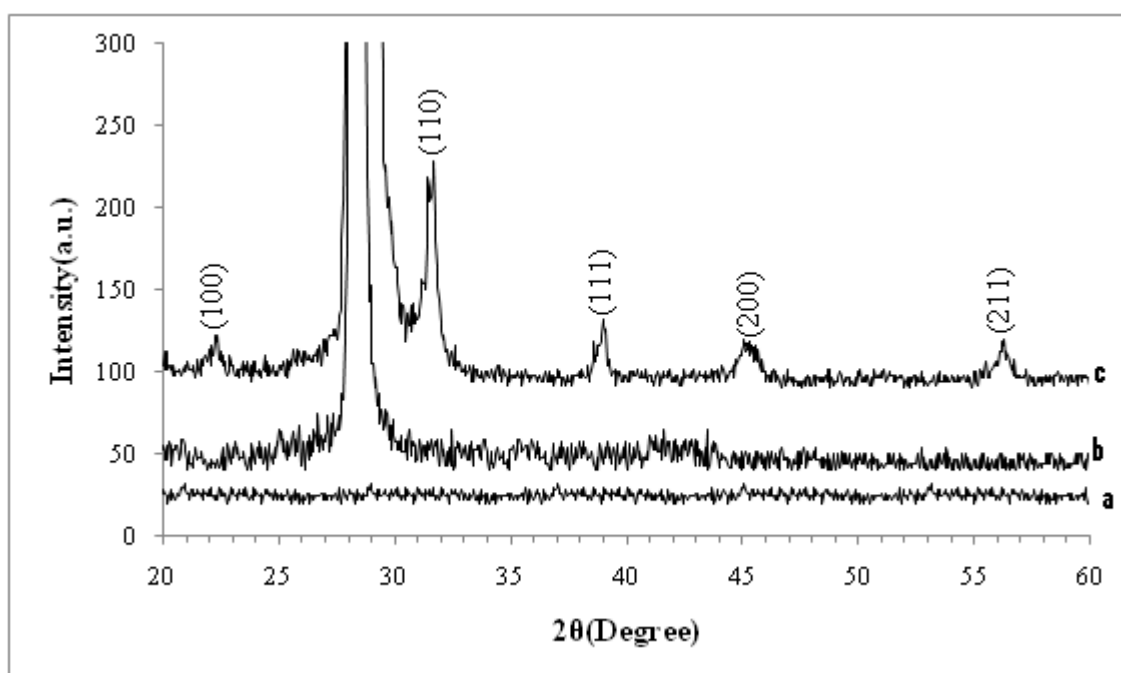


Fig. (8) The XRD pattern at:(a) MoO₃ doped BaTiO₃/glass thin film deposited at substrate temperature ($T_s=573K$), (b) MoO₃ doped BaTiO₃/Si thin film deposited at substrate temperature ($T_s=573K$), (c) MoO₃ doped BaTiO₃/Si at annealing temperature (873K).

Table (5) The XRD parameters (2θ , hkl, d exp., FWHM and Grain size) for BaTiO₃/Si thin films doped with (NiO, MoO₃ and V₂O₅) at annealing temperature (873K).

Doped BaTiO ₃	2θ (degree)	Hkl	d Exp.(Å)	FWHM	main Grain size (nm)
NiO 0.1wt %	(22.3)	(100)	3.983	0.139	58.22
	(31.65)	(110)	2.824	0.143	57.41
	(39.05)	(111)	2.304	0.102	81.97
	(45.4)	(200)	1.996	0.153	56.29
	(56.2)	(211)	1.635	0.170	52.82
MoO ₃ 0.1wt %	(22.4)	(100)	3.965	0.140	57.68
	(32.7)	(110)	2.736	0.150	54.98
	(39.05)	(111)	2.304	0.107	78.40
	(45.7)	(200)	1.983	0.273	31.40
	(56.3)	(211)	1.632	0.189	47.60

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V ₂ O ₅ 0.1wt %	(22.49)	(100)	3.950	0.121	66.68
	(31.76)	(110)	2.815	0.122	67.35
	(39.104)	(111)	2.301	0.117	71.51
	(45.48)	(200)	1.992	0.127	67.7
	(56.6)	(211)	1.624	0.148	60.64

Table (6) The lattice constants values (a,c and c/a) for BaTiO₃/Si thin films at different doping elements at annealing temperature (873K).

sample	a (Å)	c (Å)	c/a
BaTiO ₃	3.982	4.0230	1.010
BaTiO ₃ :0.1wt%NiO	3.995	4.0013	1.015
BaTiO ₃ :0.1wt%MoO ₃	3.988	4.0000	1.003
BaTiO ₃ :0.1wt%V ₂ O ₅	3.981	3.9940	1.003

The surface morphology of the undoped BaTiO₃ thin films as observed from the AFM micrograph confirms that the grains are uniformly distributed within the scanning area (429nm x 429nm). An initial visual investigation of the deposited thin film on both substrates have shown that they are compact and have good adherence to the substrate. No evidence of cracking observed when the thin film was annealed at temperature (873K). Fig. (9) shows nanostructure BaTiO₃ thin films have been deposited on glass and Si (111) substrates at substrate temperature (573K) and annealing temperatures (773K,873K). We can notice that BaTiO₃/glass thin film deposited at substrate temperature (573K) is amorphous, while the nanostructure for thin films at the annealing temperatures (773K,873K). It is observed where the RMS roughness value for thin film deposited at substrate temperature (573K) is (0.1nm), while the RMS roughness for thin films annealed at temperatures (773K,873K) is (0.25 nm,0.571nm), respectively as in Fig. (10). Our results are nearly in agreement with Torresheredia et al [21]. This result indicates that the growth of larger grains with increasing annealing temperature leads to an increase in the surface roughness. The grain size of the thin film can also be deduced from the AFM. It is observed that the average grain size increases with increasing of annealing temperature and the values of the average grain size variable from (48.8nm-58.13nm) when depend at difference annealing temperature. Our results are nearly in agreement with Reddy et al [22].

Effect of annealing and doping with (Mo , V and Ni) elements
oxides on structural properties of BaTiO₃ thin films
Ass.Professor Dr. Sabah A. Salman

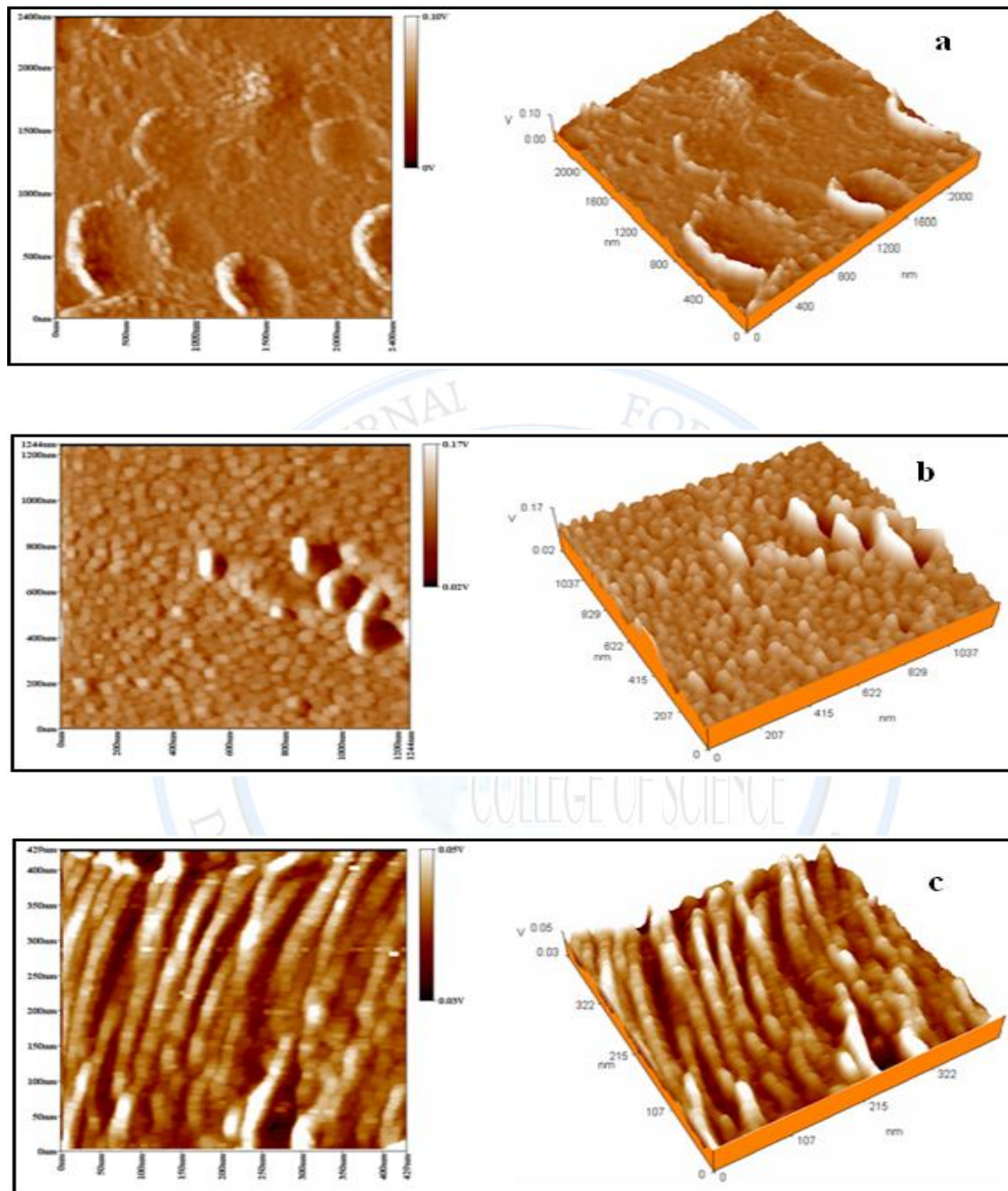


Fig. (9) The AFM images: (a) BaTiO₃/glass thin film deposited at substrate temperature ($T_s=573K$), (b) BaTiO₃/glass thin film at annealing temperature (773K), (c) BaTiO₃/Si thin film at annealing temperature (873K).

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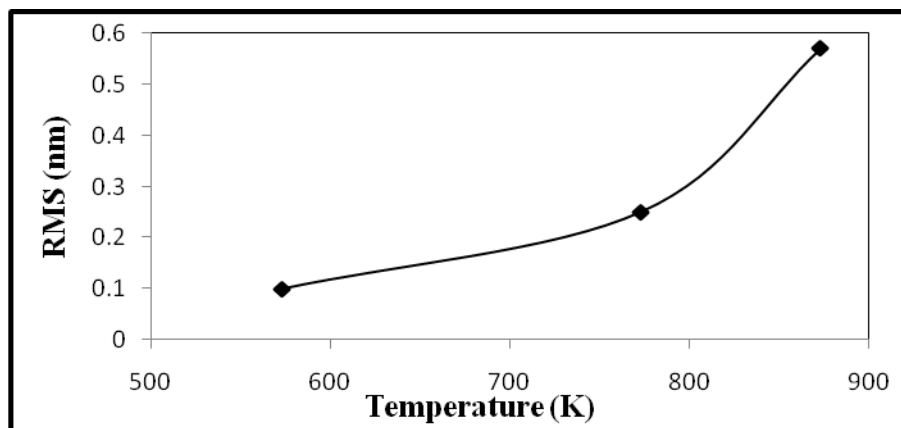


Fig. (10) RMS variation as a function of temperature for different annealing temperatures of BaTiO₃ thin films.

Fig. (11) shows the BaTiO₃/glass thin films deposited at constant substrate temperature ($T_s=573K$) with different elements of mixed oxides (NiO, MoO₃ and V₂O₅) with doping ratio (0.1wt%). It has been found that (MoO₃) doped BaTiO₃/glass thin film was more uniform than (NiO and V₂O₅). Also, It is observed that the RMS roughness values for different dopants (MoO₃, V₂O₅ and NiO) are (0.5nm, 2.77nm and 0.273nm), respectively. Fig. (12) shows nanostructure doped BaTiO₃/Si thin films at annealing temperature (873K) for different elements of mixed oxides (NiO, MoO₃ and V₂O₅) with doping ratio (0.1wt%). It is observed that the RMS roughness increased with different dopants (MoO₃, V₂O₅ and NiO) to have values of (0.569nm, 5.27nm and 2.13nm) respectively.

Table (7) The grain size and roughness for undoped and doped BaTiO₃/Si thin films at annealing temperature (873K) obtained from AFM and XRD analysis.

Sample	AFM of plane grain size (nm)	RMS roughness(nm)	X-ray of plane grain size (nm)
BaTiO ₃	58.13	0.571	68.43
BaTiO ₃ :0.1wt%NiO	44.69	2.130	58.22
BaTiO ₃ :0.1wt%MoO ₃	54.34	0.569	57.68
BaTiO ₃ :0.1wt%V ₂ O ₅	52.79	5.270	66.68

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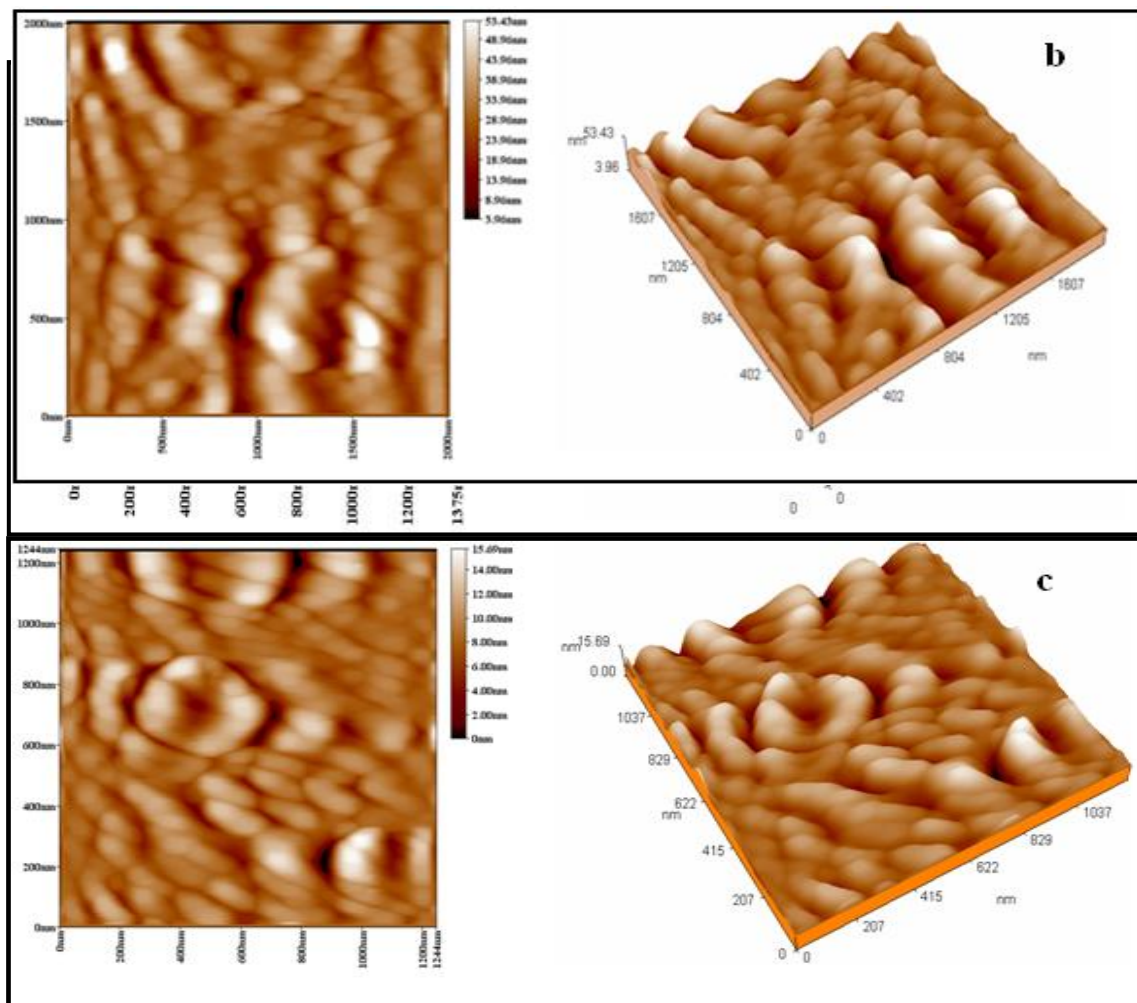


Fig. (11) The AFM images of BaTiO₃/glass thin films deposited at substrate temperature (T_S=573K): (a) MoO₃ doped BaTiO₃/glass thin film (b) V₂O₅ doped BaTiO₃/glass thin film (c) NiO doped BaTiO₃/glass thin film.

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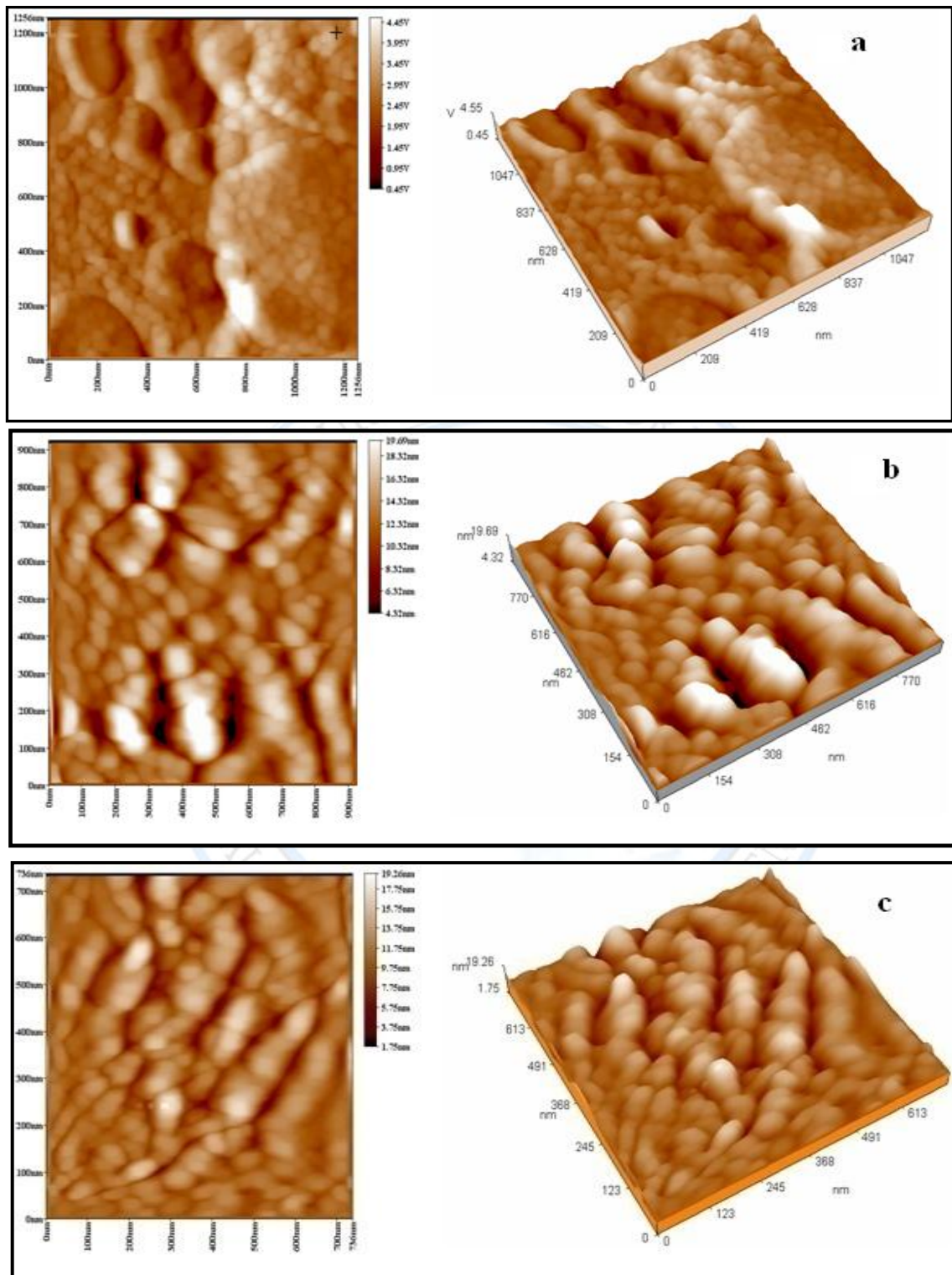


Fig. (12) The AFM images of BaTiO₃/Si thin films at annealing temperature (873K): (a) MoO₃ doped BaTiO₃/Si thin film (b) V₂O₅ doped BaTiO₃/Si thin film (c) NiO doped BaTiO₃/Si thin film.

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Conclusions:

The crystal structure of the BaTiO₃ thin films is amorphous for glass and Si (111) substrates then changes to Polycrystalline after annealing process at temperature (873K) for Si (111) substrate only. The same occurs with doping thin films.

The results from AFM of BaTiO₃/glass and /Si thin films indicates that the growth of larger grains with increasing annealing temperature leads to an increase in the surface roughness. It is observed that the average grain size increases with increasing of annealing temperature, also the RMS roughness increased with increasing annealing temperature.

The results from AFM of BaTiO₃/Si thin films at annealing temperature (873K) for different elements of mixed oxides with doping ratio (0.1wt%), NiO has the smallest grain size.

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