NOVEL APPLICATIONS OF PULSE LASER ANNEALING IN MICRO STRUCTURES BY BOUNDARY CONTROL

Wei Tang, Zhe Chen, Siming He, and Haixia(Alice) Zhang*

National Key Laboratory of Nano/Micro Fabrication Technology, Institute of Microelectronics, Peking University, Beijing 100871, People’s Republic of China

Email: zhanghx@ime.pku.edu.cn

Abstract

XeCl pulse excimer laser with a wavelength of 248 nm and pulse duration of 38 ns, was utilized to anneal the silicon carbide material deposited by PECVD around the temperature of 300°C. The energy distribution of the laser was uniformly through a mask, and energy density of it varied from 110 mJ/cm² to 270.6 mJ/cm². Then amorphous silicon carbide material was annealed, turning to be low-stress and Young Modula improved. At last, the influence of the laser annealing on the device was investigated. The Results revealed that annealing effects turned to be different with the different structures or different transition layers, which were called self-selectivity. In addition the resonance frequency of the resonator would be improved with proper energy density.

Keywords: pulse excimer laser; silicon carbide; energy density; low-stress

1. Introduction

SiC appears in MEMS application as a promising candidate in harsh environment with its high melting point, chemical inertness and superior mechanical properties [1-2]. It is mainly deposited by LPCVD, PECVD, APCVD and PLD. Compared with other methods, PECVD takes the advantage of low deposition temperature (200-300°C), which makes it compatible well with Post CMOS process. However, the SiC film made by PECVD is amorphous with some defects in its mechanical characteristics, especially in the film stress.

Pulse excimer laser annealing process is an attractive solution with its steep temperature slope and high annealing selectivity, which is also compatible with Post CMOS Process. It is utilized to improve the performance of different thin films, such as SiGe [3], amorphous Si [4]. In our work, amorphous SiC was annealed by laser pulse with different energy density, which showed a lot of improvements in the film stress, as well as the Young Modula. In addition, we also annealed resonators with SiC as the cantilever beam. That improved the devices’ resonance frequency to some extent.

2. Experiment Devices

COMPExPro201(XeCl) pulse excimer laser was utilized. Essential parameters are as follows:
Table1. Parameters of XeCl Pulse excimer laser

| Wavelength/nm | Pulse duration time/ns | Frequency/Hz | maximum pulse energy/mJ |
|---------------|------------------------|--------------|-------------------------|
| 308           | 20                     | 1            | 500                     |

Furthermore, its energy follows Gaussian distribution in horizontal direction. When the whole irradiated area is $24 \times 10 \text{mm}^2$, it is not suitable to determine the energy density where the laser irradiated, as shown in Figure 1.

In order to make the energy density uniformed in the horizontal direction, a mask, which is a rectangle aperture with the length 20mm and the width 2mm, was placed in the light path. After passing the aperture, the high energy density part of the laser was extracted, and then focused by a convex, which made the laser's shape slimmer, and its energy density higher. The schema of the use of the masks is shown as figure 2(a) and the whole experiment devices is shown as 2(b):

3. Experiments on Films and Resonators

Experiments were carried out both on SiC films and SiC resonators.

3.1 Annealing SiC Films

SiC films in our experiments were prepared by PECVD, using SiH$_4$ gas flow rate 20sccm, CH$_4$ gas flow rate 400sccm, Ar gas flow rate 400sccm, and NH$_3$ gas flow rate of 5sccm[5], at the temperature of 300°C. Then they were annealed from the energy density of 158.8 $\text{mJ/cm}^2$ to 270.6 $\text{mJ/cm}^2$, the surface of the films after annealing is shown in figure3:
Then the Young Modula of the membrane was measured by Nano-indention, which revealed that, when the energy density was around 200 $mJ/cm^2$, the Young Modula was improved most. Low energy density couldn’t get it improved enough, while high energy density would cause some damages, changing the component of SiC film. As shown in figure 3, there are some black areas. Raman scattering suggested C-C bonds formation at these areas. There is no doubt that the Young Modula of the SiC film decreased at this energy density.

In another aspect, pulse laser annealing released the stress of the SiC film immensely. It was proved by our stress testing structure just in the wafer. As shown in figure 4(a), which is the sample before annealing, the two comb structures didn’t aligned well, because of its compressive stress, while after laser annealing, they are aligned together, shown in figure 4(b), which indicated that, there was no longer stress existing.

Additionally, it showed that as the energy density went up, unlike the furnace annealing, there was no longer changing in the film stress, as shown in table 2.

| Status       | Laser Annealing | Furnace Annealing ($450^\circ$C) |
|--------------|----------------|----------------------------------|
| Stress (Mpa) | -283           | 5.6, 53, 101                     |

Table 2. Comparison of laser annealing and furnace annealing
3.2 Annealing the SiC Resonators

In order to introduce this laser annealing method to the device fabrication, we did these experiments on our SiC resonators, whose scarify layer material of SiO were not released yet. Annealing results are shown in figure 5.

![Resonator images](image)

Figure 5. Self-selectivity of laser annealing: (a) original; (b) after laser annealing.

Figure 5 (a) represents the resonator without laser annealing. Note that the cantilever beam was covered by a layer of metal, which was blue in the picture, while in 5(b), this metal was removed, owing to the mismatch between metal and SiC caused by the thermal expansion under the irradiation of the laser with high energy. The laser annealed SiC cantilever beam, which can be observed obviously from the change of the beam’s surface color, from yellow to black.

After that, the resonance frequencies of cantilevers annealed under different energy density were also measured by laser Doppler system. It showed that, as the energy density rose, the frequency didn’t rise all the way, which would get to its peak around the energy density of 200, and then decreased. It matched well with the Young Modula measurements. Details are shown in figure 6 and Table 3.

![Graph](image)

Figure 6. Results of annealed cantilever beam

Table 3. Improvement of the resonance frequency

| Parameters | original | Laser Annealing (mJ/cm²) |
|------------|----------|--------------------------|
|            |          | 220.1                    | 257.2 |
| Freq. (MHz)| testing  | 1.75                     | 2.26  | 1.82  |
|            | calculation | 2.63                     | 1.94  |
| E (MPa)    | testing  | 118                      | 265.5 | 146.3 |
|            | calculation | 196.8                    | 127.6 |
4. Results and Discussions

In fact, in the process of annealing SiC resonators, the annealing results are interesting that the SiC on the cantilever beams were always annealed deeper than those on the anchor, which is unique in the annealing process of the devices. That’s because the way of heat dissipation for the two parts are different. In general, below the cantilever beam is SiO, serving as the scarify layer, which has low thermal conductivity. During the laser annealing, heat in the cantilever beams couldn’t dissipation easily, so it always rose to higher temperature than other parts. That’s why in the figure5(b), the SiC in the cantilever beam turns black, different from other parts. This was analyzed by ANSYS, using Finite Element Simulation method. Simulation results are as follows:

![](image)

Figure 7. Difference in temperature between cantilever beams and anchors

Setting the pulse duration time 20ns, simulated results revealed that, the SiC on the cantilever beam could not dissipate the heat well, so the difference of temperature between cantilever beams and anchors rose up during the pulse duration time, and got to its highest point at the end of the pulse. This is called self-selectivity. And it means, during the devices’ annealing, different structure would be designed to get different annealing results. In that way, we could perform a novel pulse annealing with high selectivity by boundary controlling.

5. Conclusions

The effect of XeCl pulse excimer laser on the improvement of amorphous silicon carbide characteristics was investigated. Although this method didn’t realize the crystallization of SiC, it improved the Young Modular to some extent under proper energy density and also lowered the SiC stress effectively. Moreover, it improved the resonance frequency of the SiC resonators and showed some of self-selectivity, during the annealing of the devices, which promises an application of pulse annealing by boundary controlling.

Acknowledgements

Thank the college of mechanics in Peking University for the support of Nano-indentation and the institute of Physics in Chinese Academy of Sciences for the supply of XeCl pulse excimer laser. Thanks for National Pre-Research Funding support, No. 9140C790108070C7903 and 9140A08080206JW0201
References

1. M. Mehregany and C. A. Zorman, “SiC MEMS: opportunities and challenges for applications in harsh environments,” Thin solid films, Vol. 355-356, pp. 518-524, 1999.
2. D. Gao, M. B. J. Wijesundara, R. T. Howe, and R. Maboudian, “Recent progress toward a manufacturable polycrystalline SiC surface micromachining technology,” Sensors Journal, IEEE., vol. 4, no. 4, pp. 441-448, 2004.
3. W.T. Anderson, A. Christou, J.F. Giuliani, “Laser Annealed Ta/Ge and Ni/Ge Ohmic Contacts to GaAs”, Electron Device Letters, Volume 2, Issue 5, May 1981 Page(s):115 - 117
4. S. Sedky, R.T. Howe, Tsu-Jae King, “Pulsed-Laser Annealing, a Low-Thermal-Budget Technique for Eliminating Stress Gradient in Poly-SiGe MEMS Structures”, Journal of Microelectromechanical Systems, Volume 13, Issue 4, Aug. 2004 Page(s):669 – 675
5. Zhe Chen, Dayu Tian, Guobing Zhang, Haixia Zhang. "Investigation of PECVD SiC nano film” 2007 7th IEEE International Conference on Nanotechnology, Hong Kong, Sep,2007.
6. F. Mangano, L. Caristia, N. Costa, M. Camalleri, S. Ravesi, S. Scalese, S. Bagiante, V. Privitera, “Laser annealing of a-Si for realization of polycrystalline Si film on plastic substrate”, IEEE RTP 2007. 2-5 Oct. 2007 Page(s):271 - 274
7. Haixia Zhang, Hui Guo, Rui Luo, Guobing Zhang, “In-situ doped and laser annealing of PECVD SiC thin film”, IEEE NEMS 2007, 16-19 Jan. 2007 Page(s):33 - 36