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Complete List of Authors:	Rangarajan, Balaji; MESA+ Institute for Nanotechnology, University of Twente, EEMCS Brunets, Ihor; MESA+ Institute for Nanotechnology, University of Twente, EEMCS Oesterlin, Peter; INNOVAVENT GmbH Kovalgin, Alexey; MESA+ Institute for Nanotechnology, University of Twente, EEMCS Schmitz, Jurriaan; MESA+ Institute for Nanotechnology, University of Twente, EEMCS
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Characterization of Green Laser Crystallized GeSi Thin Films

Balaji Rangarajan[1], Ihor Brunets[1], Peter Oesterlin[2], Alexey Y. Kovalgin[1] and Jurriaan Schmitz[1]
[1]MESA+ Institute for Nanotechnology, University of Twente, P.O. Box 217, 7500AE Enschede, The Netherlands.
[2]INNOVAVENT GmbH, Bertha-von-Suttner Str. 5, 37085 Gottingen, Germany.

ABSTRACT

Green laser crystallization of a-$Ge_{0.85}Si_{0.15}$ films deposited using Low Pressure Chemical Vapour Deposition is studied. Large grains of 8x2 μm^2 size were formed using a location-controlled approach. Characterization is done using Scanning Electron Microscopy, Atomic Force Microscopy, X-Ray Photoelectron Spectroscopy and X-Ray Diffraction.

INTRODUCTION

Germanium-silicon (GeSi) alloys deposited at lower temperatures (400-450 °C) can be incorporated in various 3D integration schemes (e.g. monolithic integration) [1, 2]. Making the temperature CMOS-back-end compatible has generated renewed interest in such films in recent years [3]. Electrical characteristics of the devices (e.g. transistors) fabricated on such films can however be affected by the randomly positioned grain boundaries as shown earlier for Si [4, 5].

In order to control the positioning of the grain boundaries, green laser crystallization was used in our study to crystallize a-$Ge_{0.85}Si_{0.15}$ films using a location-controlled approach involving pre-patterned a-GeSi lines. The context of the present work is in infrared detection and therefore the choice of this particular film composition.

EXPERIMENT

The a-$Ge_{0.85}Si_{0.15}$ and poly-$Ge_{0.85}Si_{0.15}$ films were deposited using Low Pressure Chemical Vapour Deposition (LPCVD). The GeSi films were deposited on top of 450-nm oxide which was grown on Si substrate using wet oxidation. The custom built LPCVD system has a horizontal furnace for batch deposition and uses resistive heating (to heat the furnace walls). A quartz wafer-boat is used in order to load the 4-inch wafers directly into the furnace. The system has a base pressure of 10^{-3} mbar. The precursor gases used for the deposition were SiH_4 and GeH_4. Deposition at 430 °C using 75 sccm of SiH_4 flow and 37 sccm of GeH_4 flow, with a total pressure of 6 mbar, resulted in the formation of a-$Ge_{0.85}Si_{0.15}$ films. On the other hand, deposition performed using the same set of process parameters except for a total pressure of 0.2 mbar resulted in poly-$Ge_{0.85}Si_{0.15}$ films. In order to form nucleation sites for GeSi film deposition on oxide, a few nanometers of a-Si were previously deposited using the same LPCVD system at 430 °C using 88 sccm of SiH_4 flow with a total pressure of 0.5 mbar. The variation in the composition of LPCVD poly-GeSi films with respect to different GeH_4 partial pressures has also been explored in this study. The as-deposited poly-$Ge_{0.85}Si_{0.15}$ films acted as the reference material while a-$Ge_{0.85}Si_{0.15}$ films were used for laser crystallization.

A green laser (λ = 515 nm) pulsed at a frequency of 10 kHz with a pulse duration of 285 ns was used for the laser crystallization of a-GeSi films. The laser beam had a Gaussian energy density profile with Full Width Half Maximum (FWHM) of 15 µm along the x-axis, whereas along the y-axis a uniform energy density profile was kept with FWHM of 2 mm (see Fig 1).

The a-$Ge_{0.85}Si_{0.15}$ films of a thickness of 50 nm were patterned to form 900 nm wide periodic lines with a pitch of 3µm. Further, these lines were covered with 100-nm-thick a-$Ge_{0.85}Si_{0.15}$ film deposited again using LPCVD. This was followed by the laser crystallization process as shown in Fig.1a. During the crystallization process this topography leads to a lateral, periodic temperature gradient, causing crystallization to start at predefined locations. As a result, the preformed lines dictate the location of the dominant grain boundaries. In order to confirm the effectiveness of the preformed lines over the crystallization process, a plain 100-nm-thick a-$Ge_{0.85}Si_{0.15}$ film was also laser crystallized under the same conditions as shown in Fig.1b.

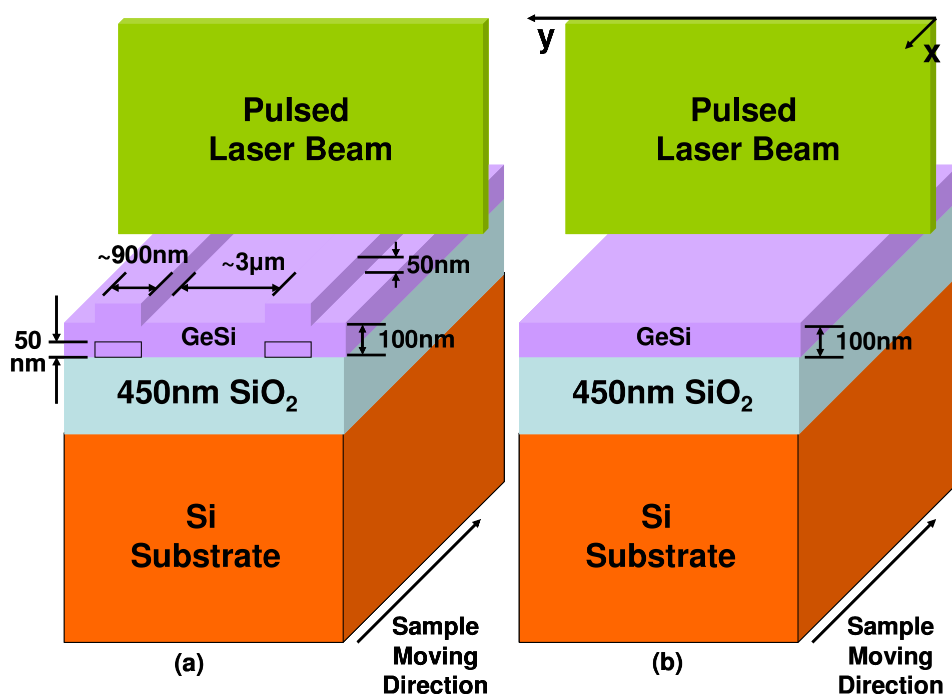

Figure 1. Overview of Laser Crystallization (a) with pre-patterned lines and (b) without lines.

Under the pulsed laser beam the samples were moved unidirectionally as shown in Fig.1a & 1b. Depending on the overlapping of consecutive laser pulses, as required for a lateral growth during the crystallization process, the scanning speed has to be adjusted accordingly. Laser pulse overlappings of 98% and 95% provided the optimal results (in terms of the formation of large grains). The samples were moved along the direction of the pre-patterned lines (as shown in Fig. 1a). Similar orientation was also adopted for the sample without the pre-patterned lines (Fig. 1b). Laser energy densities of 1.2 and 1.3 Jcm^{-2} were found to provide the best results of crystallization.

All the films were characterized using Scanning Electron Microscopy (SEM), Atomic Force Microscopy (AFM), X-Ray Photoelectron Spectroscopy (XPS) and X-Ray Diffraction (XRD).

DISCUSSION

LPCVD

Figure 2 shows the change in the composition of the deposited poly-GeSi films with respect to the relative GeH_4 partial pressure (P_{ger}). It can be noted that, even at the lowest P_{ger}, the obtained germanium content (measured using XPS) remained higher than 80%. This indicates the probable lower relative reactivity of SiH_4 at the above mentioned deposition temperature of 430 °C. A higher content of Si in the layers could be achieved by either using disilane or trisilane as one of the precursor gases replacing SiH_4 in these depositions [6]. This approach was however outside of the scope of this study and not further probed as we had already obtained our desired composition of 85% Ge in the poly-GeSi films.

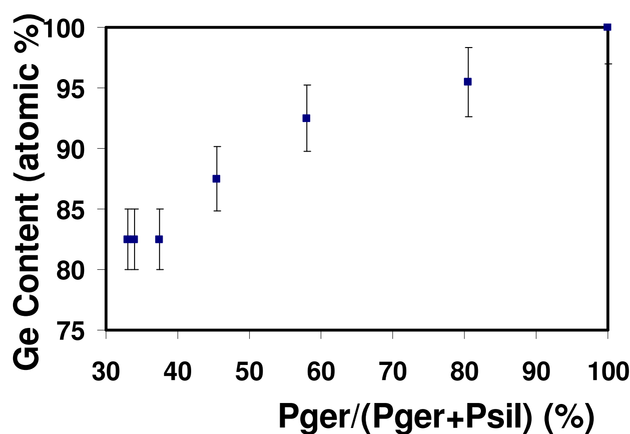

Figure 2. Variation in Ge content of the deposited poly-GeSi films versus relative (i.e. with respect to SiH_4 partial pressure - P_{sil}) GeH_4 partial pressure (P_{ger}).

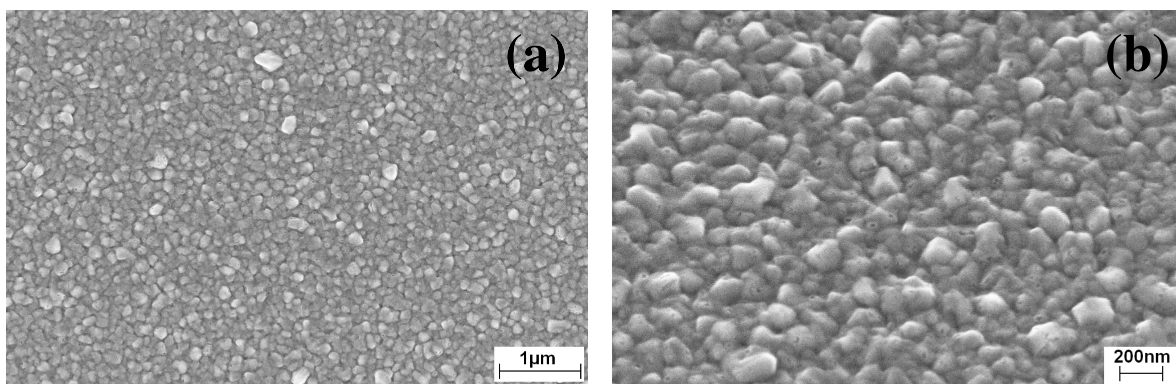

Figure 3. SEM images of the reference LPCVD poly-$Ge_{0.85}Si_{0.15}$ film: (a) top view; (b) tilted view at 50°.

The obtained reference poly-$Ge_{0.85}Si_{0.15}$ film was inspected in the SEM (Fig. 3) to reveal small grains with a typical size of 200 nm, and a surface roughness of 12.6 nm (RMS) as measured by AFM.

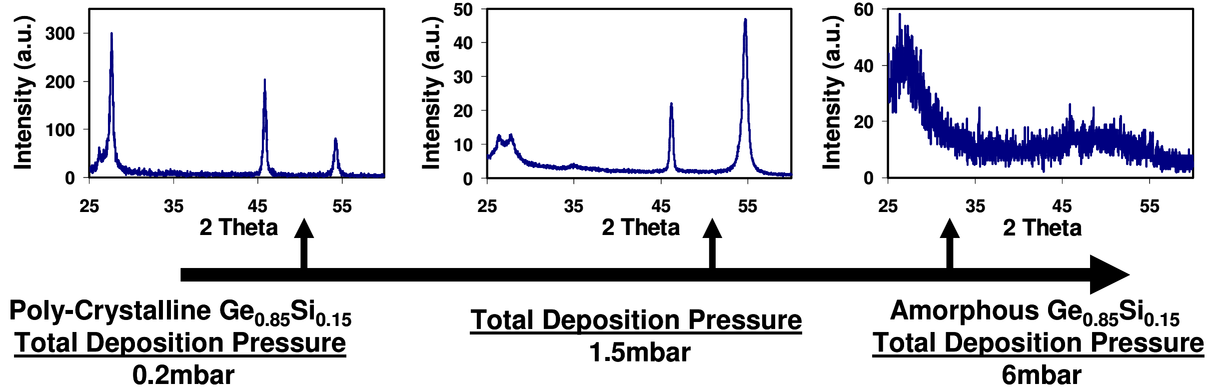

Figure 4. XRD graphs of the deposited poly-GeSi layers at three different total deposition pressures (while maintaining the other deposition parameters as constant).

The transition from polycrystalline to amorphous $Ge_{0.85}Si_{0.15}$ film was obtained using the same set of deposition parameters, by increasing the total pressure to 6 mbar, as depicted in Fig. 4 using the XRD graphs.

Green Laser Crystallization

There are earlier instances where researchers have explored (UV) excimer laser crystallization of Ge and GeSi [7, 8]. In our study, with an attempt to explore further ways to enhance material characteristics, we employed green laser for the crystallization of a-$Ge_{0.85}Si_{0.15}$ films. Fig. 5a shows the results of the laser crystallization of a-$Ge_{0.85}Si_{0.15}$ film with pre-patterned lines where large grains, typically 8x2 μm^2 in size, are formed and contained between the withered pre-patterned lines (which are represented by the dotted lines).

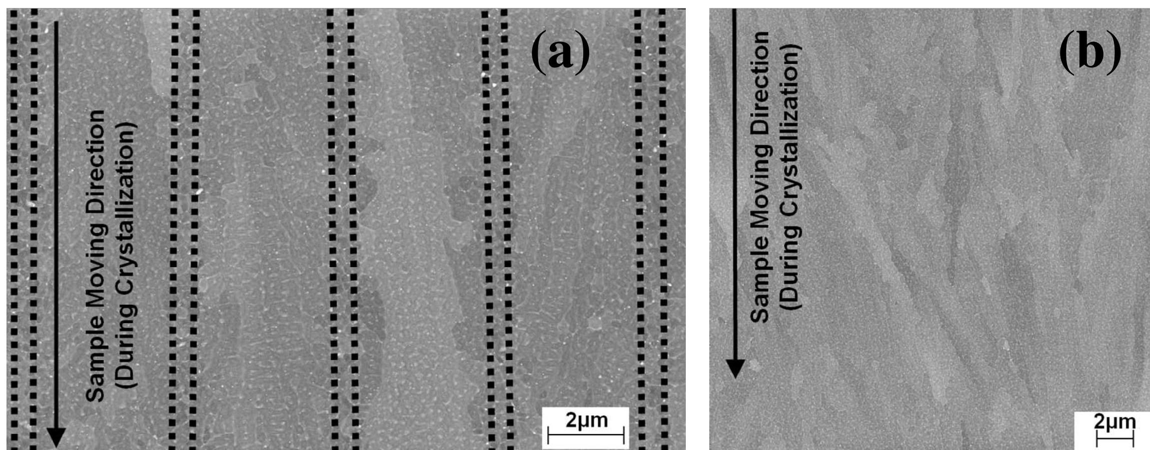

Figure 5. (a) SEM top view of laser crystallized film with pre-patterned lines; pre-patterning is indicated by the vertical dotted lines. (b) same, without pre-patterned lines.

A green laser was previously employed to crystallize a-Si films using the same approach, resulting in the dominant grain boundaries being located in between the pre-patterned lines [9].

The difference is that, in our case (see Fig. 5a), the grains originate anywhere in between the lines and eventually terminate at the pre-patterned lines. This difference in the crystallization behaviour between Si and GeSi films can be attributed to their respective thermal and optical properties. Fig. 5b shows the laser crystallization of a plain a-$Ge_{0.85}Si_{0.15}$ film resulting in the formation of elongated grains, typically 8x1 μm^2 in size, which are more randomly positioned. This shows the clear advantage of using pre-patterned lines during the crystallization process influencing the spatial orientation of the large grains. Such results have been observed for both 98% and 95% overlappings.

The surface roughness of both the films is around 2.5 nm (RMS) as shown by AFM. Both in terms of grain size and surface roughness, the laser crystallized $Ge_{0.85}Si_{0.15}$ films show a distinct advantage over LPCVD poly-$Ge_{0.85}Si_{0.15}$ films.

The XPS analysis shows a uniform composition profile along the depth for both as-deposited amorphous and poly $Ge_{0.85}Si_{0.15}$ films. The composition is measured along the depth by sputtering through the film using Ar ions. In contrast, the laser-crystallized $Ge_{0.85}Si_{0.15}$ films show that the top layers of the film are enriched with Ge compared to the bottom (Fig. 6). This Ge gradient did not exist in a-$Ge_{0.85}Si_{0.15}$ film prior to the laser treatment, indicating its occurrence is due to the laser crystallization process.

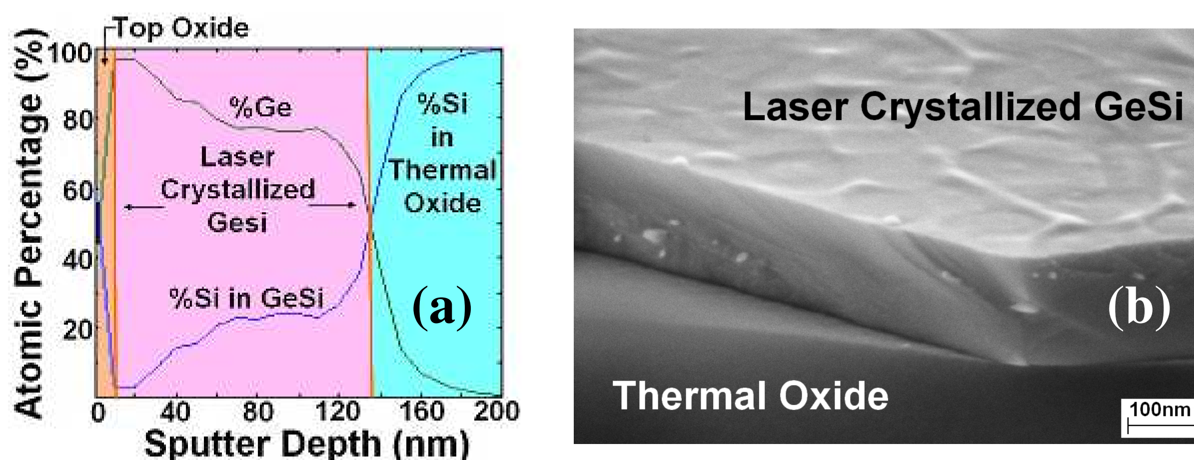

Figure 6. (a) XPS Depth profile for the laser crystallized $Ge_{0.85}Si_{0.15}$ film. (b) SEM cross-section of laser crystallized $Ge_{0.85}Si_{0.15}$ film.

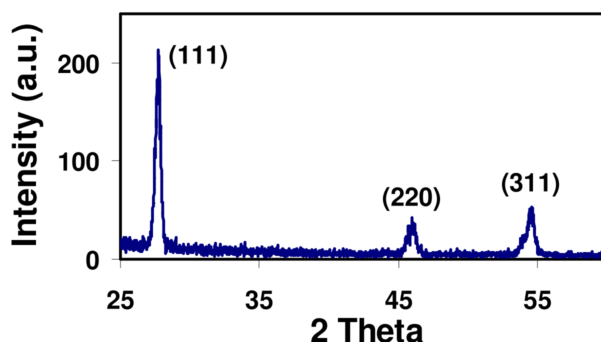

Figure 7. XRD graph of the laser crystallized $Ge_{0.85}Si_{0.15}$ film.

The XRD analysis (Fig. 7) shows the poly-crystalline nature of the laser crystallized $Ge_{0.85}Si_{0.15}$ films.

CONCLUSIONS

A custom-built LPCVD system was used to deposit poly- and amorphous-$Ge_{0.85}Si_{0.15}$ films at a temperature of 430 °C. The as-deposited poly-$Ge_{0.85}Si_{0.15}$ films showed small grains typically in the range of 200 nm.

The green laser crystallization of a-$Ge_{0.85}Si_{0.15}$ films, on the other hand, resulted in the formation of large-grained poly-$Ge_{0.85}Si_{0.15}$ films with a typical grain size of 8x2 μm^2. The pre-patterned lines influenced the positioning of grain boundaries during the crystallization process. Absence of the pre-patterned lines clearly led to more randomness in grain formation. The pre-determined-in-space grain locations are needed for the proper placement of the devices during further fabrication processes. This can likely enhance the characteristics of the device positioned properly on such films.

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REFERENCES

1. Yuan Xie, "Processor Architecture Design Using 3D Integration Technology", *23rd International Conference on VLSI Design,* DOI 10.1109/VLSI.Design.2010.60.
2. M. Vinet *et al.*, "3D monolithic integration: Technological challenges and electrical results", *Microelectronic Engineering* **88**, (2011) 331–335.
3. Fedder G.K *et al.*, "Technologies for Cofabricating MEMS and Electronics", *Proc. Of IEEE,* **Vol.96**, No. 2, Feb. 2008, pp. 306-322.
4. J.G. Fossum and A. Ortiz-Conde*, IEEE Trans. Electron Devices,* **Vol. ED-30**, NO. 8, August 1983.
5. A. K. Ghosh, C. Fishman, and T. Feng, *J. Appl. Phys.* **51(1)**. January 1980.
6. A.Gouye, O. Kermarrec, A. Halimaoui, Y. Campidelli, D. Rouchon, M. Burdin, P. Holliger and D. Bensahel, *J. Cryst. Growth* **311,** 3522 (2009).
7. Tao Chen *et al.*, "High Performance Single-Grain Ge TFTs without Seed Substrate", *IEDM 2010*, pp. 496-499, IEEE International.
8. Ishihara. R *et al.*, M, "Excimer-Laser Crystallization of Silicon-Germanium", *Solid State Device Research Conference,* pp. 1075 – 107, 1996. ESSDERC '96.
9. I. Brunets, J. Holleman, A.Y. Kovalgin, A. Boogaard and J. Schmitz, *IEEE Trans. Electron Devices,* **Vol. 56**, pp. 1637-1644, Aug 2009.