Characterization of Chalcogenide Selectors for Crossbar Switch Used in Nonvolatile FPGA

H. Numata[1], N. Banno[1], K. Okamoto[1], N. Iguchi[1], H. Hada[1],
M. Hashimoto[2], T. Sugibayashi[1], T. Sakamoto[1], and M. Tada[1]

1 NEC Corporation, 34 Miyukigaoka, Tsukuba, Ibaraki 305-8501, Japan, 2 Osaka University
Email: h-numata@cw.jp.nec.com

***Abstract* — Sputter deposited Ge_xSe_{1-x} films are characterized, prior to device fabrication for a selector. A Se-rich film has $GeSe_{4/2}$ tetrahedral structure and higher crystallization temperature than Ge-rich films. Printed Ag-paste electrodes are used for I-V measurement and an amorphous Se-rich Ge_xSe_{1-x} film shows the good switching property for the selector with an on/off ratio of 4.8×10^4.**

I. Introduction

A field programmable gate array (FPGA) is one of the candidates for data processing device in front-end of IoT. We have developed complementary atom switch (CAS) for crossbar switch for nonvolatile FPGA, and showed that the cell area and power consumption can be reduced dramatically as compared to a conventional SRAM-based FPGA [1-3]. Recently, we have developed two-varistors selected CAS (2V-1CAS) architecture, in which two varistors are used as selectors to replace a cell transistor, and the cell area was further reduced by 75% [4-5].

An ovonic threshold switch (OTS) device using chalcogenide materials is one of future candidates for the selectors in 2V-1CAS, because they have large on/off ratio and current density with simple device structures [6, 7]. However, the chalcogenide materials are well known to have nonvolatile, phase change characteristic [8, 9]. When we use them for the volatile selector, the material, composition and phase need to be carefully investigated for device fabrication. In this paper, we evaluated Ge_xSe_{1-x} materials for the selector application. A printing method is adopted to form upper electrodes, and electrical property of the OTS is characterized as a preliminary evaluation prior to device fabrication.

II. 2V-1CAS Architecture

The CAS is composed of two nonvolatile bipolar-resistive-change elements, namely atom switch. The atom switch turns to ON or OFF by forming or annihilating a conductive Cu bridge in polymer solid-electrolyte (PSE) (Fig. 1). The crossbar switch using 2V-1CAS is showed in Fig. 2, in comparison with conventional 1T-1CAS [3]. Since the two varistors are connected to independent control lines, respectively, the CASs can be programmed individually. Fig. 3 shows a 3D schematic view of 2V-1CAS. The operation principle in detail is described in [10].

III. Experimental

The Ge_xSe_{1-x} films with a thickness of 10 – 100 nm were deposited on 300mm Si wafers by co-sputtering from Ge and $GeSe_2$ targets. The film composition was tuned by changing each sputtering power. The films were characterized by X-ray diffraction (XRD), X-ray photoelectron spectroscopy (XPS), and Raman spectroscopy. For the electrical measurement, the upper electrodes were directly printed on the Ge_xSe_{1-x} films by an ink dispenser with Ag-paste (Fig. 4). The formed electrodes was about 440 μm in diameter, and a negative bias was applied during I-V measurement.

IV. Results and Discussions

The compositions of the fabricated samples are listed in Table I. They are estimated by XPS (Fig. 6). It is found that all the as-deposited films are amorphous by XRD (Fig. 5). To check the thermal stability of the films, all the samples were baked at 200 deg. C for 30 minutes. Sample C (Se−rich) is still amorphous. For sample A, however, a sharp peak appeared at 33.4 deg. It shows that Ge-rich sample A is crystalized after baking. This result indicates that amorphous Se-rich film is thermally stable. In the XPS spectra, the Ge-Se peaks show higher binding energy with increasing the amount of Se in the films (Fig. 6). It is due to the $GeSe_2$ has higher binding energy than GeSe. By Raman spectroscopy, two peaks at 201 and 216 cm^{-1}, which correspond to vibration of $GeSe_{4/2}$ tetrahedral structure [11], are observed in sample C (Fig.7).

Fig. 8 shows the I-V characteristics of Ge_xSe_{1-x} films using printed Ag-paste electrodes. For sample C, a sharp switching is observed at -2.3 V. The current ratio of on-current (@ -2.4 V) and off-current (@ -1.2 V) is 4.8×10^4, it is enough high value for varistors of 2V-1CAS. Finally, we discuss off-state I-V characteristics. Fig. 9 shows that ln(J/E) and sqrt(E) has a linear relationship and it indicates Poole-Frenkel conduction [12]. It is thought that sample A and B don't have enough wide band gap to show Poole-Frenkel conduction.

V. Conclusion

We characterized the Ge_xSe_{1-x} films for selectors, prior to device fabrication. The Se-rich film has $GeSe_{4/2}$ tetrahedral structure and higher crystallization temperature than Ge-rich films. The Se-rich film shows the good switching property. The composition ratio is a key for the selector performance, especially in GeSe-based chalcogenide system.

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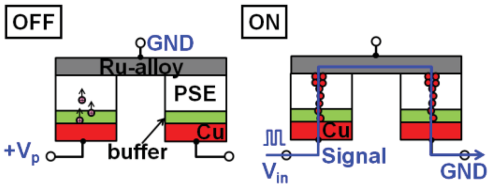

Fig. 1 complementary atom switch (CAS) [1]

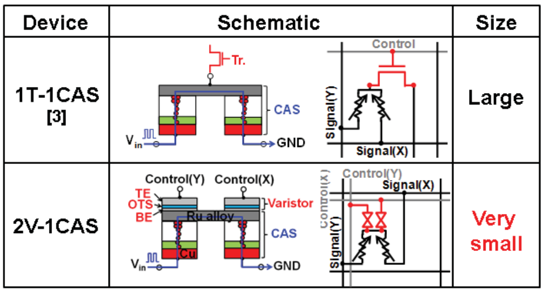

Fig. 2 2V-1CAS architecture

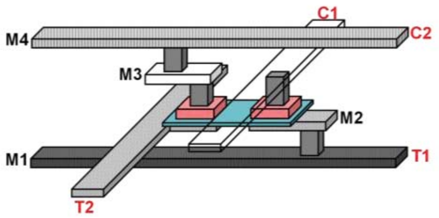

Fig. 3 3D schematic view of 2V-1CAS [4]

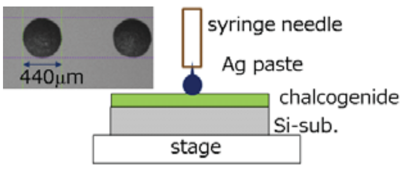

Fig. 4 Printed upper electrodes

Table I Sample List

Sample	Ge (at%)	Se (at%)
A	65	35
B	57	43
C	47	53

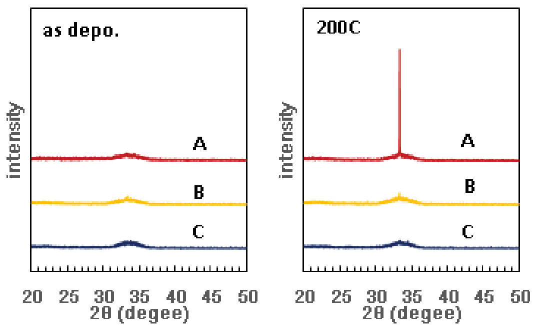

Fig. 5 XRD chart

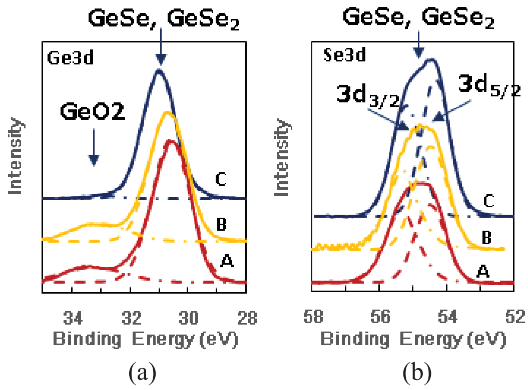

Fig. 6 XPS spectra, (a) Ge3d and (b) Se3d

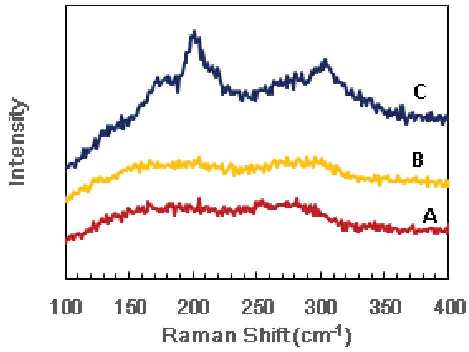

Fig. 7 Raman spectroscopy

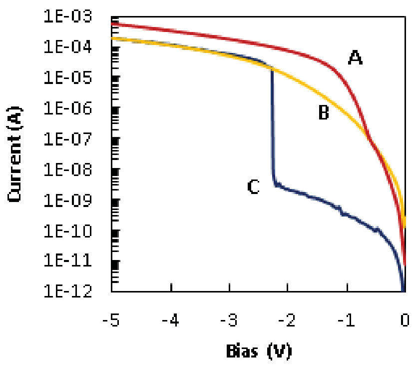

Fig. 8 I-V characteristics of Ge_xSe_{1-x} films

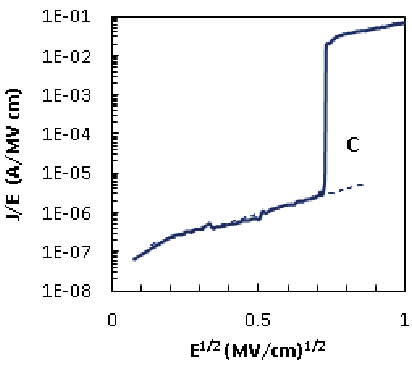

Fig. 9 Analysis of off-state I-V characteristics (Poole-Frenkel conduction)