Investigation of STI-Etch Process with Hercules Sensor

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***Abstract*—A Hercules sensor provided by Plasmetrex GmbH was used to gain and evaluate plasma parameters of a 90nm technology STI etch process performed at a LAM2300 Versys StarT chamber. It was found that there is a strong correlation between the trend of the electron collision rate at the resist strip step and the reaction with the organic resist, i.e., the complete consumption of the resist. The findings could be verified by the inspection of wafer surfaces with a SEM, where no resist residues could be detected even for reduced strip etch times and could also be supported with theoretical considerations.**
In addition to that there was found a dependance of the collision rate on the RF-hours, indicating a changed etch chamber state, despite it is run in cleanmode and should therefore always maintain a similar state. For this work the evaluation of Hercules data resulted in a better process understanding and revealed a high potential for process shortening. Moreover, the use of the electron collision rate as an automated endpoint (EP) parameter for the resist strip step is possible.

I. Introduction

The characterisation of plasma processes in semiconductor fabrication is in most cases restricted to standard recipe or tool parameters. For plasma etch processes there are mainly used recipe parameters, e.g. gasflows, rf-settings (reflected power, position of matchbox capacitors etc.) and EP-times, which are derived by optical emission spectroscopy (OES) or interferometic systems. Therefore the significance of tool monitoring or troubleshooting is strongly limited. In this article, there is described the plasma characterisation by evaluating the data of an external Hercules (**H**igh Frequency **E**lectron **R**esonance **C**urrent **L**ow Pressur**e** **S**pectroscopy) sensor [1], which delivers real plasma parameters, even independent from potential polymer deposition. This method results in an improved significance compared to a standard tool data evaluation as already proven in several diploma theses and publications (see e.g. [2]).

II. Experiments

The sensor is a commercial and well established SEERS (**S**elf **E**xcited **E**lectron **R**esonance **S**pectroscopy) device provided and supported by Plasmetrex GmbH [1], [3].
The Hercules sensor is mounted at a free view port, fits into the chamber liner, and acts as part of the liner. The plugs are built of Yttria-stabilized zirconia, which is a ziconium-oxide based ceramic, stabilized by the addition of yttrium-oxide - a similar material as the chamber liner (see Fig. 1).

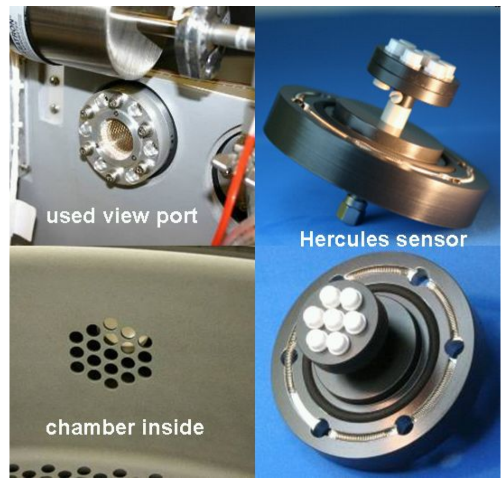

Fig. 1. View of the Hercules sensor and the mounting position.

The sensor measures the RF current at the chamber wall. This signal is processed by Fast Fourier Transformation followed by a model-based evaluation with respect to geometric resonance and damping characteristics. The resulting plasma parameters, e.g., electron density, RF peak voltage and electron collision rate are feed back to the tool in real time via LAM Plug and Play software method. So all Hercules parameters are available at the standard tool interface which effectively enables an easy chamber monitoring.

The considered STI etch process is the standard process within the Infineon 90nm Technology and consists of an Arc- and (silicon nitride) Mask-Open process followed by a Resist Strip and the actual Shallow Trench etch. It is performed at a LAM 2300 Versys StarT chamber, which has a mean time between clean (MTBC) of 500 RF-hours for a short wet clean (SWC), where only the focus ring is replaced and 1000 RF-hours for a long wet clean, where the chamber is completely cleaned.

The presented data focus on the collision rate and on the Resist Strip Step. The collision rate exhibits the most significant signal of all plasma parameters and the Resist Strip Step reveals a high potential for time reduction. Due to the lack of information content out of the OES signal, this step is "over-dimensioned" to 50 seconds in order to exclude resist residues (see Fig. 2 for details).

Parameter	1	2	3	4	5	6	7	8	9	10	11	12
Step Description	Stable	BARC ME		SiN ME		PR Strip	BT	Trench		O2 Flash	Dechuck	End
Pressure (mtorr)						20					0	0
TCP RF Power (w)						1000					0	0
Bias RF Power (w)						0					0	0
Bias RF Voltage (v)						0					0	0
Bias RF Control Mode						Power					Power	Power
Gas Injection Ratio						Center					Center	Center
						0					0	0
						0					0	0
						0					0	0
						0					0	0
						0					0	0
						0					0	0
						0					0	0
O2 (226.0 sccm)						200					0	0
						0					0	0
						0					0	0
						0					0	0
						0						0
Helium (torr)						8					0	0
Inner ESC Temp						30					30	30
Outer ESC Temp						30					30	30
Lifter Pin Position						down					down	down
Step Type	Stab	EndPT	Time	EndPT	Time	Time	Time	EndPT	Time	Time	Time	End
Process Time (sec)	20	25	30	54	15	50	5	60	12	10	3	0

Fig. 2. Etch recipe for the 90nm STI-etch process at LAM2300 Versys StarT chamber; only the step of interest (resist strip) is shown.

III. Results and Discussion

The standard OES signal (wavelength 387nm) showed only a sharp drop during the first 10 seconds of the resist strip step (Fig. 3). No improvement of the signal validity was seen when different wavelengths were observed after checking the complete available spectra from 250nm to 800nm. No significant OES signal change after roughly ten seconds step time could be observed, regardless what wavelength was used, i.e., every potential hint for any strip reaction is only visible during the first seconds of the strip step, which is strongly expected not to correlate to the complete resist removal reaction.

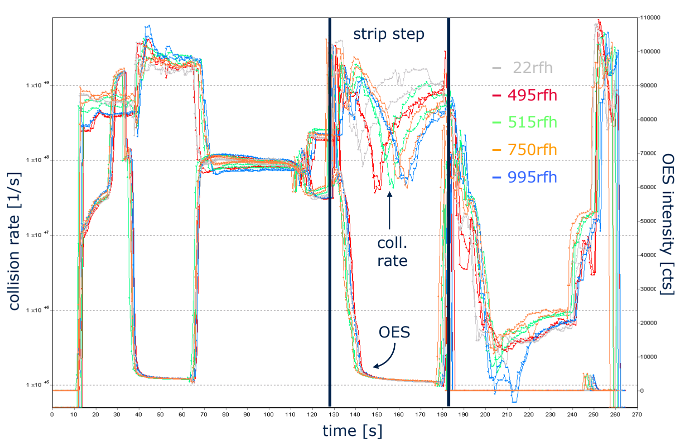

Fig. 3. Collision Rate and OES signal of several STI wafers at different rf-hours

In contrast for the Hercules collision rate there is obviously a pronounced minimum that is evident to correlate to a plasma reaction. The collision rate trend saturates after the minimum at a higher level, nearly reaching the initial step level indicating the complete conversion of the resist material on top of the wafer and removal of all reaction products. This is shown in Fig. 3, where the collision rate (left axis) is plotted together with the OES intensity (right axis) against time. It is also obvious that the collision rate shifts towards later times for higher RF-hours, meaning the resist removal process is completed later. This is totally unexpected as the chamber runs in cleanmode operation, where a waferless auto clean (WAC) is run after every wafer to assure a constant clean chamber state even for increasing usage time.

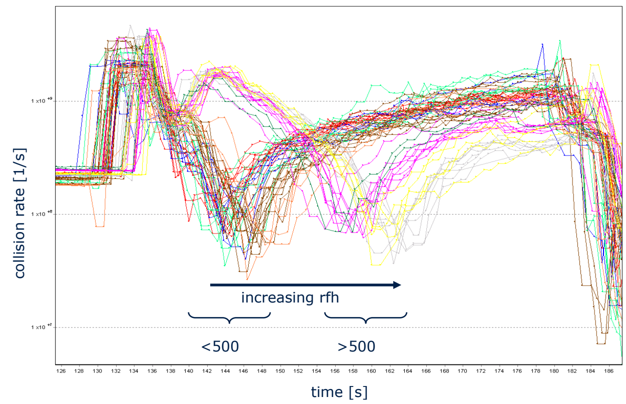

Fig. 4. Detailed view of the collision rate minimum.

In Fig. 4 it is shown a view of the collision rate zoomed to the resist strip step only. It becomes clear, that the minimum occurs at about 15 seconds, when the etch process runs before the SWC (at 500 RF-hours) and about 25 seconds after the SWC, indicating a strong impact, much more distinct than previously known, as there are only slight changes visible in etch rates and inline data after a short wet clean.

To verify the correlation between collision rate and completion of the strip reaction, there were processed 5 wafers, stopped immediately after different strip times and investigated at a standard defect density inspection at an AMAT Complus tool. The used strip times correspond to a stop before the minimum in the collision rate is reached (10s), just at the minimum (15s), at the minimum and additional 10 seconds, at the minimum and additional 20 seconds and after 50 seconds of etching, which is the process of record (POR).

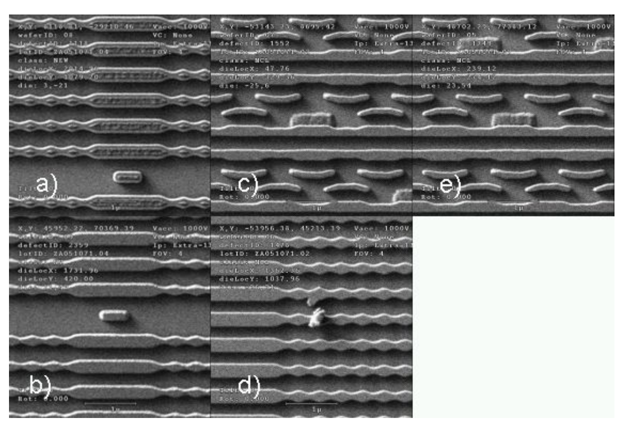

Fig. 5. SEM pictures of wafers post strip etch with various strip times; a) 10sec, b) 15sec, c) 25sec, d) 35sec, e) 50sec (POR); no residues for c) - e).

The results are shown in Fig. 5. It becomes evident, that after 10 seconds there is a closed resist layer visible. After 15 seconds the resist is already attacked but not removed completely. For all other wafers no resist residues could be found, which fits to the assumption made above and will be explained in more detail as follows.
The trace of the collision rate in the strip step can be divided into four sections as indicated in Fig. 6.

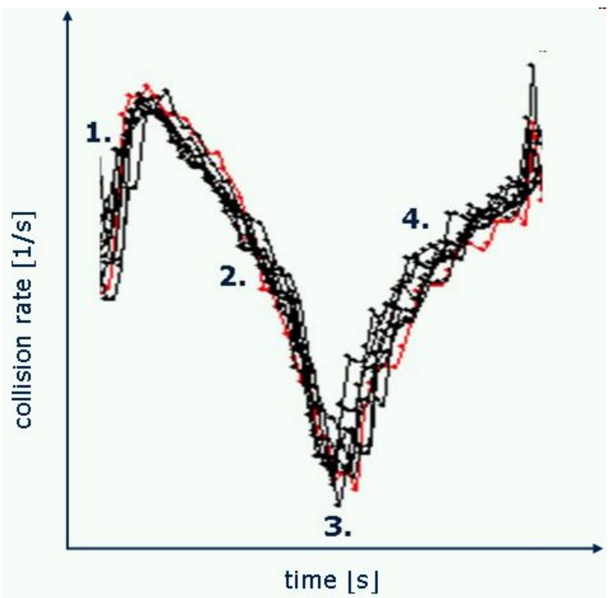

Fig. 6. Four different sections of the collision rate trace in the resist strip step. Some arbitraryly choosen traces are shown.

Section 1.: during the first 5-10 seconds there is a removal of byproducts (Si_3N_4, SiF_xN_y, ...) and modified resist from the mask surface. Afterwards the etch rate increases on now blanked resist surface through oxidation.
Section 2.: the gas flow of byproducts grows up now to the order of the O_2 gas flow, which changes the collision rate.
Section 3.: The minimum of the collision rate corresponds to the maximum of total resist removal rate, the partial pressure of the resist removal byproducts is so high, that the plasma turns into the high-density or H mode. The heating of the electrons changes - the collision rate drops down.

Section 4.: At some parts of the the wafer's surface the resist is already removed, the flow of resist removal byproduct decreases and their partial pressure declines again, O_2 becomes the dominating gas, the plasma goes back to the low-density or E-mode. Switching from E (capacitive) to H (inductive) mode is a well- known behavior for Inductively Coupled Plasmas (ICPs) and is often a hidden root cause for process instabilities (see [4] for details).

IV. Conclusion

The use of the Hercules sensor at a LAM2300 Versys StarT chamber offers unexpected potential. Previously unknown chamber instabilities could be detected in a very easy way by just plugging the sensor and evaluating the resulting plasma parameters without any influence on the chamber or process. In contrast to optical systems, there is no influence of deposited layers as the sensor is a part of the chamber wall. The Hercules parameters give a much better insight into the etch process and chamber state than the standard tool parameters. For the STI etch there was identified a time saving potential of about 25 seconds per wafer, as the strip step can be analysed and understood, which is not possible with the OES system. The significant signal change even makes it possible to use the electron collision rate as an endpoint trigger, to properly adjust the strip time to the resist removal. In general, the use of the Hercules sensor, in combination with standard tool monitoring, enhances the process understanding and offers a high potential for an improved process stability and chamber matching.

Acknowledgment

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