Synthesis and characterization of magnetron sputter deposited Ge-nanowires.

T G Nyawo[1], N P Chonco[1], CT Thethwayo[1], A P Sefage[1] and O M Ndwandwe[1]

[1]Department of Physics and Engineering, University of Zululand, Private Bag X1001, KwaDlangezwa, 3886, South Africa.

Email: tgnyawo@gmail.com

Abstract. Ge nanowires were synthesized on Si<100> substrates using Ag as a catalyst. The catalyst seeds were sputter deposited on the Si substrate at $2x10^{-2}$ Torr and thereafter Ge was deposited. The temperature of the substrate was then raised to 400 ^{o}C after depositing the catalyst. Ge was then sputtered onto the substrate using radio frequency (RF) magnetron power of 130 W for duration of times varying from 5 to 12 minutes. The pressure was kept at $3x10^{-3}$ Torr during sputter deposition of Ge. The catalytic effect of Ag to form nanowires of Ge was tested by looking at the samples using both SEM and AFM. Rutherford Backscattering Spectrometry (RBS) was also used to characterize the samples. The Ge nanowires cover the substrate uniformly.

1. Introduction

Nanostructured materials have been studied extensively in the recent past due to their importance as building blocks of nanodevices. It is advantageous when fabricating nanodevices to start with materials that have novel properties [1]. Some of the advantages of one dimensional nanowires are their large aspect ratios which give rise to flexibility that may allow them to be manipulated into different shapes as required by the designer [2]. Also the quantum confinement effects of one dimensional nanostructures give rise to new electronic properties. One dimensional nanostructures also tend to have large mechanical strengths and low dislocation densities [2]. The interest in Ge is due to its good characteristics such as high electron mobility and very low carrier freeze-out temperatures [3].

Different methods have been used to synthesize Ge-nanowires. Ge nanowires have been prepared using a hydrothermal deposition process [1]. It was found that the process produces smooth Ge nanowires. Electron beam evaporation has also been used to obtain Ge nanowires [4, 5], thermal evaporation of Ge to form nanowires on films with seeds of Au [6, 7] whereas others have used phase separation to obtain Ge nanowires. We however could not find a reference where Ge nanowires have been synthesized using magnetron sputtering.

In this work we synthesize Ge nanowires using magnetron sputtering and characterize the film using various methods. Sputtering has several advantages when compared to other Physical Vapour Deposition (PVD) methods, e.g. electron beam evaporation. It can be used to deposit a relatively uniform film over a large area. It is easy to control film thickness. Grain structure can also be controlled by finding a suitable deposition pressure. Substrates may be cleaned in-situ before deposition. Sputtering also avoids device damage that results from X-rays generated by an electron beam during evaporation. We also decided to test whether Ag instead of Au can be used for synthesizing Ge nanowires.

2. Experimental procedure

Silicon wafers were cut into strips of 12 mm by 12 mm and then chemically cleaned using methanol, followed by acetone, then trichloroethylene, then acetone, and finally methanol. The samples were then rinsed in ionised water and thereafter dried in air. The sputtering system used was AJA's Orion 5 Sputtering System. Before any deposition could be done the chamber was evacuated to a base pressure of better than $4x10^{-7}$ Torr. Argon was used as a sputter gas and it was introduced at 4sccm. All substrates were cleaned at a radio frequency (RF) power of 20 W for 5 minutes before any deposition took place. This was done to remove the native oxide on Si wafers. In order to obtain nano particles of the catalyst the pressure in the chamber was increased to $2x10^{-2}$ Torr by partially closing the downstream valve (just before the turbo pump). The sputtering target used to obtain Ag nanoparticles was a 2 inch diameter, 0.250 inch in thickness, disk whose purity was 99.99%. DC Magnetron power used to deposit Ag was 20 W for a duration of 0.5 minutes. All targets used were obtained fron AJA Inc. of Massachussets. All catalyst nanoparticles were deposited at room temperature. The temperature of the substrate was then raised to 400 ^{o}C after depositing the catalyst. Ge was then sputtered onto the substrate using radio frequency (RF) magnetron power of 130 W for duration of times varying from 5 to 12 minutes. The pressure was kept at $3x10^{-3}$ Torr during sputter deposition of Ge. Samples were allowed to cool before breaking vacuum (using N_2 gas).

3. Results and discussion

3.1 SEM characterization

We used an SEM to characterize the sample. An SEM used is a Zeiss Model operating at 10 kV.

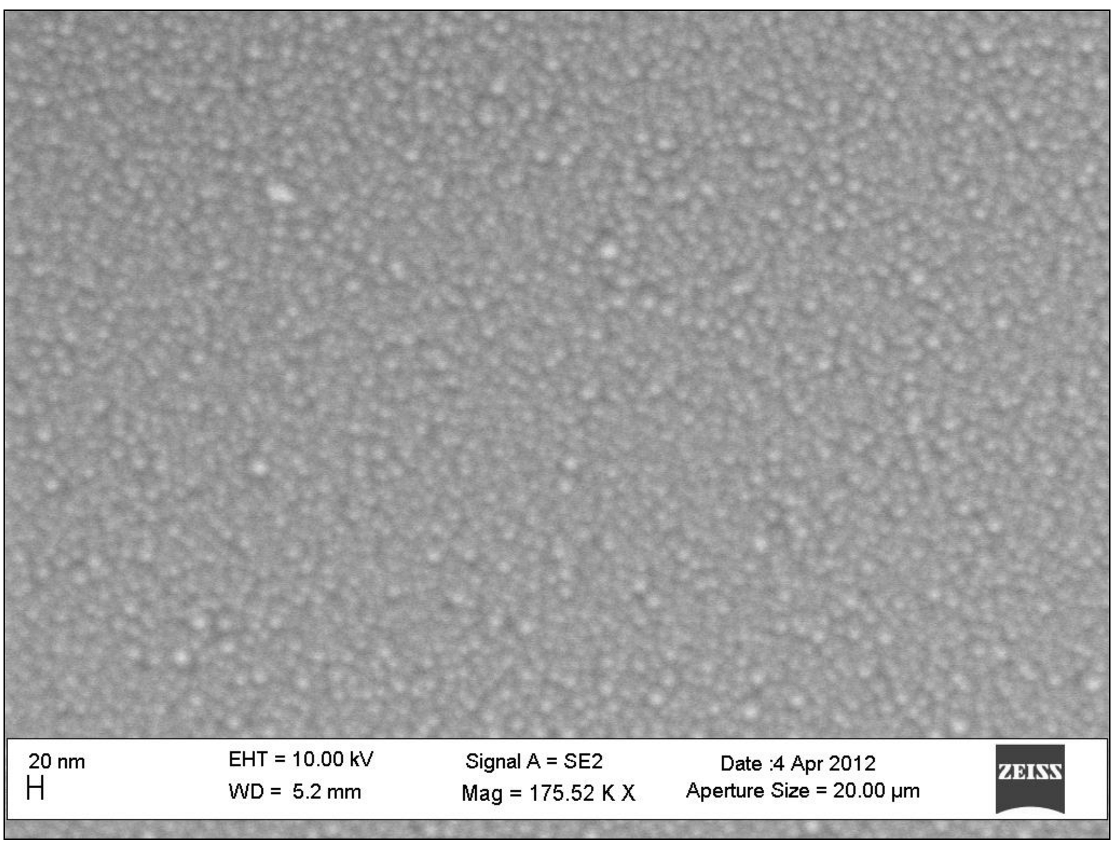

Figure 1: An SEM image of Ge nanowires deposited using Ag as a catalyst. It is seen from the image that the wires have very small diameters and that they are oriented vertically on the substrate.

Figure 1 is an SEM image obtained from a sample deposited at 400 ^{o}C, using DC magnetron sputtering at 20 W for a duration of 0.5 minutes. The Ge nanowires were obtained by depositing Ge from a Ge target at 130 W using an RF magnetron for a period of 12 minutes. It is seen from the image that the wires have diameters of less than 20 nm. The Ge nanowires cover the substrate uniformly

3.2 AFM results.

We used DC sputtering to deposit Ag inside a chamber kept at a pressure of 3 x10^{-2} Torr for a period of 0.5 minutes. The flow rate of argon was 3 sccm and the power on the magnetron was 20 W. The argon switched off and then the chamber temperature raised to 400 ^{o}C. Ge was deposited on top of catalyst Ag using a RF magnetron power of 130 W for 12 minutes.

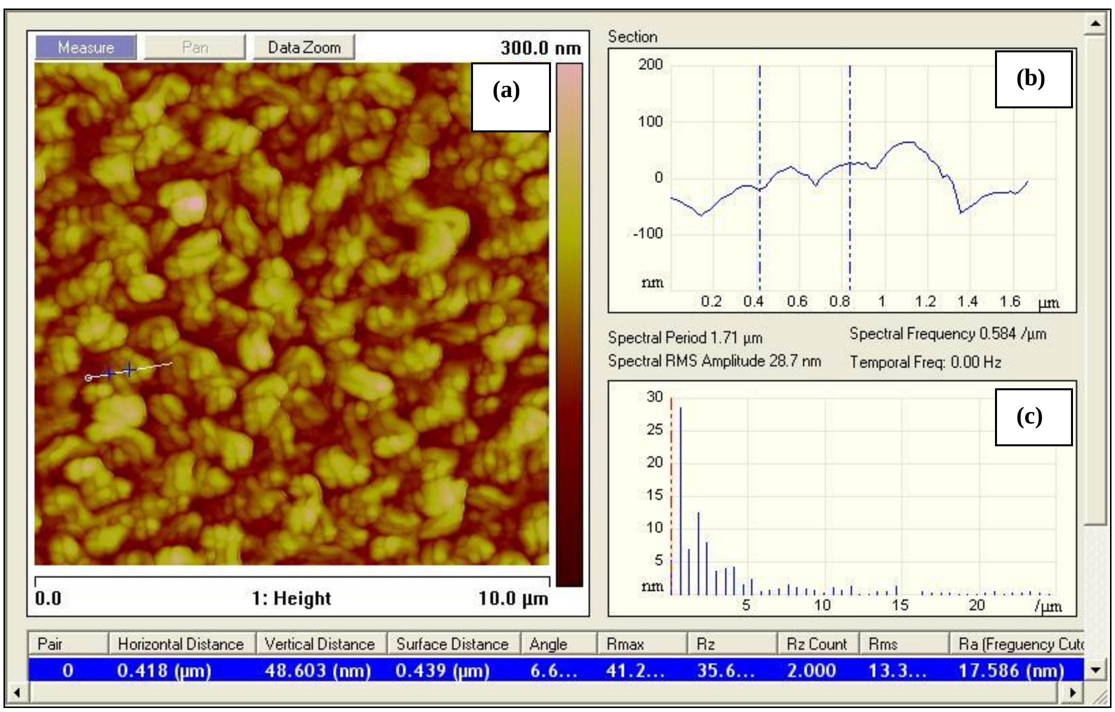

Figure 2: (a) Top view of an AFM image obtained from samples where Ag was used as a catalyst. Ge was deposited for 12 minutes using RF magnetron sputtering at a power of 130 W. The chamber pressure was kept at 3x10-3 Torr. (b) and (c) Measurements on the sample surface (see mark on image) showed that the vertical height of the chosen peak is 48.6 nm and surface (area) roughness is approximately 17.6 nm.

Figure 2 shows a top view of a Ge on Si sample where the catalyst used is Ag. It is seen from this image that there is good coverage of the surface by the Ge. The Ge on Si is structured and the vertical height of the chosen peak is about 48.6 nm. Diameters on the structure vary but are all less than 20 nm. The structures are therefore very small (wires). We have analysed the surface and have area roughness of about 17.6 nm. A side view of the structures may shed more light on these structures.

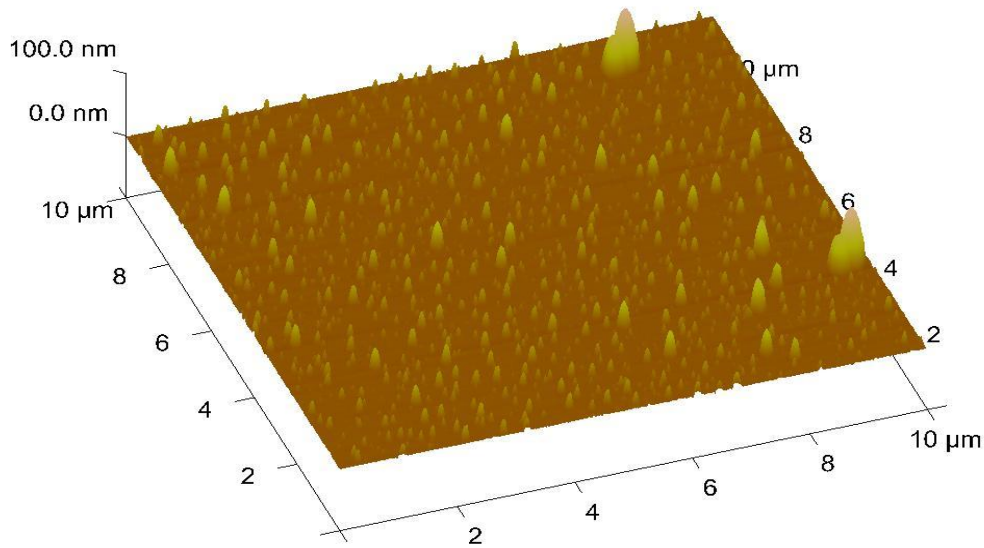

Figure 3: A side view of the Ge nanostructures.

Figure 3 is a side view of the Ge structures discussed in figure 1 and figure 2. It confirms that the structures are vertically oriented on the sample surface.

4. Conclusion.

We have successfully deposited nanowires of Ge on the surface of a Si wafer using Ag as a catalyst. Ag is cheaper than Au, which has been used by other workers to deposit Ge. The nanowires were deposited at a temperature of 400 ^{o}C using RF magnetron sputtering. This method has been used for the first time to deposit Ge nanowires. It is an easy and inexpensive method to create nanowires of Ge.

Further work will focus on improving the method (i.e. creating longer nanowires, testing whether they remain a Ge phase after deposition, etc.).

Acknowledgements:

We thank the (SA) National Research Foundation for financial assistance through the Local Equipment Travel/Training & Synchrotron Grant UID No. 80465 of April 2012. We also thank iThemba LABS for their hospitality and the use of their Ion Beam Analysis equipment and AFM instrument. Assistance from the University of Zululand Research Committee through Grant S67/93 of 2012 is acknowledged.

References:

[1] Pei L Z, Zhao H S, Tan W, Yu H Y, Chen Y W, Fan C G and Qian-Feng Zhang 2009 *Smooth germanium nanowires prepared by a hydrothermal deposition process* (*Materials Characterisation*) **60** pp. 1400-1405.

[2] Kuchibhatla S V N T, Karakoti A S, Bera D and Seal S 2007 *One dimensional nanostructured materials (Progress in Materials Science*) **52** pp. 609-913.

[3] Ndwandwe OM, Theron C C, Marais TK and Pretorius R 2003 *Thin-film compound phase formation at Fe-Ge and Cr-Ge interfaces* (J. Mater. Res, Vol. 18, No 8) pp. 1900-1907.

[4] Kramer A, Albrecht M, Boeck T, Remmele T, Schramm P and Fornari R 2009 *Self-assembled and ordered growth of silicon and germanium nanowires* (Superlattices and Microstructures) **46** pp. 277-286.

[5] Kumar R R, Yuvaraj D and Rao K N 2010 *Growth and characterization of germanium nanowires* (electron beam evaporation, Materials Letters) **64** pp. 1766-1768.

[6] Gu G, Burghard M, Kim G T, Dusberg G S, Chiu P W and Krstic V 2001 *Growth and electrical transport of germanium nanowires* (J. Appl. Phys) **90** pp. 5747-5751.

[7] Mocking T F, Stam D, Poelsema B and Zandvliet H J W 2010 *Dynamics of Au-induced nanowires on Ge(001)* (Surf. Sci.) **604** pp. 2021-2023.