Post-CMP cleaning of silicon-germanium wafer surfaces

Andreas Krüger, Awwal Adeniyi Adesunkanmi, Rasuole Lukose, Yuji Yamamoto, Wei-Chen Wen, Marco Lisker
IHP – Leibniz-Institute für innovative Mikroelektronik, Im Technologiepark 25, 15236 Frankfurt (Oder), Germany, akrueger@ihp-microelectronics.com

Abstract

Silicon/silicon-germanium (Si/SiGe) and germanium/silicon-germanium (Ge/SiGe) layers are required for the production of quantum well structures for an electron spin-based quantum computer. A chemical mechanical polishing (CMP) step is required to reduce the surface roughness after the SiGe layer has been produced by epitaxy. The particles generated on the wafer surface during CMP are only insufficiently removed with the standard post-CMP cleaning step.

1 Background

We investigated how the wafer surface of a SiGe layer with germanium concentrations of 10% - 80% can be cleaned after processing by chemical-mechanical polishing. All wafers were polished with a fumed silica slurry (SS12). For this purpose, the particle concentrations of SiGe layers with different germanium contents were first recorded after polishing (**Chart 1**). Since the particle concentration was highest with a lower germanium content and in order to reduce the effort and costs for the production of SiGe layers, wafers with a pure silicon surface were used for the further investigations. These are more hydrophobic than the silicon surfaces with germanium content. Hydrophobic surfaces such as SiGe are difficult to clean without chemical additives [1].

2 Experimental

Two different polishing systems (CMP_Tool_A & CMP_Tool_B) were used for this study. The polishing systems differ in wafer handling as well as in the type of post-CMP cleaning. A plasma ashing tool (Clean_c) was used to remove organic particles (from the contact of the wafer surface with the polishing cloth and during wafer handling). This process is used to incinerate organic impurities (polymers).

CMP_Tool_A is equipped with a pad that is in contact with the front of the wafer when loading and unloading the wafer onto the polishing head before and after polishing. The post-CMP cleaning (Clean_a) is equipped with a Megasonic module, 2 brush modules and a spin-rinse-dryer module (SRD). The wafer to be cleaned is placed vertically in the clean modules. The Megasonic module is filled with de-ionized water and the Megasonic is coupled into the water via transducers installed installed at the bottom of the megasonic basin. The brush modules are each fitted with 2 rotating silicone brushes, which clean the front and back of the wafers. Wafer cleaning in the brush modules is also carried out using only de-ionized water.

CMP_Tool_B has a wafer handling system that has no contact with the front of the wafer. Post-CMP cleaning (Clean_b) takes place in two modules in which the wafers are loaded horizontally. Both modules are equipped with a megasonic function. The megasonic is indexed in a water jet that moves over the rotating wafer.

After the roughness of a wafer with $Si_{0.7}Ge_{0.3}$ layer was initially reduced by polishing with a polishing time of 200 seconds on the CMP_Tool_A and subsequent post-cleaning (Clean_a) (**Figure 1**), a particle test (tool: Surfscan SP1 KLA Tencor) showed a high particle concentration of > 70000 particles (particle size 0.2 µm - 5.0 µm) (**Figure 2**).

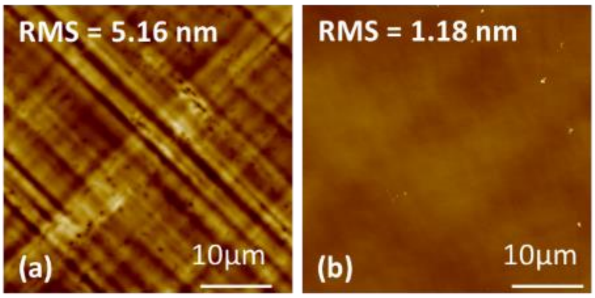

Figure 1: Cross hatch (pattern oriented along {110}) on $Si_{0.7}Ge_{0.3}$ before (a) & after (b) CMP

This high number of particles is problematic for further wafer processing, as tools in the process line could be contaminated.

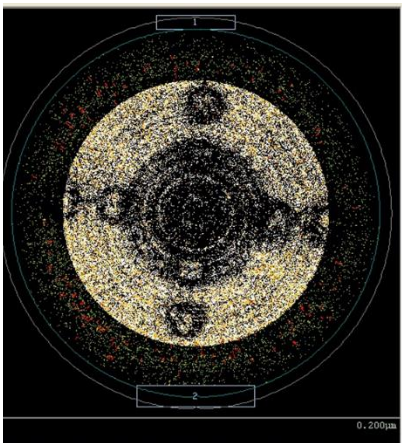

Figure 2: Particle distribution after CMP_Tool_A & Clean_a process

For further test series, these particles were first provoked by polishing bare silicon wafers with CMP_Tool_A and Clean_a. The polishing time was 30 seconds. Afterwards, the pattern-like arrangement of the particles was also revealed. The particles were analyzed using a scanning electron microscope with energy-dispersive X-ray spectroscopy. Carbon, silicon and oxide could be detected. This means that the particles were not only generated from the slurry (SiO_2 abrasive), but also originated from an organic source. Based on the pattern, the wafer loading unit of the CMP_Tool_A, which is used to load the wafers onto the polishing head, was identified as the source (**Figure 3**).

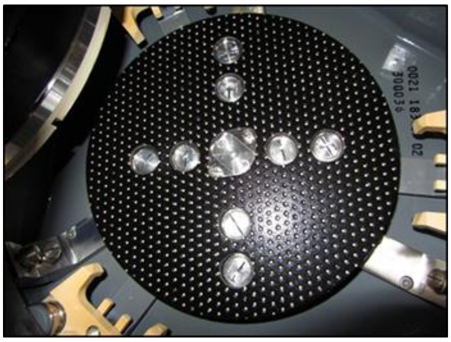

Figure 3: Wafer load unit with Pad at CMP_Tool_A

The pad, which is installed there, comes into direct contact with the wafer surface and then leaves particles behind. Handling without polishing also showed this particle signature. Replacing the wafer load unit pad had no effect on the number of particles. Polishing a silicon wafer on the CMP_Tool_B with subsequent cleaning (Clean_b), on the other hand, showed no pattern on the wafer surface. The CMP_Tool_B has a different wafer loading system for loading and unloading the wafers onto the polishing head than the CMP_Tool_A.
Next, a silicon wafer showing the pad imprint of the wafer loading unit after processing on CMP_Tool_A and Clean_a was additionally treated with Clean_b. The particle concentration was significantly reduced (from 65409 to 31425 particles) and the pad imprint was no longer visible. Further variants with additional water rinsing time on the wafer surface during loading and unloading of the wafers onto the polishing head of the CMP_Tool_A, as well as a doubling of the megasonic time to 60 seconds, did not result in any significant changes in the particle concentration. An ashing step was used to remove the organic particles. The particle concentration was then significantly reduced (from 31425 to 2870 particles). This was followed by a wet cleaning step with PIRSC1[1] and cleaning with HF[2] for 60 seconds. The particle count was then reduced to 84 particles (**Figure 4**).

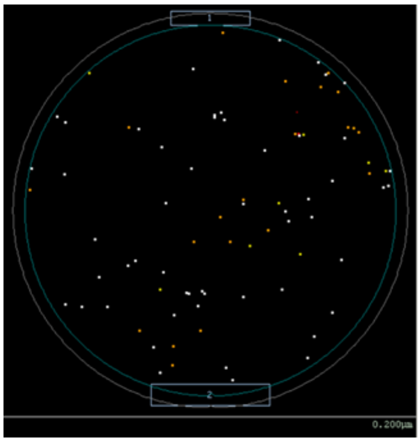

Figure 4: Particle distribution after the whole cleaning process at Silicon wafer (84 counts)

3 Discussion

It turned out that there are two different main particle sources and that these can be removed well. One particle source was of organic origin (polishing pad, pad of the wafer loading unit of CMP_Tool_A) and the other was the abrasives of the polishing suspension itself (SiO_2 particles). The post-cleaning modules of the polishing systems did not contain any chemical additives and were only operated with de-ionized water. This meant that not enough particles could be removed. The post-cleaning of the CMP_Tool_B Clean_b was more effective at removing particles than Clean_a. An ashing process (Clean_c) was then used to remove the remaining organic particles from the pads. After this process, the number of particles on the wafer surface was already significantly reduced (**Figure 5**). The result of the particle test on the Si0.3Ge0.7 wafer includes scratches. Therefore, the measured particle count is higher than the actual particle count that comes directly from the CMP process.

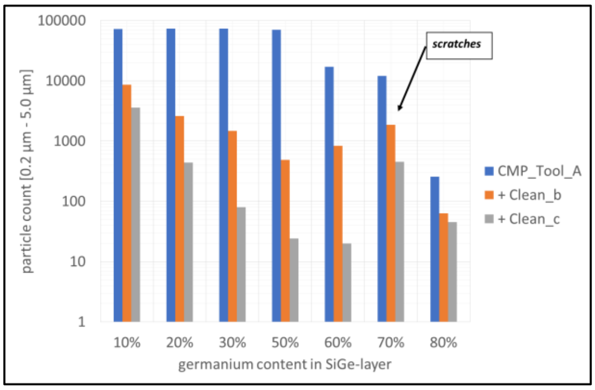

Figure 5: Particle counts with different germanium contents and different cleaning methods

[1] PIRSC1: PIR (sulfuric acid, hydrogen peroxide in the ratio 7.5:1); SC1 (ammonium hydroxide, hydrogen peroxide, DI-water in the ratio 1:1:5)

[2] HF: means hydrofluoric acid (hydrogen fluorid, DI-water in the ratio 1:100)

4 Conclusion

It was shown how the number of particles on Si-/SiGe wafer surfaces can be reduced after processing with CMP (**Table 1**).
For this purpose, an extended post CMP cleaning of 2 different polishing systems followed by an ashing step was used. The additional cleaning steps (PIRSC1 & HF), from the investigation on silicon wafers, should also be applied to SiGe wafers in the future.

Particle test [size 0.2 µm - 5 µm]							
Material	Ge content [%]	CMP_Tool_A	+ Clean_b	+ Clean_c	PIRSC1	HF 1 min [1:100]	Remarks
Silicon	0	65409	31425	2870	887	84	
SiGe	10	72835	8626	3587			
SiGe	20	73656	2590	438			
SiGe	30	73133	1475	80			
SiGe	50	70526	489	24			
SiGe	60	17081	837	20			
SiGe	70	12015	1870	454			<-- scratches
SiGe	80	258	63	45			

Table 1: Particle counts on bare silicon wafers and SiGe wafers with different Ge content and different cleaning methods

The next step is to transfer the polishing process from CMP_Tool_A to CMP_Tool_B. This means that the polishing and cleaning process could then be carried out in just one system (CMP_Tool_B & Clean_b), which would simplify the process sequence.

5 Literature

[1] P. Ong, L. Teugels: Advances in Chemical Mechanical Planarization (CMP), Elsevier Ltd. 2016, Chapter 5, CMP processing of high mobility channel materials: alternatives to Si, p. 125