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Resistive switching effect on Al_2O_3/InGaAs stacks

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ABSTRACT

The resistive switching (RS) phenomenon is currently attracting a lot of attention due to its potential applicability for nonvolatile memory devices. Among all the systems currently under consideration, the analysis of MG/Al_2O_3/InGaAs is very relevant since this stack is a strong candidate for the new generation of CMOS devices with high mobility channels.

1. Introduction

The resistive switching (RS) phenomenon is currently attracting a lot of attention from academia and industry due to its potential applicability for nonvolatile memory devices [1].

The phenomenon has been reported for a wide variety of structures with more or less similar characteristics, but there is a lack of understanding of the origin of the physical effect that causes a change in the stack. Some studies have related RS to the rupture and recovery of conducting paths caused by the drift of atoms or vacancies and by Joule heating effects, respectively [1,2].

Among all the system that shows a change of the resistive state after a forming event, it is relevant the analysis on MG/Al_2O_3/InGaAs since these stacks are strong candidate for the new generation of CMOS devices due o the high mobility of the carriers on the substrate and the high-*k* values of the dielectrics [3]. To date, little is known about the RS effects and its origin in this kind of MG/HK/III–V structures.

In this work, we focus our attention on the origin of the RS effect combining the electrical characterization with a deep analysis on the composition of the interface.

2. Samples and experimental details

The origin of the resistive switching phenomenon is studied by combination of electrical characterization and X-ray photoelectron spectroscopy (XPS) spectra of the oxide-substrate interface for MOS structures of MG/Al_2O_3/InGaAs. Different set of samples were manufactured on n- and p-type InGaAs substrates epitaxially grown on InP wafers. For samples A and B (p-type substrate, and Au gate metals) molecular-atomic-deposition (MAD) system have been used for the Al_2O_3 deposition. The sample A received no additional surface treatment before Al_2O_3 deposition in a N_2 ambient (5 nm); the sample B received forming gas ($95\%N_2 + 5\%H_2$) plasma treatment at room temperature, followed by Al_2O_3 deposition in an N_2 ambient (3 nm). On the other hand, sample C (n-type substrate and Ti/Au gate metals) received 9 nm of Al_2O_3 deposited by ALD. After gate metal deposition, the samples were annealed in N_2 for 30 min at 400 °C.

The XPS spectra were collected in a Thermo VG Scientific Sigma Probe system using a monochromatic Al Ka (1486.6 eV) X-ray source.

A complete electrical characterization has been carried out with capacitance–voltage (*C–V*), at different frequencies from 30 KHz to 1 KHz using the LCR meter Agilent 4285 A, and current–voltage (*I–V*) measurements using the parameter analyzer Agilent 4155 C.

3. Results

Figs. 1 and 2a show the multi-frequency *C–V* curves (1–30 kHz) of samples A and B. At 1 KHz it is clear that the *C–V* curves are different in both samples. In sample A, the *C–V* curve increase significantly at positive voltage, while the sample B shows a small increase of the capacitance under the same condition. The capacitance is increased significantly in the inversion regime (defined in literature as "weak inversion hump") due to interface states [3].

Fig. 1(b) shows consecutives voltage sweep curves revealing the resistive switching (RS) characteristics of those MOS stacks. In this case, an initial current-limited breakdown step was needed to generate the filamentary path (curve not shown). After this forming operation (which can occur at a negative and a positive bias), the RS phenomenon is characterized by reversible transitions from a high resistive state (HRS) to a low resistive state (LRS).

Based on the BD (breakdown) percolation model, the RS statistics can be analyzed as reported in [4]. Fig. 3(a) shows the Weibull

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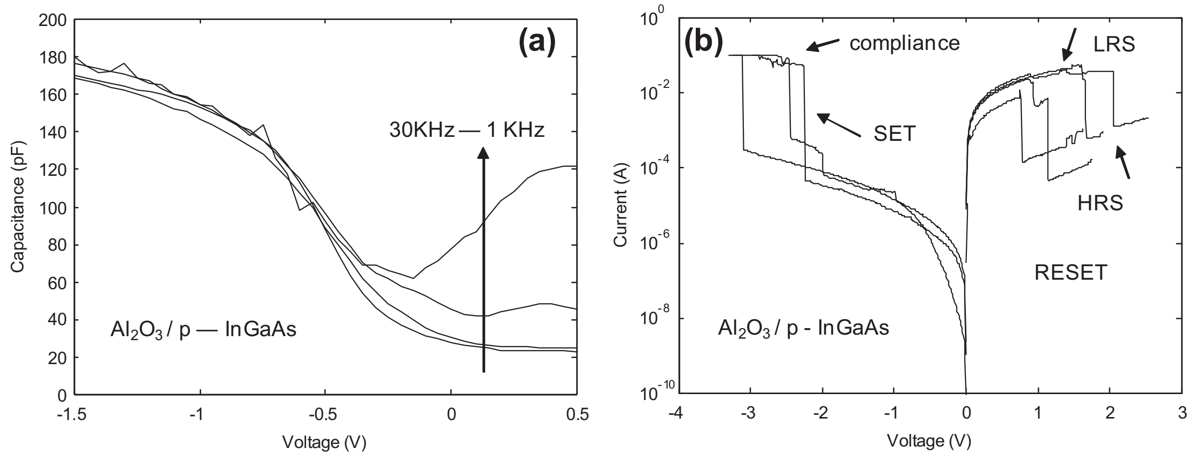

Fig. 1. Typical electrical characteristics of sample A. (a) Multi-frequency *C–V* curves from 30 kHz to 1 KHz. (b) Consecutives *I–V* curves showing transition between low resistive state (LRS) and high resistive state (HRS).

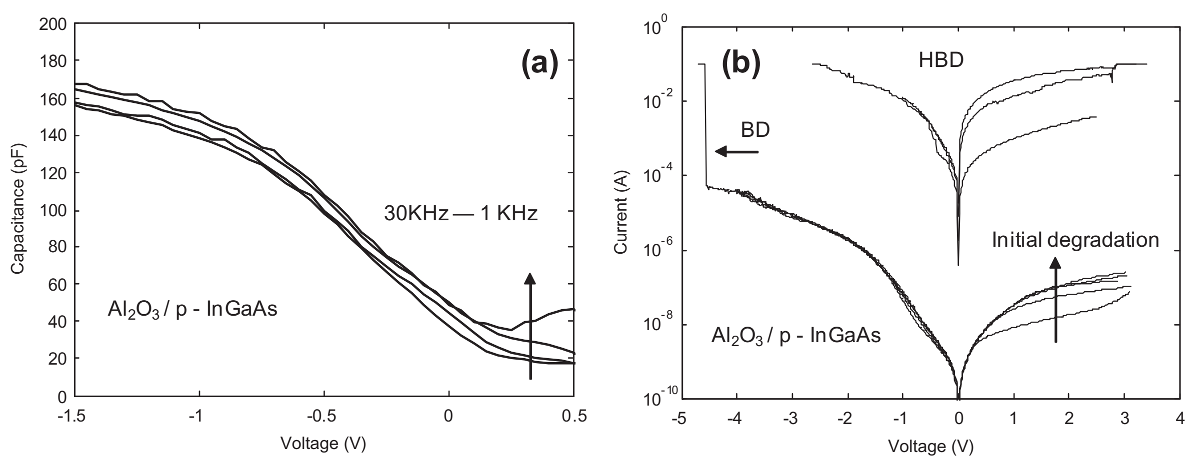

Fig. 2. Typical electrical characteristics of sample B. (a) Multi-frequency *CV* curves from 30 kHz to 1 KHz. (b) Consecutives *I–V* curves showing transition between low resistive state (LRS) and high resistive state (HRS).

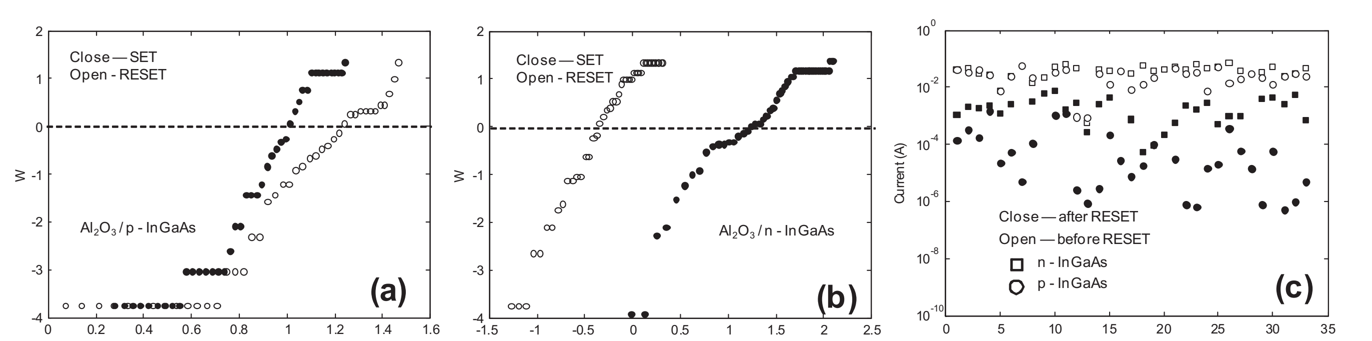

Fig. 3. Analysis of the transition between low resistive state (LRS) and high resistive state (HRS). Weibull distribution of the RESET and SET voltage for (a) sample A, and for (b) sample C, (c) current level before and after the RESET for InGaAs p-type and n-type as function of switching cycles.

distributions of the threshold voltages for SET and RESET and the current levels before and after the RESET event over around a dozen of cycles (sample A). In these results, the distinction between two resistive states is clear. The same methodology was carried out for sample B. Fig. 2(b) shows typical consecutive *I–V* measurements revealing a clear different behavior. There is no evidence of the resistive switching effect.

The XPS spectra were studied in our previous work [5] showing that the main difference for As3d between samples A and B are the two peaks at 43.3 eV and 44.6 eV that are additional to the bulk

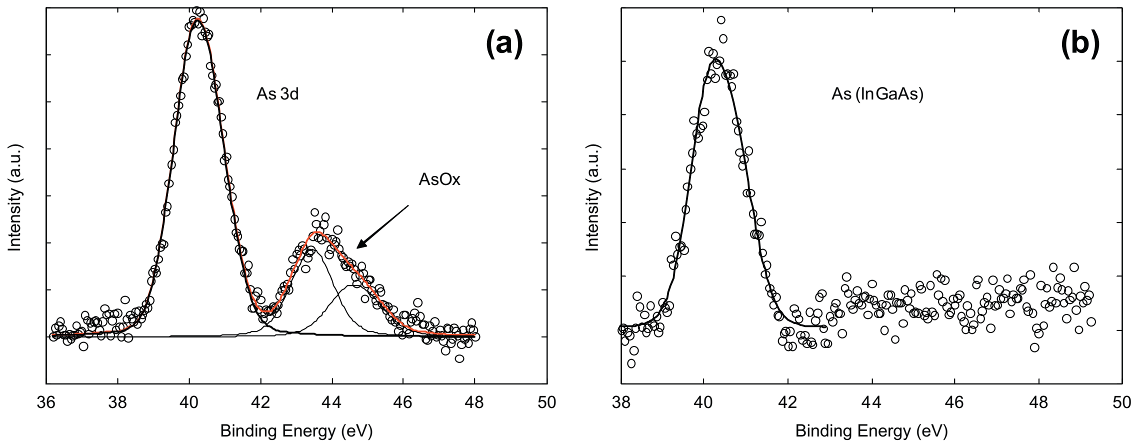

Fig. 4. The XPS spectra of As 3d for (a) sample A, and (b) sample B. Figure from our previous work Ref. [5].

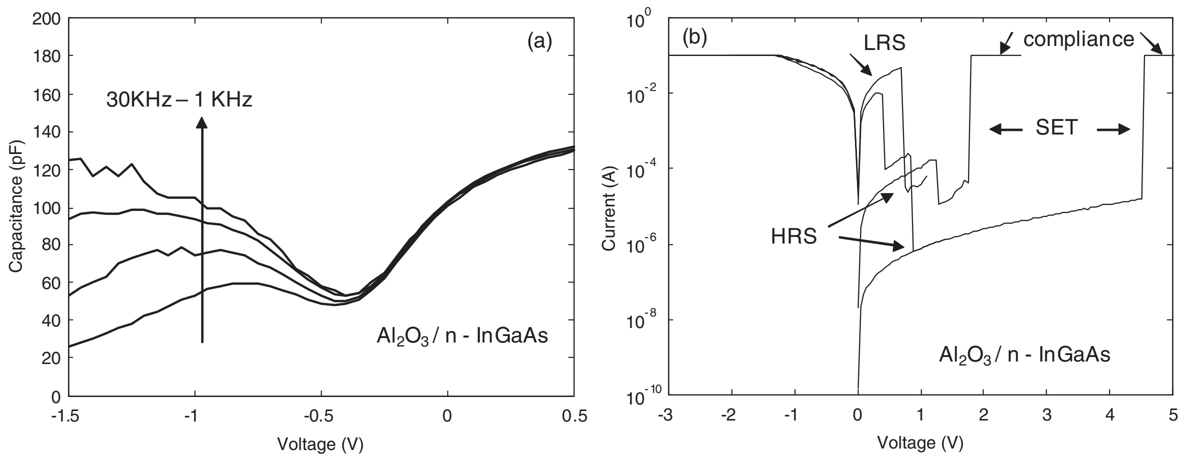

Fig. 5. Typical electrical characteristics of sample C. (a) Multi-frequency *CV* curves from 30 kHz to 1 KHz. (b) Consecutives *I–V* curves showing transition between low resistive state (LRS) and high resistive state (HRS).

signal at 40 eV (Fig. 4(a)); they fit two different AsOx moieties. For the samples that underwent FG plasma treatment (sample B on Fig. 4(b)), no peak other than the As bulk peak was visible in the spectra [5]. The presence of As–O bonds is commonly associated with gap states and high density of interface states. Therefore, the significant improvement in the electrical properties (as it is observed in Fig. 2(a)) due to the pre-deposition FG treatment is attributed to the complete removal of As–O bonds [5]. Hence, such differences observed in the current voltage characterization could be attributed to the characteristics of the oxide interface.

The strong frequency dependence of the deviations on the *C–V* curves accompanied by RS effects and As–O bonds suggest two kinds of border traps, slow and fast, where the fast borders traps – associated to As–O bonds – are responsible for large frequency deviations and the RS effect [6,7].

To understand the role of the substrate, additional measurements were performed on sample C (Fig. 5). In Fig. 5(b), we observe that at positive bias the transition from LRS to HRS is revealed. So, similarly to the previous set (A) RESET is observed only under positive bias. The Weibull distributions of the SET and RESET voltages (Fig. 3(b)), and current level before and after the RESET event (Fig. 3(c)) also show two distinct regimes.

It is important to note that the Weibull distributions show some differences between both samples. The slope for the sample A, which is p-type (6.6), is almost twice the slope of sample C, n-type (3.4). Moreover, the electric field at which the RESET takes place is also different. It is 6 MV/cm for p-type, and 0.7 MV/cm for n-type. Both values calculated from the RESET voltage at $W = 0$. The origin of the differences of the Weibull characteristics of the RESET event is an indication of the different nature of the defects, although the RESET occurs at the same polarity on both samples.

4. Conclusions

In this work the post breakdown characteristic of metal gate/Al_2O_3/InGaAs structures show transition between two resistive states. The experimental data of different deposition processes of the dielectric layer and the different substrate types seems to indicate that the resistive switching effect is related to an interface mechanism independent of the substrate, and is associated with As–O bond states as concluded from the XPS spectra

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