Vacuum 151 (2018) 261–265

Contents lists available at ScienceDirect

Vacuum

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

Short communication

Origin of a continuously enlarge memristor effect in Nb inserted into MgB_2 multilayer constructed heterojunctions

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ARTICLE INFO

Article history:
Received 10 December 2017
Received in revised form
26 January 2018
Accepted 26 February 2018
Available online 27 February 2018

Keywords:
MgB_2 multilayer
Heterojunctions
Enlarge memristor effect
Schottky barrier

ABSTRACT

In this work, a resistive switching memory device, in which niobium (Nb) inserted into magnesium diboride (MgB_2) multilayer constructed heterojunctions, was prepared by vacuum sputtering at 400 °C. Furthermore, a continuously enlarge memristor memory effect was observed in $Ti/(MgB_2/Nb)_n/MgB_2/Ti$ (n = 0, 1, 2, 3) devices with the increasing of the inserted Nb layers numbers for the first time. Finally, a model of Schottky barrier based on interfaces of Ti/MgB_2 and Nb/MgB_2 are used to explain the memory characteristics.

1. Introduction

With the continuous developments of information technology and progress of science technology, the period of big data and information have been also setting in. To develop information storage devices to satisfy the widespread demand of memory, many novel concepts memory devices had been continuously emerging [1,2]. In a variety of new storage device, one of the most promising is the resistive random access memory (RRAM), which is based on the resistive switching effect of a material [3,4]. The resistive switching behaviour is that the resistance of the fabricated device can be switched between a high resistance state (HRS) and a low resistance state (LRS) under bias voltage. If the HRS is defined as a logical “0” and the LRS is defined as a logical “1”, the switching phenomena can store information and can be used for storage device preparation [5–7].

Since the superconductivity of simple metal compound MgB_2 was discovered in 2001, the understanding of this new material has been constantly deepened, and its practical application is also increasing gradually. With the development of microscopic theory, the superconductivity of superconductors was interpreted based on the theory of Bardeen, Cooper and Schrieffer (BCS) [8]. In nowadays society, with the development of semiconductor materials and electronic integrated circuits, the information storage devices is being continuously improving. The memory devices with higher storage density, superfast read and write speed, low power consumption and miniaturized storage units are actively pursued in present research [9,10].

Considering the above reasons, we prepared Nb inserted into MgB_2 multilayer constructed heterojunctions devices and studied their resistive switching memory characteristics. In our work, Nb inserted into MgB_2 multilayer constructed heterojunctions devices with $Ti/(MgB_2/Nb)_n/MgB_2/Ti$ (n = 0, 1, 2, 3) structures was prepared by vacuum deposition at 400 °C. The complete preparation process of device is shown in (Fig. 1a). The prepared process of $Ti/(MgB_2/Nb)_n/MgB_2/Ti$ (n = 0, 1, 2) devices are similar to that of $Ti/(MgB_2/Nb)_n/MgB_2/Ti$ (n = 3) device (Fig. 1a). In particularly, a continuously enlarge memristor memory effect is observed with the increasing of the inserted Nb layers numbers. Finally, a model of Schottky barrier based on interfaces of Ti/MgB_2 and Nb/MgB_2 are used to explain the memory characteristics.

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https://doi.org/10.1016/j.vacuum.2018.02.038

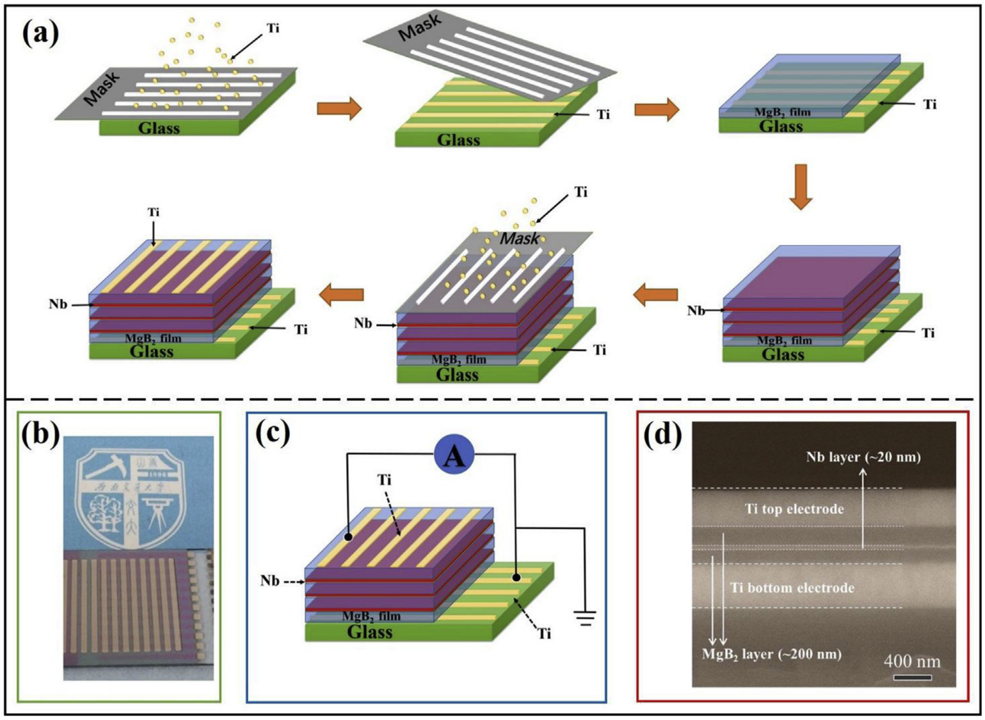

Fig. 1. (a) The schematic preparation process of a Ti/$(MgB_2/Nb)_n/MgB_2$/Ti (n = 3) device. (b) The photograph of the as-prepared memory device. (c) The experimental test circuit. (d) The cross-sectional SEM image of prepared device.

2. Experimental

In our works, Nb inserted into MgB_2 multilayer constructed Ti/$(MgB_2/Nb)_n/MgB_2$/Ti (n = 0, 1, 2, 3) devices were prepared by vacuum deposition. Raw materials are Ti and Nb metal targets with a diameter of 6 cm, their purity is 99.999%. The purity of MgB_2 target is 99.99% with the diameter of 6 cm. Firstly, the glass substrate was washed with deionized water, ethanol, acetone, ethanol, deionized water for 20 min respectively. Secondly, Ti electrode was deposited on a glass substrate as bottom electrode (BE) by using a metal shadow mask, the sputtering current is 0.4 A and the time is 20 min. There are two main technical difficulties in the preparation of MgB_2 film, the one is Mg extremely oxidizing the other one is Mg easily volatile. In our experiment, the MgB_2 thin film was deposited in a high vacuum environment. Thus, the reaction between Mg and oxygen will be hindered and the impurity content in MgB_2 film will be reduced. Secondly, the preparation MgB_2 films were deposited on Ti covered glass via radio frequency (RF) magnetron sputtering. The vacuum reached 10^{-5} Pa, while the high purity argon (Ar) as working gas, the pressure was maintained at 2.0 Pa. The vacuum sputtering power was 200 W, the total sputtering time of MgB_2 film is 30 min and the substrate temperature was controlled at 400 °C during deposition. In the preparation of Nb layer, we used direct current vacuum sputtering system, the current of sputtering is 0.3 A and the sputter time is 30 s. Thirdly, Ti top electrode (TE) was prepared by using a metal shadow mask. Thus the resistive switching devices with Ti/$(MgB_2/Nb)_n/MgB_2$/Ti (n = 0, 1, 2, 3) structures were prepared. (Fig. 1b) shows the photograph of the as-prepared memory device.

All the electric performance was measured by using the electrochemical workstation (CHI-660E), the test scan rate is 0.2 V s^{-1} at room temperature. The experimental test circuitry was shown in Fig. 1c.

3. Results and discussions

Fig. 1d exhibits scanning electron microscopy (SEM) image of prepared device, which shows a thickness of about 400 nm of MgB_2 film layer deposited on the Ti BE. And the thickness of layer Nb is about 20 nm. It can be seen from the SEM image that the sample indeed is Nb inserted into MgB_2 multilayer constructed heterojunctions. Next, the Ti/$(MgB_2/Nb)_n/MgB_2$/Ti (n = 0, 1, 2, 3) devices are contrastively investigated in our work. All the electrical properties were measured by electrochemical workstation (CHI-660E) with the bias voltage applied on the Ti TE while the Ti BE was grounded at room temperature. In the testing process, we set up a compliance current (CC) of 0.1 A to avoid too large current to cause permanent breakdown of the device [10]. The scanning direction of the applied voltage is 0 → 6.0 V → 0 → −6.0 V → 0, which applies a scan voltage on the Ti TE. There is no hysteresis behavior for the Ti/$(MgB_2/Nb)_n/MgB_2$/Ti (n = 0) device (Fig. 2a). However, the device exhibit hysteresis behavior when Nb is inserted into MgB_2 multilayer constructed Ti/$(MgB_2/Nb)_n/MgB_2$/Ti (n = 1) heterojunctions, and the hysteresis behavior becomes more obvious with the increasing of Nb interlayers number. The current-voltage (I-V) curve shows an obvious hysteresis behavior on a linear scale (Fig. 2b). This I-V curve characteristic shows resistive switching memory behavior. In other words, the Nb inserted into MgB_2 multilayer constructed heterojunctions exhibit a bipolar resistive switching memory characteristics, which can reversibly changing-over between HRS and LRS, thus our device can provides a clear memory window under read and write voltage. If HRS is defined as logical “0”, LRS is defined as logical “1”, this transformation process can be used to store information, in which the memory window can write and read data in different logical states [11]. We carefully observed the measured data, the Ti/$(MgB_2/Nb)_n/MgB_2$/Ti (n = 1) device display an obvious memory storage window in the negative voltage region. Of course, the memory storage window of the Ti/