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Stability of switchable SmS for piezoresistive applications

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Abstract

In this work samarium sulfide thin films have been deposited by using e-beam evaporation under H2S atmosphere. Optical and structural properties were studied in several environments. The stability in several environments allows further processing into piezoelectronic devices.

Stability of switchable SmS for piezoresistive applications*

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***Abstract*— In this work samarium sulfide thin films have been deposited by using e-beam evaporation under H_2S atmosphere. Optical and structural properties were studied in several environments. The stability in several environments allows further processing into piezoelectronic devices.**

I. INTRODUCTION

SmS is a switchable material, providing a pressure-induced transition from the semiconducting to the metallic state. The close vicinity between the 5d state and the 4f states of Sm ions is the origin of the switching behavior between the two states. The metallic state can switch back to the semiconducting state by annealing or upon release of the pressure in the case of using other rare-earths elements, such as Eu and Gd.[1] The electronic changes between the states are accompanied by changes in optical and electrical properties. By applying pressure to SmS, the 5d degenerate state moves towards the 4f state of the Sm ion. Practically, the pressure, which can be provided by polishing or scratching, increases the energy distance between doubly degenerate (e_g) and triply degenerate (t_{2g}) states. [2] In SmS there is no phase change, but only volume collapse during the acquisition of the metallic state. XRD patterns of both states are displayed in Fig. 1 for a SmS thin film with a thickness of 50nm. The switching behavior can be used in low-voltage consumption transistors and gauge sensors. Apart from the aforementioned transition, an additional magnetic transition from the paramagnetic state to an antiferromagneticly ordered state takes place at around 18.5 kbar at 0K. [3]

Even though the transition back to the semiconducting state reportedly takes place at 400°C, [4] we found that the transition back to the semiconducting state initiates at lower temperatures. Nonetheless, the temperature of around 400°C is quite crucial as at that temperature two effects occur. The first one is related to the transition back to the semiconducting state and the second one stems from the oxidation of SmS thin films at that temperature, when annealed under ambient air.

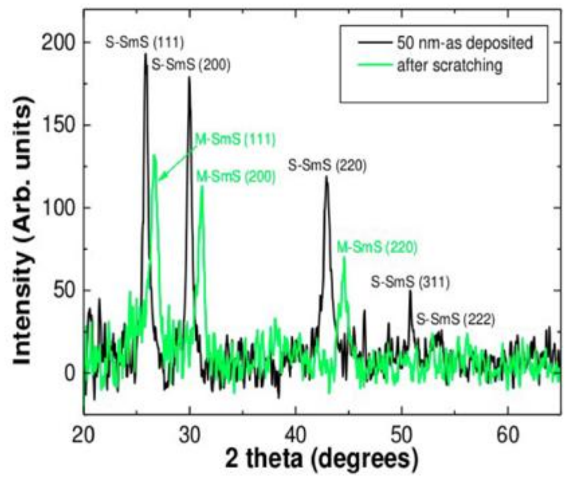

Figure 1. XRD patterns of a 50 nm SmS thin film in semi-conducting state (S-SmS), and after transition into the metallic one (M-SmS).

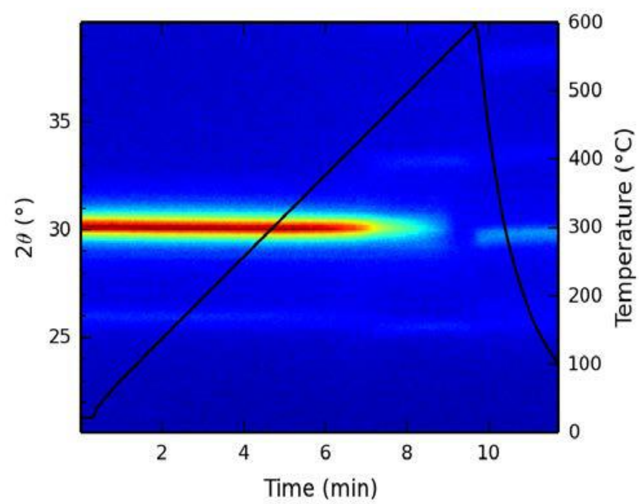

Figure 2. In-situ XRD pattern of the semiconducting state of SmS after annealing in an atmosphere containing 80% of He and 20% of O_2. Black line represents annealing and cooling down of film as a function of time.

Optical and structural studies have shown that SmS is quite stable upon annealing under ambient air at 300°C to 350°C, without any important traces of any other compounds which would strongly modulate the switching behavior. In-situ XRD measurements (Fig. 2) showed that SmS is stable up to 350°C when annealing in a mixed oxygen-helium atmosphere. Further increase in temperature leads to the formation of other crystalline phases. Finally, the behavior of SmS films under N_2 and H_2S annealing will also be presented.

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For the thin film deposition of SmS, we used e-beam evaporation of metallic Sm in H_2S atmosphere. Structural characterization of the S-SmS thin films was carried out by X-ray diffraction (XRD) using a standard powder diffractometer (Siemens D8) with CuKa1 radiation λ=0.154059 nm). Selected samples were viewed via scanning electron microscopy (SEM). The SEM analysis was carried out in a FEI electron microscope, with a point resolution of 1.7 nm at 20 kV. The Uv-Vis. spectra were recorded at room temperature in transmission geometry with a Varian Cary 500 Uv-Vis. spectrophotometer in the wavelength range of 200–1100 nm.

II. Conclusion

Our results demonstrate that SmS can be used in several environments, allowing a wide range of processing in microelectronics industry. Therefore, possible usage of SmS on low-voltage high-speed piezoelectronic memory devices [2,5] becomes reality, as the close vicinity of the 5d band with the 4f states of Sm^{2+} (switching behavior) provides suitable characteristics for future devices, with quite low energy consumption in comparison with conventional memory devices (e.g. flash devices).

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