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Fabrication of 128×128 element optical switch array by micromachining technology

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Abstract

Polycrystalline VO_2 thin films were obtained on Si substrates by ion beam sputtering deposition and annealing in flowing Ar gas. SEM images indicate that VO_2 thin films were grown into compact surfaces. Four-probe measurements indicated that the VO_2 thin films own good electrical homogeneity. After the films' production, micromachining technology including lithography, reaction ion etching and metallization connection processes was used to produce the optical switch array. As a result, the 128×128 element optical switch array was achieved.

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Keywords: Vanadium oxide thin films; Ion beam sputtering; Temperature coefficient of resistance; Photolithography; 128×128 Element; Infrared optical switch array

1. Introduction

Since 1958, F.J. Morin had observed the switch-able property of VO_2 [1]. V–O system has been studied in a wide field. Among all V–O oxides, VO_2 thin films have attracted many attentions. Many methods have been used to prepare vanadium oxide (VO_2) thin films, such as: ion beam sputtering, evaporation, magnet sputtering, sol–gel method, etc. Referring to many papers [3–4], ion beam sputtering is regarded as an excellent method to obtain high quality of VO_2 thin films at lower temperature with stronger coherence. However, it is not easy to get high quality of vanadium oxide (VO_2) thin films using this method. Usually VO_2 has been proven to be a kind of novel switch-able material owning dramatic transition in electrical and optical properties around 68 °C. As mentioned, the vanadium oxide obtained are usually made up of several phases, noted as: V_2O_3, VO_2, V_2O_5 etc. [2,3]. These have different properties. V_2O_3 is a phase owning low phase transition temperature (about 139 K), on the contrary, V_2O_5 changes into metallic state at high temperatures (∼523 K).

Vanadium dioxide (VO_2) thin films that are used frequently as electrical or optical switch, at room temperature (RT), the phase is a semiconductor, when increasing the temperature, semi-conducting vanadium dioxide changes into a conducting metallic status with low transparency in near IR spectrum range. The material is thought ideal to be used as optical-switch and/or electrical-switch for its phase transition occurs usually in extreme short period (∼ns level) [3]. The phase transition not only changes the conductivity of thin films, but also the optical, magnetic, and mechanical properties of the material are changed. All these changes bring the material a great potential to be used in fields, such as: optical communication, microwave devices, IR optical switches, optical memory elements, etc. In addition, the phenomenon optical/electrical inducing color-changing has been known long before and has been developed into many applications [4–6].

Although VO_2 thin film is a good optical and electrical switch-able material, its transition temperature (∼68 °C) is little higher in normal occasions. If the transition temperature could be reduced a little, there would be many potential

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applications, such as: intelligent windows with VO_2 coatings, which changes its transparency while inner temperature is higher than its transition temperature [7–8]. Moreover, many temperature controllers could be taking the place of the film material [10].

In this letter, we reported our experiments on fabricating the vanadium oxide films by ion beam sputtering and also, our experiments on lithography of VO_2 thin films for 128 element optical switch array and its characterizations.

2. Experimental

2.1. Deposition of VO_2 thin films

Firstly, the chamber was evacuated to a high vacuum as 1×10^{-3} Pa at a preliminary vacuum level (the schematic diagram of the chamber is shown in Fig. 1). Then, argon gas was delivered into ion gun closet. The Ar ions were drawn out under an extract voltage that was applied onto the grid of the ion gun. After a sputtering to remove the surface layers of targets, sputtering was stopped. Ar gas inlet valve was closed, when the vacuum achieved 1×10^{-3} Pa and back-filling to 2–3×10^{-3} Pa with pure O_2 gas (99.995%), then back-filling to 2.6×10^{-2} Pa with 99.995% pure Ar gas. Therefore, the partial pressure ratio of Ar to O_2 is 24: 1–12: 1. The vanadium oxide films were deposited onto the wafers by sputtering metallic vanadium target (purity of 99.9%) for 5 min.

The annealing was carried out in a flow gas annealing quartz furnace. The samples were annealed at 485 °C in flowing Ar gas. The furnace temperature was controlled in a PID program-controlling mode. The gas flow was about 150 sccm. Annealing time was changed from 60 to 120 min. After annealing, the samples were cooled in furnace slowly (Table 1).

2.2. Fabrication of 128×128 element optical switch array

After deposition of thin films, lithography was used to produce the 128×128 element optical switch array.

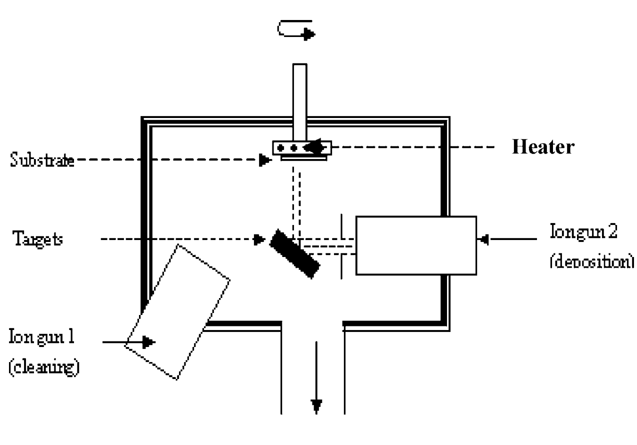

Fig. 1. The schematic diagram of ion beam sputtering instrument.

Table 1
The deposition conditions of the VO_2 films

Parameter	Value
Preliminary vacuum	$<1\times10^{-3}$ Pa
Oxygen pressure	$1\sim2\times10^{-3}$ Pa
Ion energy	700 eV
Beam current	70 mA
Deposition period	5 min
Substrate temperature	380 °C

Table 2
The parameter of 128 element optical switch array produced

Parameter	Value
Pixel size (μm)	50×60
Array format	128×128
Resistance of element (kΩ/□)	500

Among the processes, AZ1500 photo-resist was used to spin and expose to UV radiation for its precise resolution (∼sub-micrometer level) in sub-micrometer level. Then reaction ion etching (RIE) was also proceeded.

The NiCr(200 nm)/Au(150 nm) heating resistor and electric contacts were deposited by ion beam sputtering. The corresponding parameters of the optical switch array were shown in Table 2.

2.3. Measurement

After deposition, four-probe electrical measurement was carried out, XRD and SEM were also used to analysis the structure and morphology.

The four-probe measurements were carried out on a hot plate where temperature was detected and transported by a highly sensitive data acquisition board connected to a personnel computer. When the temperature was escalated from RT to a higher temperature, the corresponding sheet resistance was recorded automatically. The temperature was kept stable (within 0.2 °C oscillation) by a PID feedback controlling mode. Using this instrument, we carried out

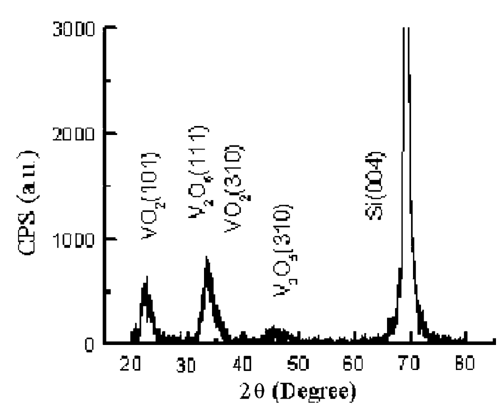

Fig. 2. The XRD pattern of the as-deposited samples under lower O_2 pressure (1×10^{-3} Pa).