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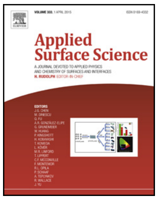

Investigated performance of uncooled tantalum-doped VO_x floating-type microbolometers

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ABSTRACT

Various tantalum (Ta)-doped vanadium oxide (VO_x:Ta) films with various Ta doping contents were deposited on the Si substrates as the sensitive layer of the floating-type microbolometers using a magnetron radio frequency (RF) co-sputtering system. The vanadium (V) target and the tantalum pentoxide (Ta_2O_5) target were used to deposit the VO_x:Ta films. To improve the microbolometer responsivity by effectively reducing the thermal loss from the Si substrates, the floating-type microbolometers were fabricated using bulk micromachining technique. From the X-ray photoelectron spectroscopy (XPS) spectra, except the V_2O_5 and V_6O_{13}, the lower oxygen state of VO_x films, such as VO_2 and V_2O_3, were also obtained by doping Ta into the VO_x films. Consequently, compared with the VO_2 microbolometers, the VO_x:Ta microbolometers could operate at a higher operating temperature range. The temperature coefficient of resistance (TCR) and the resistivity of the VO_x:Ta (Ta content of 7.63%) films measured by four point probe measurement in heating system were −3.47%/K and 9.32 Ω-cm, respectively. The Ta-doped VO_x microbolometer revealed a higher responsivity of 341 kV/W compared with 106 kV/W of the undoped VO_x microbolometer.

1. Introduction

In recent years, infrared (IR) sensors have been developed and applied in many fields, such as military, medicine, and industry [1]. In view of the advantages of lower cost and lower power consumption, the uncooled IR microbolometers (operated at room temperature) become the most preferred candidate. There are several materials, such as Pt [2], Ti [3], Ni [4], vanadium oxide (VO_x) [5,6], amorphous silicon (a-Si) [7,8], and superconductors [9], were utilized as the IR sensitive layer of the IR bolometers. Among them, the VO_x is widely used as the bolometric materials due to its high temperature coefficient of resistance (TCR) [10,11], suitable thermal time constant, and low cost preparation methods. In the phase of VO_x, it was found that the V_2O_5 and the VO_2 possessed a higher TCR [12]. However, the V_2O_5 could not compatible with the resistivity of the readout integrated circuit (ROIC) (1–10 Ω-cm) [13] due to its a higher resistivity [14]. Besides, although the polycrystalline or single crystalline VO_2 films prepared with high processed temperature between 500 °C to 700 °C could possess a higher TCR [15,16], the narrow operated temperature range of 10 °C limited the practical applications [17,18]. Consequently, it was deduced that the individual V_2O_5 film or VO_2 film was not a suitable sensitive material for the IR microbolometers.

To obtain high performances of the IR microbolometers with a high TCR, a wider operated temperature range about 30 °C, and a lower resistivity to match the ROIC, the VO_x films with proper phases are required to be developed. Several techniques, such as W-doping [19,20], Mn-doping [21], Mo-doping [22,23], and nanostructure VO_x films [24], were utilized to improve the TCR of VO_x films. In this work, the tantalum (Ta) element was selected to dope into the VO_x films using a magnetron radio frequency (RF) co-sputtering system. Since the binding energy of Ta bound to oxygen (O) was lower than that of vanadium (V) bound to O, the oxidation state of the VO_x films would be decreased by doping the Ta into the VO_x films. This phenomenon could enhance more proper mixed phases in the deposited VO_x films. In this work, the deposited VO_x:Ta films and the VO_x films were respectively applied in the floating-type microbolometers as the sensitive

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layers. Furthermore, the performances of the resulting floating-type microbolometers were also measured to investigate the function of the VO_x:Ta sensitive layers.

2. Experimental procedure

Using V target (99.9%) and tantalum pentoxide (Ta_2O_5) target (99.9%), various Ta-doped VO_x (VO_x:Ta) films were deposited on Si substrates at room temperature by a magnetron RF co-sputtering system. The VO_x:Ta films with various Ta doping contents were obtained by controlling the RF power of the Ta_2O_5 target, while the RF power of V target was kept at 200 W. The reactive gas ratio of oxygen gas to argon gas was 1:9 and the processing chamber pressure was 5 mTorr. The distance between the Si substrate and the targets in the co-sputtering system was 5 cm. Furthermore, the various deposited VO_x:Ta films were annealed in furnace system of nitrogen ambience at 673 K for 90 min. Using an energy dispersive spectroscopy (EDS), the Ta atomic ratio was 1.19%, 7.63%, and 14.29%, corresponded to the VO_x:Ta films deposited with RF power of 10 W, 15 W, and 20 W for the Ta_2O_5 target, respectively.

Fig. 1 shows the schematic configuration of the VO_x:Ta floating-type microbolometers in which the pixel size and the sensitive size were 50 μm × 50 μm and 40 μm × 22 μm, respectively. The 500-nm-thick silicon oxide (SiO_y) buffer layer and the 200-nm-thick silicon nitride (SiN_z) supporting layer were sequentially deposited on Si substrates using a plasma enhanced chemical vapor deposition (PECVD) system. The 130-nm-thick VO_x:Ta and VO_x sensitive layers were respectively deposited on the SiN_z supporting layers and were then annealed in a nitrogen ambience at 673 K for 90 min using furnace system. Furthermore, the electron-beam evaporator was used to deposit the Ni/Au metals (20 nm/100 nm) as the electrode of the microbolometers. As shown in Fig. 1, to protect the sensitive layer, the 200-nm-thick SiO_y passivation layer was deposited and patterned using the PECVD system and standard photolithography technique, respectively. To reduce the thermal conductance of the microbolometers from the Si substrates, the Si area under the sensitive zone was removed to form the floating zone. The photolithography technique was utilized to define the wet etching window of the floating zone and an inductively coupled plasma (ICP) system was used to etch the SiN_z supporting layer and SiO_y buffer layer until the Si substrates. The Si substrate under the floating zone was etched away by tetramethyl ammonium hydroxide (TMAH) (wt% = 5%) solution.

The crystallinity and chemical binding of the VO_x:Ta films were examined using an X-ray diffraction (XRD) and an X-ray photoelectron spectroscopy (XPS), respectively. To estimate the TCR values, the resistivity of the various VO_x:Ta films were measured by a four-probe system with a heater at temperature range from 303 K to 333 K. The responsivity, the thermal time constant, and the thermal conductance of the VO_x:Ta and the VO_x floating-type microbolometers were also measured and analyzed. The blackbody radiation system used as the IR power was illuminated on the floating-type microbolometer to make the various temperatures. A chopper with different frequency was utilized to chop the IR radiation from the blackbody radiation source.

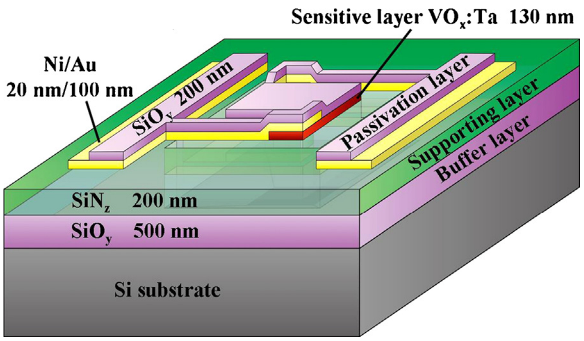

Fig. 1. Schematic configuration of the VO_x:Ta floating-type microbolometers.

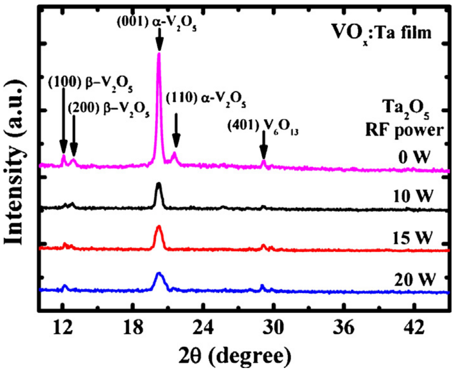

Fig. 2. XRD spectra of the VO_x:Ta films.

3. Experimental results and discussion

Fig. 2 shows the crystallinity of the various VO_x:Ta films measured by an XRD. As shown in Fig. 2, the XRD spectrum of the VO_x films without Ta doping content exhibited diffraction peaks at (1 0 0) β-V_2O_5, (2 0 0) β-V_2O_5, (0 0 1) α-V_2O_5, (1 1 0) α-V_2O_5, and (4 0 1) V_6O_{13}. The intensity of the (0 0 1) α-V_2O_5 peak evidently decreased for Ta doping into the VO_x films. This phenomenon was attributed to that because the atomic radius of Ta (146 pm) was larger than that of V (134 pm), the α-V_2O_5 structure was elongated as Ta doped into VO_x films. Consequently, the crystallinity of VO_x:Ta films was degenerated.

The chemical binding of the VO_x films and the various VO_x:Ta films was analyzed using an XPS. Fig. 3(a) and (b) shows the XPS spectra of the V $2p_{3/2}$ core-level for the VO_x:Ta films deposited

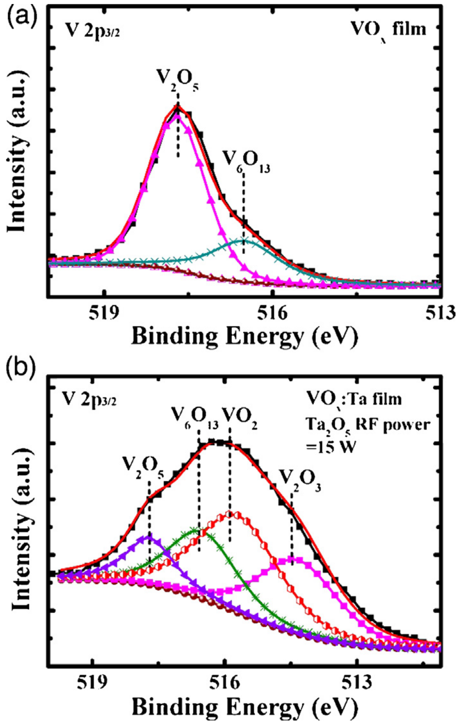

Fig. 3. XPS spectrum of the V $2p_{3/2}$ core-level for (a) VO_x films and (b) VO_x:Ta films deposited with Ta_2O_5 RF power of 15 W.

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