Germanium Grains Location Control using µ-Czochralski Process

Alessandro Baiano, Ryoichi Ishihara, Johan van der Cingel, and Kees Beenakker

Abstract—**2D location control of germanium (Ge) grains at different process temperatures is obtained using the µ-Czochralski technology. Single Ge grains can reach diameter of 5 or even 8 µm at sputtering temperatures of 100 or 550 °C, respectively. Crystalline structure of single Ge grain is confirmed by electron backscattering diffraction.**

Index Terms—**Germanium grains, 2D location control, µ-Czochralski process, low-temperature process.**

I. INTRODUCTION

THE downscaling of complementary metal-oxide semiconductor (CMOS) transistors below the 65 nm node requires new material with higher carriers mobility to replace silicon for the channel. If this technology would also be at low-temperature process, new application could be thought such as ultra wide band wireless applications on a glass or flexible substrate [1]. Germanium is a promising candidate for this because of high mobility. However, poly-Ge TFTs result in a lower mobility [2] and high leakage current, because of random grain boundaries and narrow bandgap. We believe that those problems could be solved if the transistor can be made in high quality Ge grain. Hence, 2D location control of Ge grains and single grain Ge TFTs are important objectives for high performance and low-temperature applications. Single grain Si TFTs [3] with location control of Si grains by the µ-Czochralski process [4] have successfully achieved SOI-like performance due to the high quality of the silicon channel, because CSL boundaries inside the channel do not affect carriers mobilities, as shown in the ref. [5]. In this paper, we investigate 2D location control of Ge grains at different process temperatures using the µ-Czochralski technology [3] and the crystalline quality of such grains.

II. FABRICATION

The germanium grains are obtained as follows: firstly, 1 µm diameter holes are formed in oxide and 840 nm thick SiO_2 layer is then deposited by TEOS-PECVD at a substrate temperature of 350 °C in order to reduce the hole diameter to approximately 100 nm. An etch-back of the SiO_2 is needed to make slope of sidewall gentle for the following sputtering deposition of 250 nm thick a-Ge film at 100 °C, 400 °C, and 550 °C. Afterwards, a single 20 ns long pulse of XeCl (308nm) excimer laser irradiates the Ge surface with energy densities ranging from 200 up to 800 mJ/cm^2. Fig. 1 shows the schematic diagram of the single Ge grain process. Fig. 2 shows the SEM image of location controlled of Ge grains after island patterning.

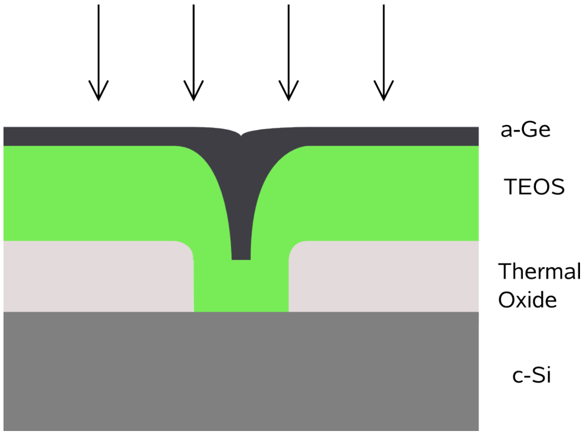

Fig. 1. Schematic diagram of germanium grain location control by the µ-Czochralski process

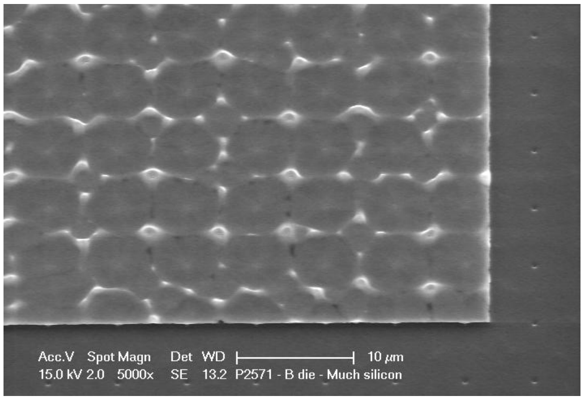

Fig. 2. SEM image of germanium grain location control by the µ-Czochralski process

III. RESULTS AND DISCUSSION

From the energy dispersive x-ray (EDX) spectroscopy (fig. 3), which diagnoses and counts amount of atoms present into the layer, it is possible to confirm that both sputtered and crystallized Ge is pure. We could not detect presence of Ar atoms due to the sputtering process. Very small amount of silicon and oxygen are detected into the layer. However, the detection of these atoms is due to the SiO_2 underneath the Ge layer. Indeed, making a series of measurements at different beams, the silicon and oxygen peaks decrease. Hence, the

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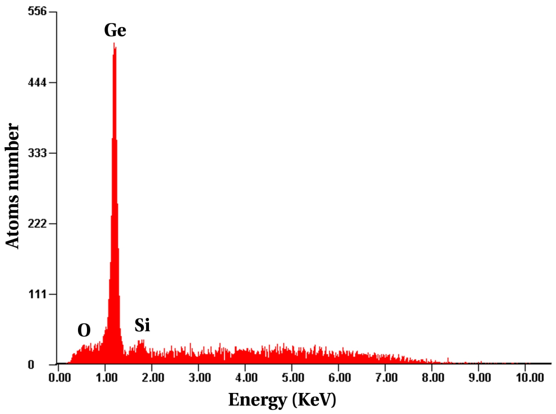

Fig. 3. Energy dispersive x-ray (EDX) spectroscopy of the single Ge grains layer after laser crystallization

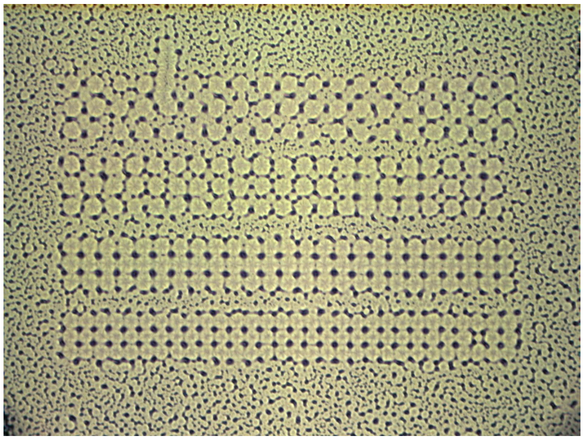

Fig. 4. Microphotograph of single Ge grains sputtered at 550C and crystallized at 700 mJ/cm. Four matrices of single Ge grains are shown. The distances of grain filters are 8, 7, 6, and 5 µm from top to the bottom matrices. This test structure makes easy the calculation of the grain diameter.

SiO_2 layer is not mixed up into the Ge layer. It is found out that Ge grains having a diameter up to 8 µm are successfully positioned on the grain filters as shown in the microphotograph shown in fig. 4. The location control of Ge grains is achieved by lower energy density range than that of the Si, as shown in fig. 5. This is consistent with lower melting temperature of the Ge than that of the Si. Furthermore, the increase of grain size versus laser energy density is more rapid than the one of the Si. That leads a smaller process window (550 - 725 mJ/cm^2) for the Ge crystallization than that of the Si (1200 - 1600 mJ/cm^2). For laser energy density higher than 725 mJ/cm^2, it is found out that first, many small grains (approximately 3 µm) are grown on random positions, as shown in fig 6, and then the ablation of the layer appears.

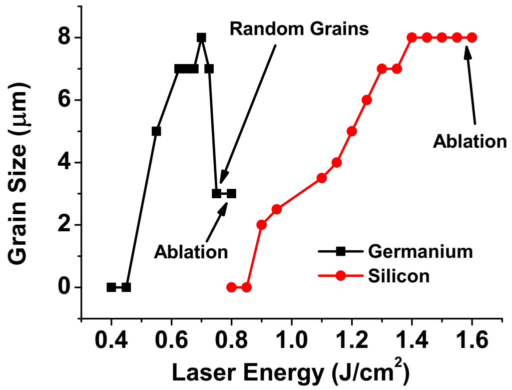

Fig. 5. Grain size of location-controlled sputtered Ge at 550 °C and LPCVD Si at 545 °C versus laser energy

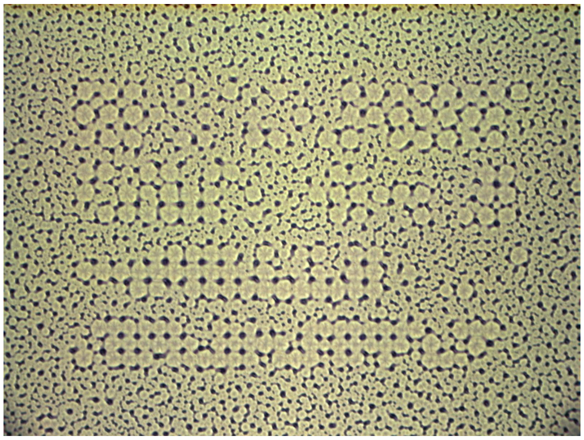

Fig. 6. Microphotograph of single Ge grains sputtered at 550 °C and crystallized at 750 mJ/cm^2

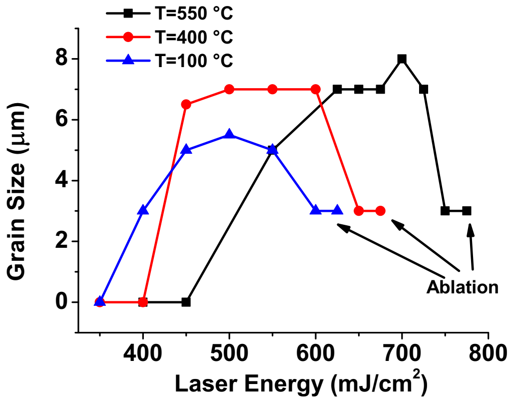

Fig. 7. Grain size of location-controlled at different sputtered Ge temperatures

It is also investigated the effect of Ge sputtering temperature on crystallization. Decreasing the sputtered Ge temperature, the laser energy density needed for its crystallization decreases, as shown in fig. 7. At 400 °C, the process window is slightly smaller (450 - 600 mJ/cm^2) than that of 550 °C and the grain size can reach 7 µm at most. At 100 °C, the process window is the smallest (450 - 550 mJ/cm^2) and the maximum grain size is 5 µm.

Fig. 8 shows the microphotograph of single Ge grains sputtered at 100 °C and crystallized at 500 mJ/cm^2. This figure confirms that single Ge grain is as larger as 5 µm.

An important analysis needed to confirm crystalline struc-

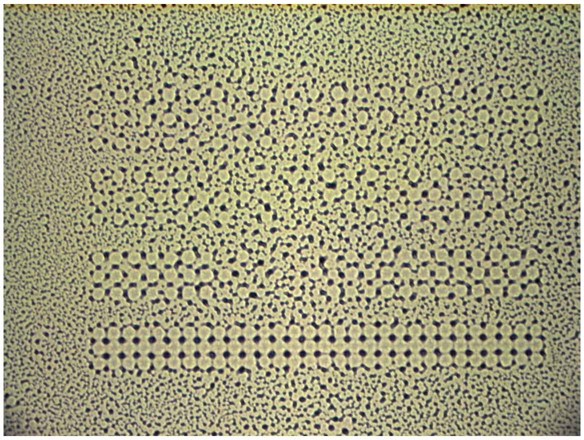

Fig. 8. Microphotograph of single Ge grains sputtered at 100C and crystallized at 500 mJ/cm^2

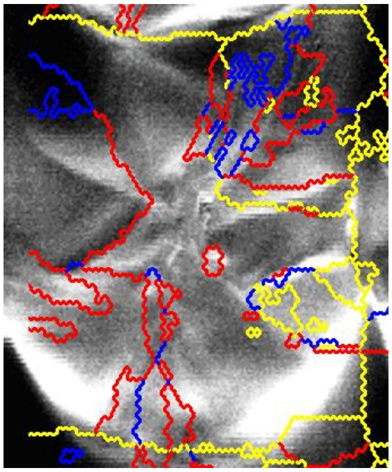

Fig. 9. Electron backscattering diffraction (EBSD) using grain filter size of 100 nm

ture of the Ge layer is the electron backscattering diffraction (EBSD) of location-controlled Ge grain, as shown in figures 9 and 10. As shown from fig. 9, the Ge grain has single-crystalline structure, with planar defects generating from the grain filter holes, which are meanly $\Sigma3$ and $\Sigma9$. Random grain boundaries are only on the edge of the grain where others grains collide. The crystalline quality of the Ge is also depending on the grain filter diameter. In fact, as shown in fig. 10, for 500 nm grain filter diameter, random grain boundaries are incorporated in the grains due to decreased filtering of grain in the grain filter.

IV. CONCLUSION

2D location control of Ge grain has been obtained by the μ-Czochralski technology at low temperature of sputtered Ge down to 100 °C. The process window to obtain as large Ge grains as 8 μm has been shown narrower than the case of silicon grains. Furthermore, it has been shown that single Ge grain has not random grain boundaries when a grain filter size of 100 nm has been used to obtain better filtering.

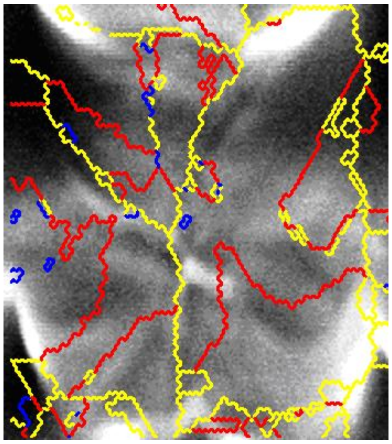

Fig. 10. Electron backscattering diffraction (EBSD) using grain filter size of 500 nm

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