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The effect of substrate surface roughness on ZnO nanostructures growth

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ABSTRACT

The ZnO nanowires have been synthesized using vapor–liquid–solid (VLS) process on Au catalyst thin film deposited on different substrates including Si(1 0 0), epi-Si(1 0 0), quartz and alumina. The influence of surface roughness of different substrates and two different environments ($Ar + H_2$ and N_2) on formation of ZnO nanostructures was investigated. According to AFM observations, the degree of surface roughness of the different substrates is an important factor to form Au islands for growing ZnO nanostructures (nanowires and nanobelts) with different diameters and lengths. Si substrate (without epi-taxy layer) was found that is the best substrate among Si (with epi-taxy layer), alumina and quartz, for the growth of ZnO nanowires with the uniformly small diameter. Scanning electron microscopy (SEM) reveals that different nanostructures including nanobelts, nanowires and microplates have been synthesized depending on types of substrates and gas flow. Observation by transmission electron microscopy (TEM) reveals that the nanostructures are grown by VLS mechanism. The field emission properties of ZnO nanowires grown on the Si(1 0 0) substrate, in various vacuum gaps, were characterized in a UHV chamber at room temperature. Field emission (FE) characterization shows that the turn-on field and the field enhancement factor (β) decrease and increases, respectively, when the vacuum gap (d) increase from 100 to 300 μm. The turn-on emission field and the enhancement factor of ZnO nanowires are found 10 V/μm and 1183 at the vacuum gap of 300 μm.

1. Introduction

Nanostructured materials, such as nanowires [1], nanobelts [2] and nanorods [3] have been important research topics in nanotechnology for their novel properties and potential applications in nanoelectronic [4], nanophotonic [5], and nanobiotechnology [6]. Zinc oxide (ZnO) because of its attractive optical functions based on its wide band gap of 3.37 eV and the exciton binding energy of 60 meV which is larger than the thermal energy at room temperature is a good candidate [7].

For growing one-dimensional ZnO nanostructures, various vapor-phase methods, such as chemical vapor deposition (CVD) [8], metal organic chemical vapor deposition (MOCVD) [9] and thermal chemical reactions vapor transport deposition (TCRVTD) [10] as well as solution phase methods, including electrochemical deposition [11], sol–gel deposition [12] and surfactant-assisted growth [13] can be used for different applications. In addition, various mechanisms such as vapor–liquid–solid (VLS) mechanism [14], vapor–solid (VS) mechanism [15] and redox growth mechanism [16] were proposed to elucidate their growth process. A fundamental aspect of the VLS-based nanowire growth is the necessity of a metal particle acting as a nanocatalyst for the crystal growth. Very recently, function, properties and application of nanoparticle catalysts for growth of nanostructures is reviewed by the author [17].

There are various studies on formation of different nanostructure materials on proper substrates. Table 1 lists some of important nanostructures grown on different substrates. In this regard, growth of ZnO nanostructures was studied by TCRVTD method and VLS mechanism directed by metallic catalysts on different substrates such as Si and Al_2O_3 by others [20]. But, the influence of surface roughness of these substrates on the formation of nanostructures has not been studied, yet. In addition, a very little attention has been focused on understanding the relationship between different substrates and the nature of nanostructures formation.

In this study, ZnO nanowires and microwires were synthesized by TCRVTD method on various substrates such as Si(1 0 0), Si(1 0 0) with epi-taxy layer, SiO_2 and c-sapphire under VLS mechanism. Moreover, the influence of surface roughness of these substrates and two different environments (N_2 and $Ar + H_2$ (80% + 20%)) on the formation of nanowires was also investigated using different analytical techniques.

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Table 1
Growth of 1D nanostructure using various methods.

Nanostructure type	Substrate	Preparation method	Diameters (nm)	Reference
Na_xWO_3 nanorods/nanobelts	Soda lime	Sputtering-thermal method	27–300	[18]
TiO_2 nanowires	Si	TCRVTD	60–100	[19]
ZnO nanowire networks	Al_2O_3	Vapor–solid deposition process	20–100	[20]
MnO_2 nanowires	(AAO)[a]	Sol–gel	70	[21]
β-Ga_2O_3 nanowires	Si	TCRVTD	100–250	[22]
Zn nanowires	Al_2O_3	TCRVTD	50	[23]
In_2O_3 nanowires	Si	TCRVTD	30–50	[24]
InP nanowires	InP	Metalorganic vapor-phase epitaxy	20–100	[25]
MoO_2 nanostars	Si	Thermal vapor deposition	50	[26]

[a] Anodic aluminum oxide.

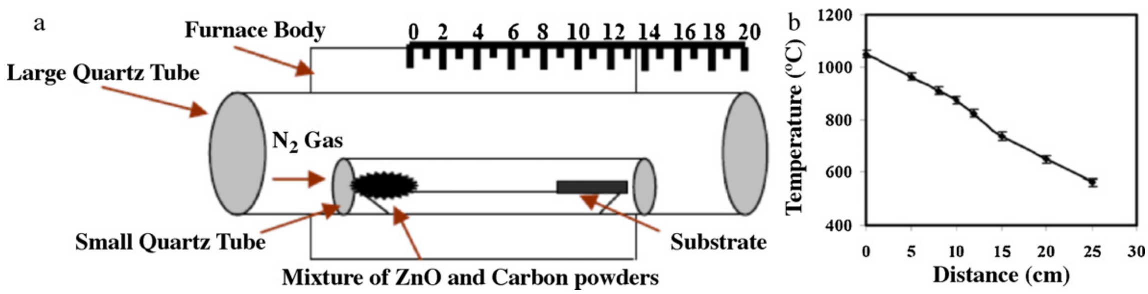

Fig. 1. (a) The basic elements of the experimental setup and (b) temperature gradient inside the furnace during growth of ZnO nanostructures.

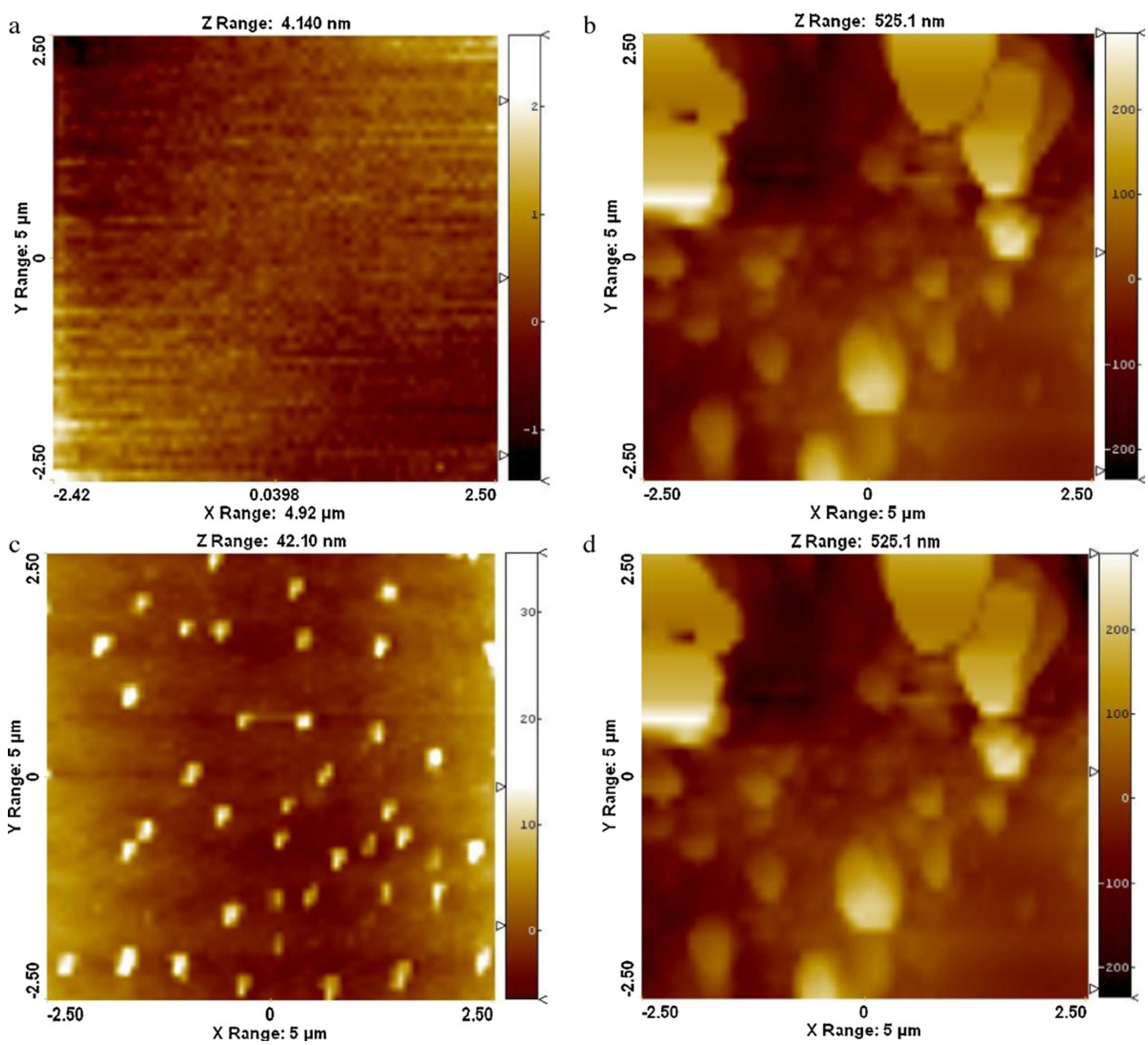

Fig. 2. The AFM images of different substrate surface: (a) Si (with epi-layer), (b) Si (without epi-layer), (c) quartz and (d) alumina.