Idaho Incubation Fund Program

Progress Report Form

Proposal No. **IF14-004**
Name: **Maria Mitkova**
Name of Institution: **Boise State University**
Project Title: **Research on Films with Columnar Structure to Improve Memristors Speed, Reliability and Lifespan**

Period of the progress report: July 1 – December 31 2013

Information to be reported in your progress report is as follows (attach additional information as needed):

1. Summary of project accomplishments for the period just completed and plans for the coming reporting period:

We worked on deposition of films from chalcogenide glasses under different angles by varying also the composition, the deposition angle and the speed of substrate rotation. The study included compositions containing 20at%, 30at% and 40at% Ge in combination with the three chalcogen elements – S, Se and Te, i.e. 9 different compositions under 6 different angles. This gave us big material that we could use to optimize the angle of evaporation in order to obtain the best quality films. It also helped us to develop theoretical calculations under which to extract the dependence upon the angle of the forming columns in regard to the angle of the incoming vapors beam. All materials behave differently and accurate predictions are difficult. Since there is not a theory describing the conditions of formation of films with required parameters, due to the sensitivity of the columnar structure on deposition conditions and material dependent parameters, we used our experimental results as a guide for creation of conditions for formation of films with specific structure. As a result of these calculations and high number of experimental data we established an empiric formula, which can be used to predict the angle under which the columns will be developed during the formation of columnar structure by thermal evaporation (1).

$$\tan\beta = 2/3\ [\tan\alpha/(1+\Phi \tan\alpha \sin\alpha)] \qquad (1)$$

Here α is the arriving angle of the deposited material, β is the angle of the film growth and Φ is a coefficient related to the diffusion ability of the films' material. With other words, we have established a close dependence of the growth angle from the composition which is a unique property of the studied materials. The most important step of our research plan was to establish the conditions under which we can check the films quality and growth angle. In the initial plan we had in mind to do a cross section surface imaging using scanning electron microscopy (SEM), which offers high resolution and is an excellent characterization method. An SEM image of the cross section of a film with composition $Ge_{40}Se_{60}$ deposited under the angle of 45^0 is presented in Fig. 1. However, thinking about the following steps of our study, when we want to image the growth of a Ag filament into the chalcogenide matrix,

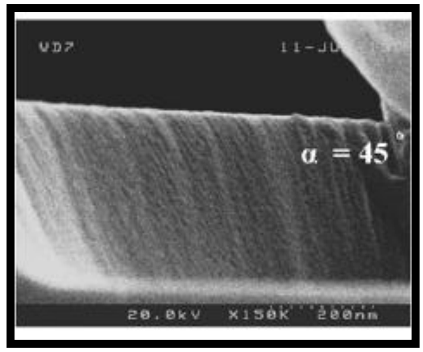

Fig. 1. SEM image of a $Ge_{40}Se_{60}$ film deposited under an angle of 45^0

we realized that this technique although being the best for surface structural characterization, could introduce error in the imaging, since the electron beam can interact with the chalcogenide glass and the growing Ag filament. To avoid this, we developed a unique technique not described in the literature so far for structural studies of the films using Atom Force Microscopy (AFM) as illustrated in Figure 2, which gives details about the structural organization of the cross section.

Figure 2. AFM cross section image of obliquely deposited film of $Ge_{30}Se_{70}$ under the angle of 60^0

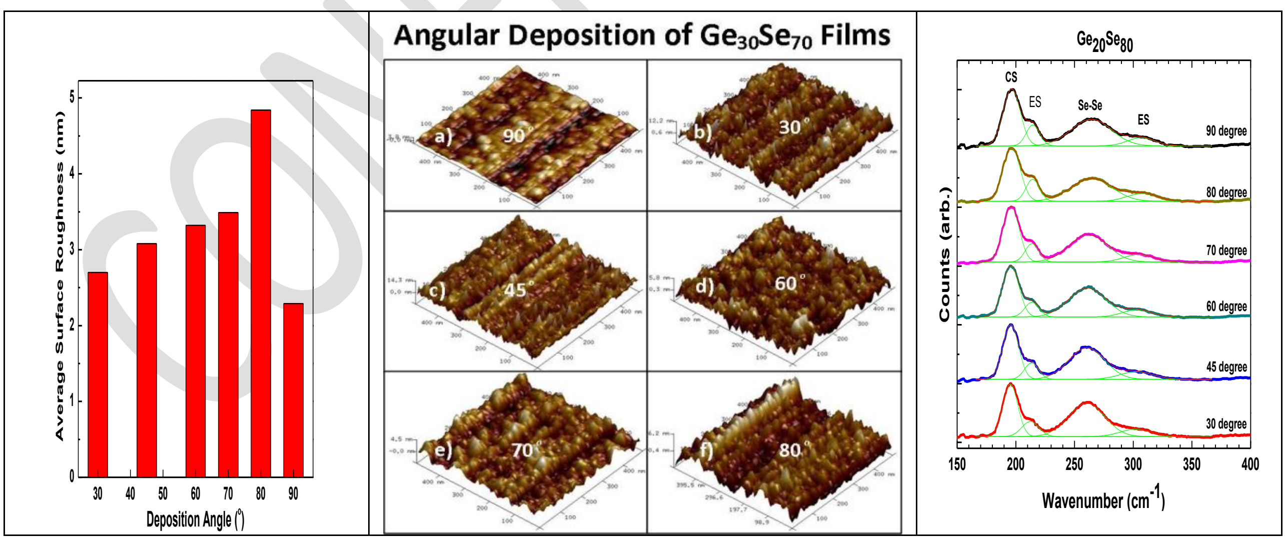

Fig. 3. a)Development of the surface roughness of $Ge_{30}Se_{70}$ film as a function of the deposition angle; b)surface roughness AFM scans for films deposited under different angles; Raman spectroscopy of films deposited under different angles.

We studied also the surface roughness of the films with different composition applying AFM and the compositional dependence upon the deposition angle using Raman spectroscopy. Examples of these studies for glasses with composition $Ge_{30}Se_{70}$ are shown on Fig. 3 a, b, c.

These data show that the surface roughness improvement can be achieved through deposition under a lower angle when we consider formation of a columnar structure of the films. In this case the structure of the films includes higher amount of Se-Se bonding and the areal intensity of the edge-sharing bonding increases.

For the next period we foresee formation of memory devices and their cross section AFM characterization by which to demonstrate the growth of a Ag filament in the chalcogenide film. In addition to the proposed plan we will make devices electrical characterization – measurements of the current-voltage characteristics of the studied devices and collection of data for their retention. In this manner we will deliver a full list of characterization data in support of the patent applications on which this project is based.

2. **Summary of budget expenditures for the period just completed (include project burn rate):**

The number students foreseen to work on the project were not available in the first two – three months of the project work, so that the PI had to work herself to deliver results on time. This changed a bit the distribution of the expenses by which no student support was paid for this period of time and the summer salary of the PI was foreseen to extend for a month instead of half month as initially foreseen. As a result of this, so far about $17,728 are spent.

The projected burn rate is as follows:

1. Salaries – students (one graduate and three undergraduates), PI and tuition compensation for the graduate student: - 21,570
2. Fringe benefits: - 2,404
3. Payment to rechargeable centers: (IML and BSCMC) – 2,150
4. Travel – 1,898

3. **Numbers of faculty and student participation resulting from the funding, including internships**:

Right now there is one faculty – Maria Mitkova, one graduate (PhD) student Muhammad Rizwan Latif and three undergraduate students – Tyler Nichol, Brian Dambi and Jasen Nielsen engaged to work on the project. The students started work in October 2013 but with the initial work done by the PI they succeeded to fulfill all planned work for the time till the end of the 2013 year.

4. **List patents, copyrights, plant variety protection certificates received or pending**:

    1) Structured Chalcogenide Glass Films for Redox Conductive Bridge Nonvolatile Memristors (BSU FIle #132, patent app. 61/823,783)

    2) Structured Oxide Films for Redox Conductive Bridge Nonvolatile Memristors, (BSU File # 141, patent app. 61/847,974)

5. **List technology licenses signed and start-up businesses created**:

    N/A

6. **Status of private/industry partnerships (include enough information to judge level of engagement):**

Discussion with Micron Technology Inc. and Adesto Technology Inc. which are dealing with this type of non-volatile memory. The subject of this study will bring a big improvement in the reliability and life span of the devices. These companies would like to get as much possible results, which we are collecting now, to be able to judge the importance of the patents for them.

7. **Any other pertinent information that will indicate to the council that the project is meeting satisfactory progress.**