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Switching Characteristics of SRO-MISS Devices

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ABSTRACT

The switching characteristics of the Metal-Insulator-Semiconductor-Switch (MISS) device with Silicon-Rich-Oxide (SRO) as the semi-insulating material have been studied at room temperature. The SRO films were deposited by atmospheric presure chemical vapour deposition (APCVD) at 650°C with SiH_4 and N_2O reactant gases and N_2 carrier. The reactant gas phase ratio, R_0, varies from 0.09 to 0.25 and the deposition time from 0.6 to 2 minutes.

ABSTRAK

Ciri pensuisan peranti MISS dengan lapisan oksida terkaya silikon (SRO) sebagai bahan penebat separa dikaji pada suhu bilik. Lapisan SRO diendapkan secara pemendapan kimia wap tekanan atmofera (APCVD) pada suhu 650°C dengan gas penindak balas SiH_4 dan N_2O dan pembawa N_2. Nisbah fasa gas penindak balas, R_0, berubah dari 0.09 ke 0.25 dan masa pemendapan dari 0.6 ke 2 minit.

INTRODUCTION

The Metal-Insulator-Semiconductor-Swicth (MISS) devices have three regions in their current-voltage characteristics, a high impedance (OFF state), a negative resistance region and low impedance (ON state) as shown in Figure 1. The current and voltage at which the device begins to switch from the high resistance state to the low resistance state are called the switching current (I_s) and switching voltage (V_s). The minimum current to sustain the device in the low impedance state is called the holding current (I_h), and the voltage at this point in called the holding voltage (V_h).

The negative resistance region is generally regarded as an unstable region in which there is no operating point that is stable with time. This characteristic is similar to that of the p-n-p-n Shockley diode or thyristor, but the physics of the operation is quite different. The MISS device also has a higher switching speed compared to the p-n-p-n diode, and it has better compatibility with standard IC fabrication.

The basic structure of the MISS device, as shown in Figure 2, consisting of an MIS tunnel diode backed by a p-n junction. The p-n junction can be either $n\text{-}p^+$ or $p\text{-}n^+$, where the n or p layer is often an epitaxial film. Most research on MISS devices are based on silicon as the semiconductor. However, switching has also been reported for GaAs MISS [Yamamoto et al. 1979; Thomas 1986]. Metals such as aluminium, gold and molybdenum [Yamamoto & Morimoto 1972, Yamamoto et al. 1976] have been used as the top electrode.

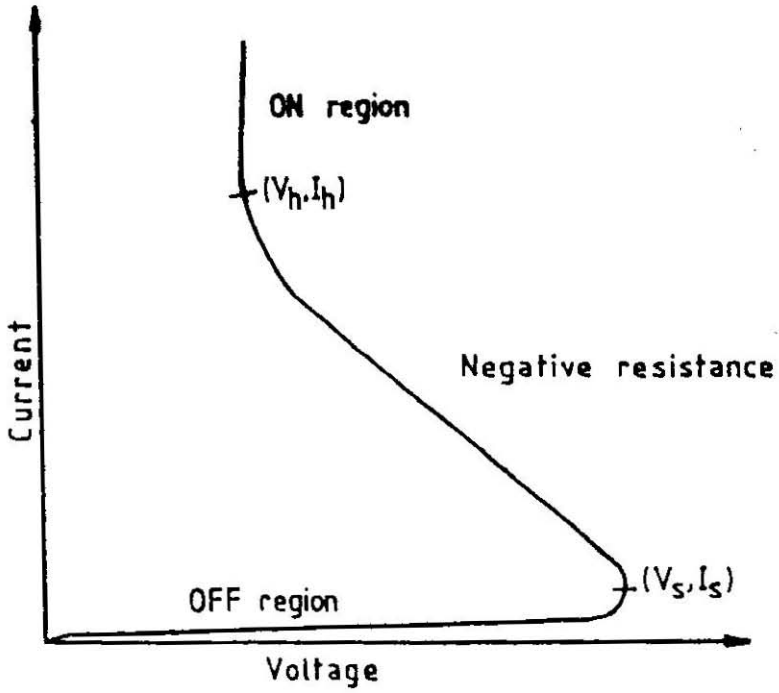

FIGURE 1. Current-voltage characteristics of MISS device

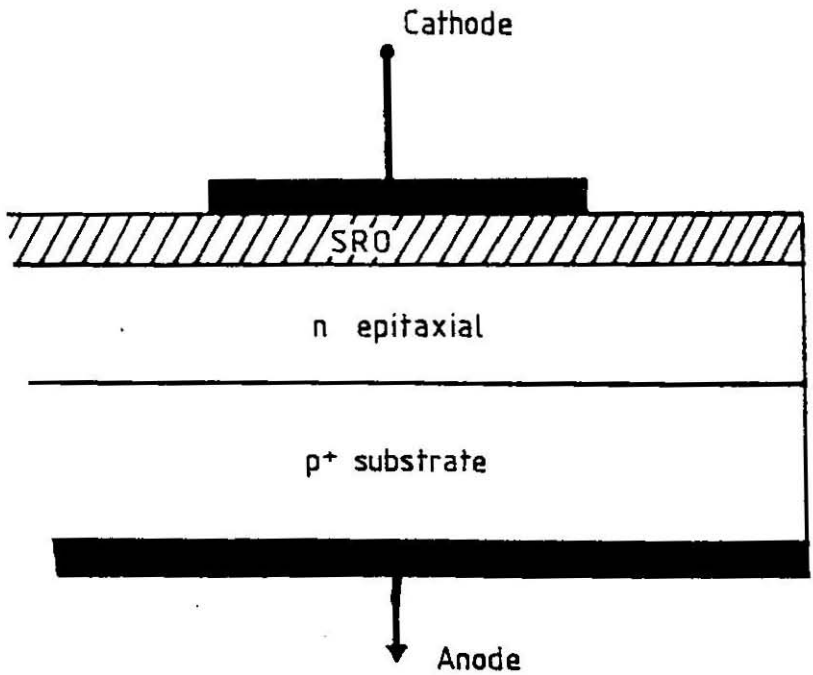

FIGURE 2. Basic structure of MISS device

In most previous research, a thin silicon dioxide film (thickness < 50 Å) has been used as a tunnel insulator in the MISS device (Kroger & Wegener 1973; Yamamoto et al. 1976; El-Badry & Simmons 1977; Buxo et al. 1978; Chick & Simmons 1979; Kawamura & Yamamoto 1983). The conduction of the semi-insulating film has been found to have a considerable effect on the electrical characteristics of the MISS while the conduction through the layer can be controlled by changing the insulator thickness, as is the case for silicon dioxide, or any other material. However it is very difficult to control the thickness of silicon oxide, typically within a few tens of Angstrom, sufficiently accurately. Hence, a thicker and a less insulating material are considered. Semi-insulating materials like silicon nitride (Kroger & Wegener 1973; Wu et al. 1984), silicon-rich-silicon-nitride, and polycrystaline silicon (1000 – 2000 Å) (Martinez and Piqueras 1984; Darwish 1981; Kroger & Wegener 1978) and organic films depossited by the Langumuir-Blodgett technique (Thomas 1986), have been found to give similar switching characteristics in MISS devices.

SILICON-RICH-OXIDE

The semi-insulating material used in the present study is silicon-rich-oxide (SRO), which is certainly polycrystaline silicon, but heaviley doped with oxygen. These films are generally deposited by means of chemical vapour deposition using either a N_2O/SiH_4 system with N_2 carrier gas or a CO_2/SiH_4 system with H_2 carrier gas (Buchanan 1986). The macroscopic chemical composition of SRO can be expressed as SiO_x ($0 < x < 2$) while it already shown that microscopically the SRO layer as deposited is made up of two phases, Si and SiO_2, with the Si being amorphous (Goodman et al. 1980). After annealing at 1,000°C in a nitrogen ambient SRO becomes a mixture of silicon crystallites, amorphous silicon and silicon dioxides (Hamasaki et al. 1978; Hortstein et al. 1980). The size of the Si microcrystals, (< 10 Å) in as deposited SRO depends both on the deposition temperature and on the oxygen concentration. However, in heat-treated SRO the size, (50–100 Å) depends on the annealing temperature and slightly on the annealing time. The conductivity of the SRO films depends upon the silicon content, and the higher content gives higher conductivity. The silicon content can be controlled by changing the gas phase reactant flow ratio $R_0 = (N_2O/SiH_4)$.

The SRO films deposited in the APCVD reactor for this work, used a composition of 5% SiH_4/N_2 together with nitrous oxide N_2O and nitrogen N_2 as the carrier gas. Deposition temperatures are generally between 620 – 700°C, but for the present purpose a temperature of 650°C was used. The phase ratio of the reactant gases, R_0, is given by,

$$R_0 = \frac{\text{flow rate of } N_2O}{\text{flow rate of } SiH_4} \qquad (1)$$

As the phase reactant ratio, R_0, increases the silicon content decreases and this relationship is not linear (see Figure 3), and it is also dependent on the deposition temperature (Buchanan 1986; Hitchman et al. 1981). The growth rate of the SRO films at a constant flow rate of SiH_4 was shown to be dependent on R_0 (Darwish & Board 1981) and it also decreases as R_0 increases. However, at constant R_0 the growth rate increases with the SiH_4 flow rate. For the present purpose the flow of the carrier gas was maintained at 35 l/min., the flow rate of the N_2O varied between 5 and 14 ml/min., and the silane flow maintained at 61 ml/min.

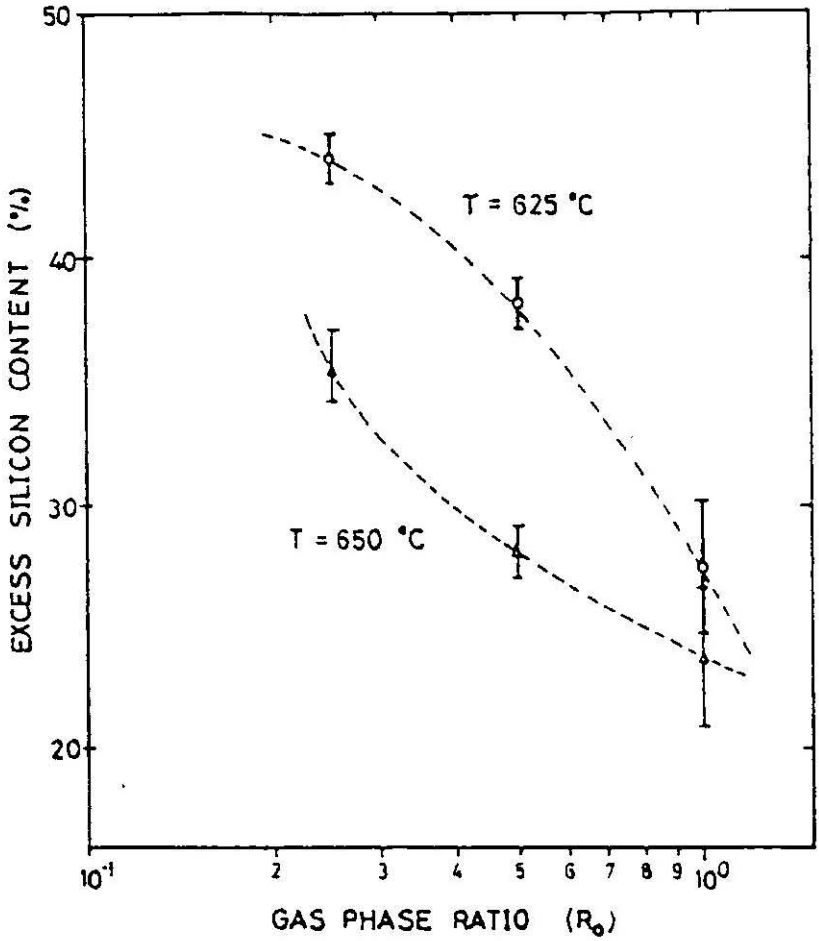

FIGURE 3. Excess silicon content (over stoichiometric silicon dioxide) as a function of gas phase ratio, R_o, for deposition temperatures at 625°C and 650°C (from ref. 5)

SAMPLE FABRICATION

The silicon used in these experiments are in the form of silicon wafers with a 4.4 μm n-type epitaxial layer on a p^+ substrate with either $\langle 111 \rangle$ or $\langle 100 \rangle$ orientation. The resistivity of the epitaxial layer was 5.3 Ω. cm, which corresponds to a doping concertration of 9×10^{14} cm^{-3}.

The wafer was cleaned using standard cleaning procedures. After the cleaning process, the wafer was again dipped in .10% HF, rinsed in deionized water, and blown dry immediately before loading into the CVD reactor. The reactant gases ratio R_0 of 0.1 – 0.25 were used and deposition times were between 0.6 and 2.0 minutes. Immediately after deposition, the thickness and index of refraction of the films were measured using an ellipsometer which was designed mainly for measurement on highly transparent films like SiO_2.

An electrode pattern was defined by standard photolithography. A mask with seven different sizes of dots was used in most of the work, the smallest and largest being of 0.18 mm^2 and 2.36 mm^2 area respectively.

RESULTS AND DISCUSSION

Since the SRO is non-stoichiometric in nature and the growth is not accurately controlled is was not possible to vary the thickness without changing the index of refraction, which is influenced by the percentage of silicon in the film. As SRO absorbs some of the light, measurement of the thickness and refractive index are only reliable for index values from 1.4 to 3.2 (Buchanan 1986). The error in the measurement increases with increasing silicon content. Figure 4 shows the relationship of refractive index and film thickness with deposition time for $R_0 = 0.2$. As we can see, increasing in the deposition time increases the thickness as well as the refractive index of the film. Therefore the preliminary investigations were carried out merely to see the variation of the switching parameters with the deposition time at a constant gas phase ratio. For this purpose, the SRO deposition was carried out by keeping the flow rate of N_2O and SiH_4 constant at 6.5 ml/min and 61.3 ml/min respectively, and the deposition time was varied from 0.6 to 2.0 minute. The apparent refractive index and thickness of the films used is shown in Table 1.

TABLE 1. The ellipsometer readings of apparent refractive index and thickness with SRO deposition time

Deposition time (min.)	index (n)	thickness d(Å)
0.6	< 1.5	100
0.8	2.4	194
1.0	2.9	304
1.5	3.1	310
2.0	1.3	120

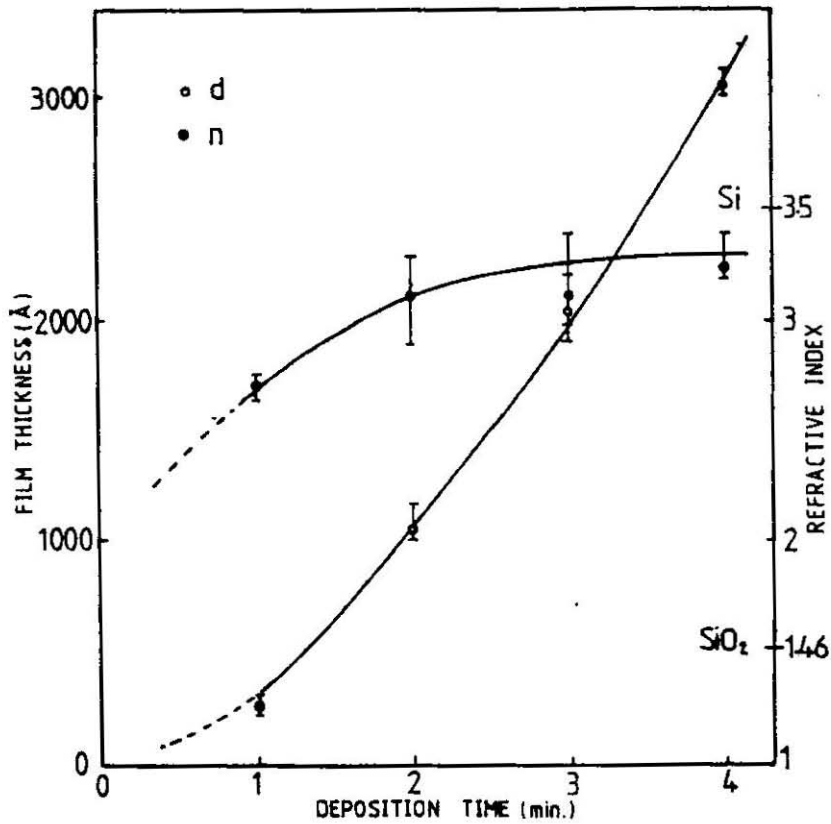

FIGURE 4. Refractive index and thickness of SRO as a function time

As shown in Figures 5 and 6, increasing the deposition time from 1.0 to 2.0 minutes results in an increase of the switching parameters, V_s, V_h and I_s, whereas I_h is rather different. The variation of the switching current with deposition time appears to show a peak at 0.8 minute. The holding current was very high at 0.6 minute and it then decreases with time up to 1.0 minute and after this point it increases slightly with time as shown in Figure 6.

The SRO films deposited on silicon under the present conditions are believed to have a three layer structure. The first layer is the atmospheric oxide, about 15 A, the second is the SRO, and the third is another layer of atmospheric oxide. At a small deposition time, the measured refractive index was very close to the oxide value, and this is because the ellipsometer readings only give the average values of the total composition over the film thickness and oxide is more dominant in this case. As the deposition time increases, the measured refractive index and thickness are increased because the SRO layer becomes dominant compared to the atmospheric oxides. At larger deposition time (2 minute) the ellipsometer readings may give false values of refractive index and thickness because the SRO become less transparent due to the increase in the silicon concentration.

Based on a symmetrical Schottky barrier (SSB) model as a conduction mechanism in SIPOS, Bolt and Simmons [Bolt et al. 1987] have shown that

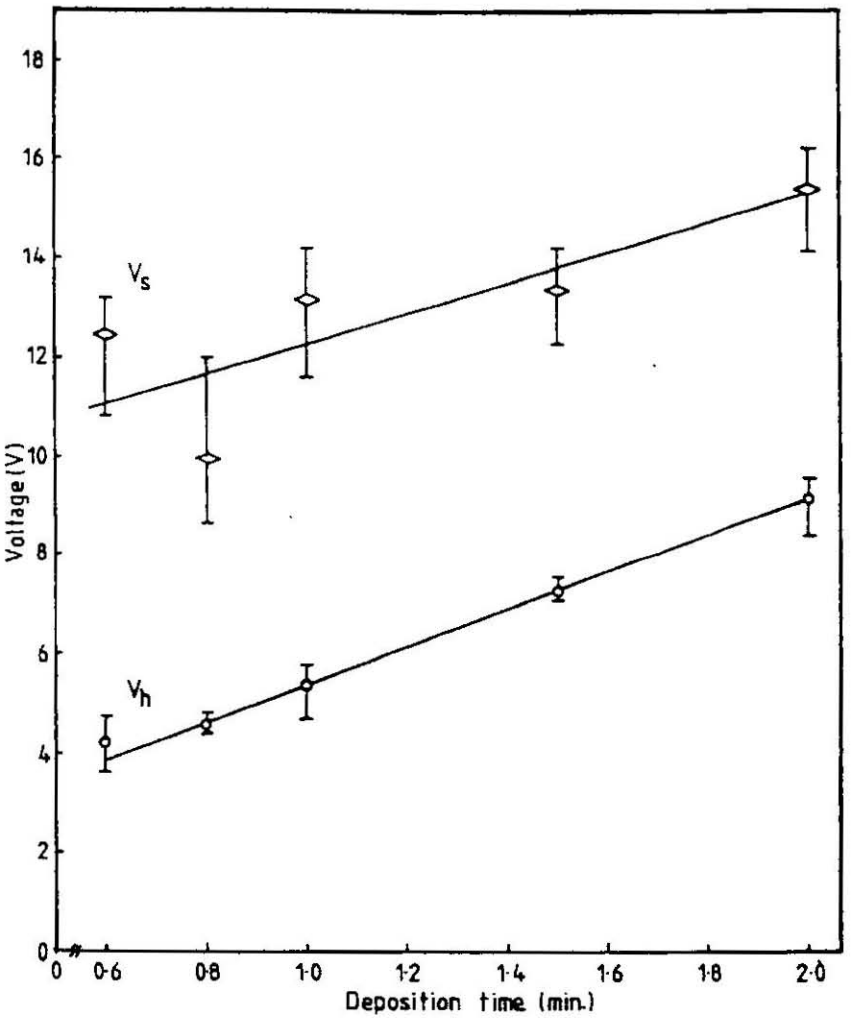

FIGURE 5. Switching voltage V_s and holding voltage V_h of the non-isolated MISS versus SRO deposition time

the increase in oxygen concentration was equivalent to decreasing the effective Richardson constant, and increasing the barrier height between grains. This resulted in the theoretical increase of V_s, V_h, I_s, and I_h, but in their model the thickness of the film was not taken into account. For the present SRO, the apparent refractive index and hence the average silicon concentration increases with deposition time so that the switching parameters are expected to fall. As they give opposite results, the effect of thickness must then predominate. A rise of all the parameters with thickness are expected from the general mechanism of a tunnel oxide device. This trend has been observed by other workers (Wu et al. 1984; Martinez & Piqueras 1984, Darwish 1981; Bolt et al. 1987) for tunnel oxide, polysilicon and SIPOS-types of MISS divices.

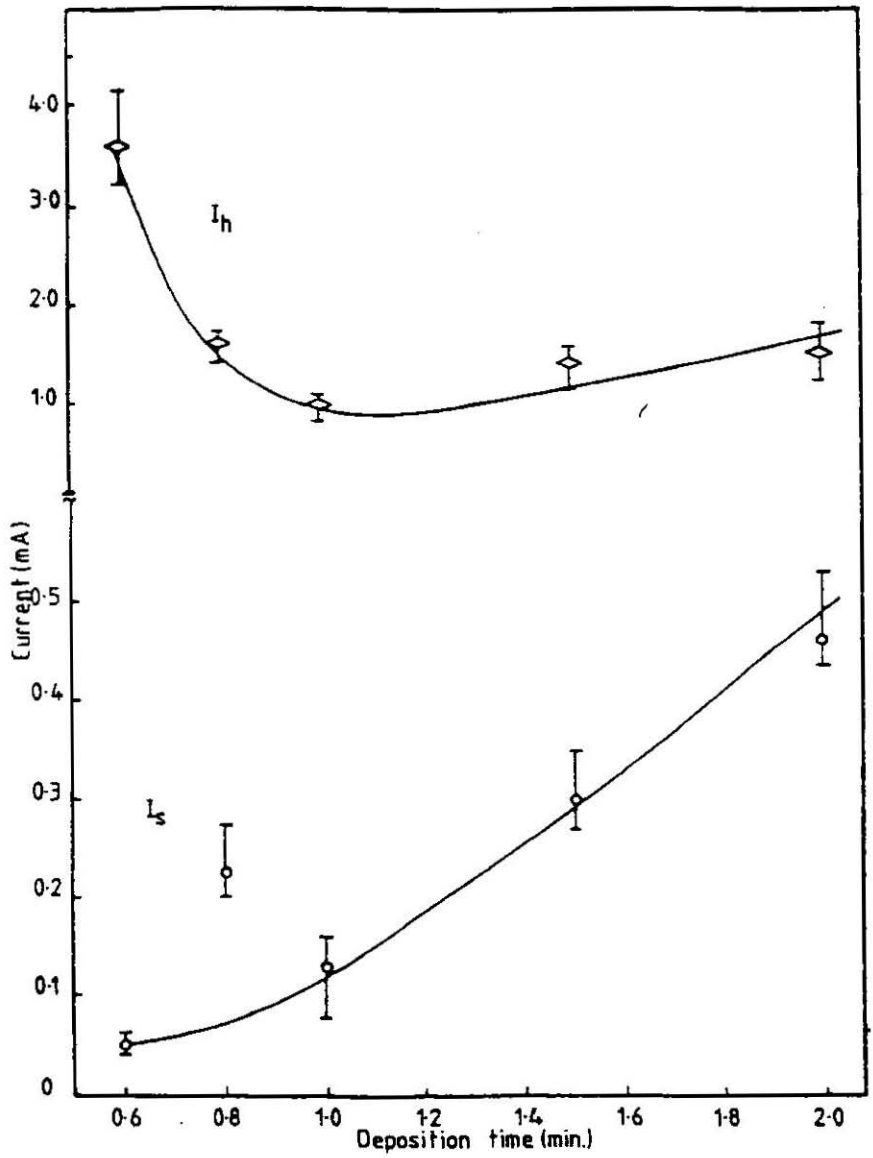

FIGURE 6. Switching current I_s and holding current I_h of the non-isolated MISS versus SRO deposition time (electrode area=0.18mm²)

The switching characteristic at a deposition time of less than. 0.8 minute is probably governed by the oxide layer rather than the SRO so that it can be excluded in viewing the variation of the switching parameters with the SRO deposition time.

CONCLUSION

It was found that the thickness and composition of the SRO films strongly influences the switching of the SRO–MISS divice. For constant R_0, increasing the deposition time will increase the switching and holding voltage.

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