Thin Solid Films 519 (2011) 3383–3387

Contents lists available at ScienceDirect

Thin Solid Films

journal homepage: www.elsevier.com/locate/tsf

Experimental investigation of dimension effect on electrical oscillation in planar device based on VO_2 thin film

Giwan Seo [a,b], Bong-Jun Kim [a], Yong Wook Lee [a,c,*], Sungyoul Choi [a], Jun-Hwan Shin [a,b], Hyun-Tak Kim [a,b]

[a] Metal-Insulator Transition Device Team, ETRI, Daejeon 305-700, Republic of Korea
[b] School of Advanced Device Technology, University of Science and Technology (UST), Daejeon 305-350, Republic of Korea
[c] School of Electrical Engineering, Pukyong National University, Busan 608-737, Republic of Korea

ARTICLE INFO

Article history:
Received 13 July 2010
Received in revised form 17 December 2010
Accepted 17 December 2010

Keywords:
Metal-insulator transition
VO_2 thin film
Electrical oscillation
Planar device
Dimension effect

ABSTRACT

In this paper, we report on an experimental analysis of dimension effect on a room-temperature electrical oscillation in a planar device using vanadium dioxide (VO_2) thin film. We investigate the variation of the oscillation current (I_O) and frequency (f_O) due to the variation of the dimension of the VO_2 devices, i.e., the length and width of the current channel of the device. For five different VO_2 devices with different dimensions, I_O and f_O are observed at room temperature in a simple circuit composed of a dc voltage source and a standard resistor including one of the VO_2 devices. From the experimental investigation, it is concluded that the peak-to-peak amplitude of I_O and f_O decrease with the increase of the length and width of the current channel. This indicates that f_O depends on not only the external source voltage but also the device dimension.

1. Introduction

Owing to the sharp electrical switching property based on its electric field-induced resistance change, vanadium dioxide (VO_2) thin films have attracted considerable attention for demonstrating the metal–insulator transition theories and its potential in various electrical and optical applications [1–11]. Especially, two-terminal planar junction devices based on VO_2 thin films show strong nonlinear current–voltage (I–V) characteristics [5]. This characteristic was also observed in other materials including perovskite oxides [10], organic materials [11], and gallium arsenide (GaAs) [12]. The oscillatory electrical responses have been observed in a circuit composed of a thin-film-based device and serial standard resistor at very low temperatures. Recently, it was reported that the room-temperature electrical oscillation could be obtained in a planar device based on VO_2 thin film [13–15]. In previous studies, however, the device dimension, i.e., the length (L) and the width (W) of the current channel, was fixed as a square-shaped one like 5×5 or $10\times10\ \mu m^2$, instead of rectangular-shaped ones [14,15].

In this paper, we experimentally investigate the variation of the electrical oscillation properties including an oscillation current (I_O) and an oscillation frequency (f_O) for planar devices with the variation of the device dimensions. Through the experimental investigation, we observe the modification of the generation window of the electrical oscillation (oscillation window) determined with an external source voltage (V_S) and an external standard resistor (R_E) according to the variation of the device dimensions. For the examination of the variation of the oscillation properties (I_O and f_O), the resistance of the serial resistor (potentiometer) was fixed at 3.5 kΩ in order to focus only on the dimension effect by removing resistance change. From the examination, it is concluded that f_O can be controlled by not only the applied voltage but also the device dimension.

2. Experimental details

VO_2 thin films were grown on c-plane sapphire (Al_2O_3) substrates by employing a pulsed laser deposition technique [16]. The substrate temperature $T_{substrate}$ was kept constant at 500 °C during the deposition. The base pressure of the chamber was 1.33×10^{-4} Pa. A total gas pressure of 0.67 Pa was maintained in the chamber at an oxygen flow of 50 sccm. After the deposition process, the films grown on the substrate were cooled down to room temperature with the same gas condition. The thickness of the grown films was typically ~100 nm. In order to fabricate planar VO_2 devices, the films were patterned into line shapes with photolithography processes and were etched by an ion-beam assisted milling method. For an Au/Ti electrode layer on the etched VO_2 layer, a metallization process was progressed by using an RF sputtering method and a lift-off technique [17]. For the facilitation of the adhesion, the Ti electrode layer was deposited first below the Au electrode one. The widths of the current channels of the VO_2 devices were designed to be narrower than those of the electrodes to avoid a delayed transition of VO_2 outside the

* Corresponding author. School of Electrical Engineering, Pukyong National University, Busan 608-737, Republic of Korea. Tel.: +82 51 629 6323; fax: +82 51 629 6305.
E-mail address: yongwook@pknu.ac.kr (Y.W. Lee).

0040-6090/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.tsf.2010.12.168

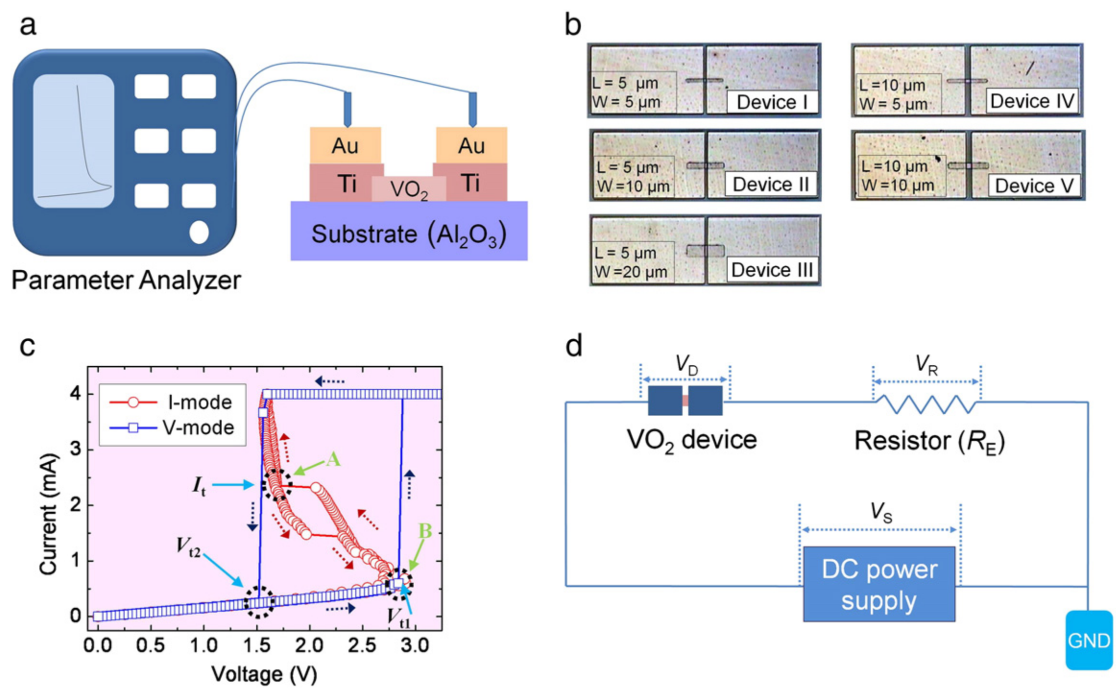

Fig. 1. (a) The cross-sectional diagram of the fabricated device and the schematic diagram of an experimental setup for measuring the *I–V* characteristics of the devices. (b) The optical microscope plane-view images of five VO_2 devices (Devices I–V). (c) The *I–V* hysteresis loops of Device I measured. (d) The single-loop circuit was designed with a planar VO_2 device, an external standard resistor (R_E), and a dc power supply (V_S).

electrodes. The dimensions (L×W) of the current channels of five different VO_2 devices designated as Devices I, II, III, IV, and V were 5×5, 5×10, 5×20, 10×5, and 10×10 μm^2, respectively. Fig. 1(a) shows a cross-sectional diagram of the fabricated device and a schematic diagram of an experimental setup for measuring *I–V* characteristics of the devices. Fig. 1(b) shows optical microscope plane-view images of five VO_2 devices (Devices I–V). For measuring *I–V* characteristics, we used a parameter analyzer (Agilent B1500A) with tungsten probe tips of 5 μm in diameter. The contact resistance with the devices was ≤5 Ω, which was ≤0.05% compared with the resistance across the device (R_D) at room temperature. To implement the field-induced oscillation and control f_O, a single-loop circuit was designed with a planar VO_2 device, an external standard resistor (R_E), and a dc voltage source (V_S) as shown in Fig. 1(d). A function generator (Agilent 33120A) and a dc power supply were simultaneously utilized to generate rectangular voltage pulses with adjustable dc offsets. The electrical waveforms from the circuit were recorded by a digital storage oscilloscope (HP 54810A).

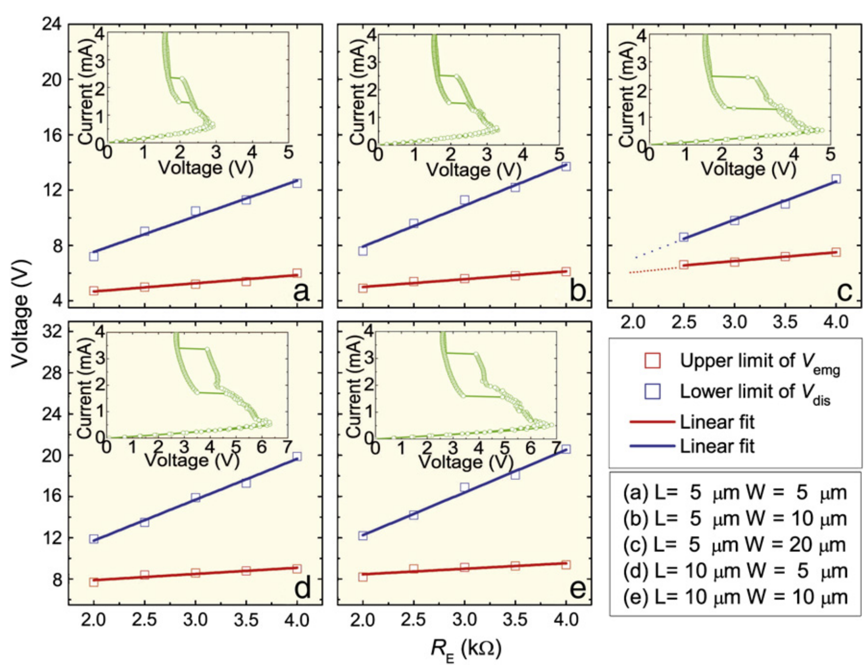

Fig. 2. (a)–(e) The oscillation window with respect to five devices (Devices I–V). The lower and upper limits of V_{emg} and V_{dis} where the oscillation can be existed are plotted with red squares and blue squares, respectively. Inset panels show *I–V* hysteresis loops of Devices I–V at $R_E = 0$ kΩ.