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COMPARISON OF PLASMA-INDUCED SURFACE DAMAGES IN VARIOUS PLASMA SOURCES

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ABSTRACT

This study was an investigation of plasma-induced damages on silicon substrate in the semiconductor manufacturing technology. The plasma-induced damage level on silicon substrate was analyzed and compared in various plasma etching systems. The analysis methods were therma wave, life-time recovery, SCA (Surface Charge Analyzer) and TRXF (Total Reflection X-ray Fluorescence) measurements, and the measured values were compared for each systems. In the comparison of the values which were obtained by a system that had low life-time recovery, there was not any differences in DC parameters. However, the reflesh time distribution of device of that system had decreased about 10 to 20m sec compared to a system which had high life-time recovery.

INTRODUCTION

Nowadays, plasma processing has become an important part in the fabrication of integrated circuits since it offers advantages in terms of directionality, low temperature operation and process convenience. However, plasma processing also offers increased damage potential because of surface charging of floating gates in MOS devices[1]. Moreover, there can be possibilities to make plasma damage greater than coventional plasma system because plasma trends have become using high density plasma (HDP), for example, ICP (Inductively Coupled Plasma), ECR (Electron Cyclon Resonance), helicon source plasma, etc, in main equipments of manufacturing system recently. The damage can degrade all the electrical properties of a gate oxide which include fixed oxide charge density, interface state density, flat band voltage, leakage current and various breakdown related parameters[2, 3, 4]. As expected, all the MOS transistor parameters which depend on the oxide properties can be degraded by charging[5]. Charging damage to thin oxide is a big concern for many plasma processing steps, especially, plasma etching processes. While it is known that plasma nonuniformity is the major cause for charging and that damage is the result of excess oxide current from this charging, many aspects of these mechanisms are still uncertain. Efforts to define those mechanisms are performed by many engineers and scientist who are related to semiconductor business during past decade.

Plasma damage levels can be measured in various methods and they also be intepreted in different ways. In this study, general measureing methods which are therma-wave, life-time recovery, SCA measurement, TRXF measurement and refresh time measurement are used after several plasma etching processes which are LOCOS, LDD and contact etch.

EXPERIMENTAL PROCEDURE

Sample wafer manufacturing and process flow are as follows;

1. p-type prime wafer preparation.
2. Plasma treatment for each processes and equipments.
3. Therma wave measurements (25 points).
4. Wet cleaning (SC1 + SC2).
5. 1 : 99 HF dip.
6. Dry oxidation (780℃).
7. Life time measurements (25 points).
8. Surface charge analyzer (SCA) measurements before annealing (5 points).
9. Hydrogen annealing (420℃, 20 minutes).
10. Surface charge analyzer (SCA) measurements after annealing (5 points).

Testing plasma source types, chemistries and applied etching processes are shown in Table. 1 as split table. And the measureing tools used for this study are as follows;

1. Therma wave measurements : TP-4000XP, Therma Wave.
2. Life time measurements : LTA-550, LEO
3. SCA measurements : SCA-2000, Semi-Test, Inc.
4. TRXF measurements : System 3726B, Ikaku.
5. Refresh time measurements : T5363P, Advan Testor.

RESULT AND DISCUSSION

Therma Wave Measurements Result

Therma wave measurements show the amorphous silicon state level through broken silicon bond by plasma damage. Some therma wave measurements result is shown in Fig. 1 for different etching processes and plasma type. Fig. 1(a) shows that helicon plasma

Table. 1. Etch Processes and Split Table.

PROCESS	PLASMA TYPE	ATC ETCH DEPTH				CHEMISTRY	ETCH TARGET
		0	50Å	100Å	200Å		
LOCOS	MERIE	●				$CHF_3/CF_4/O_2/Ar$	LP Nitride 530Å
	C/PLASMA	●				$CHF_3/CF_4/Ar$	
	HELICON	●				CHF_3/CH_2F_2	
SiETCH	MERIE	●	●	●		HBr/Cl_2	Si 500Å
LDD	MERIE	●	●	●	●	$CHF_3/CF_4/O_2/Ar$	LP Nitride 300Å
	C/PLASMA	●	●	●	●	$CHF_3/CF_4/Ar$	
CONT	ICP	●	●	●	●	C_2F_6/O_2	HLD Target 5000Å
	C/PLASMA	●	●	●	●	$CHF_3/CF_4/Ar$	

MERIE : Magnetic Enhanced Reactive Ion Etching
C/PLASMA : Conventional Plasma
ICP : Inductively Coupled Plasma

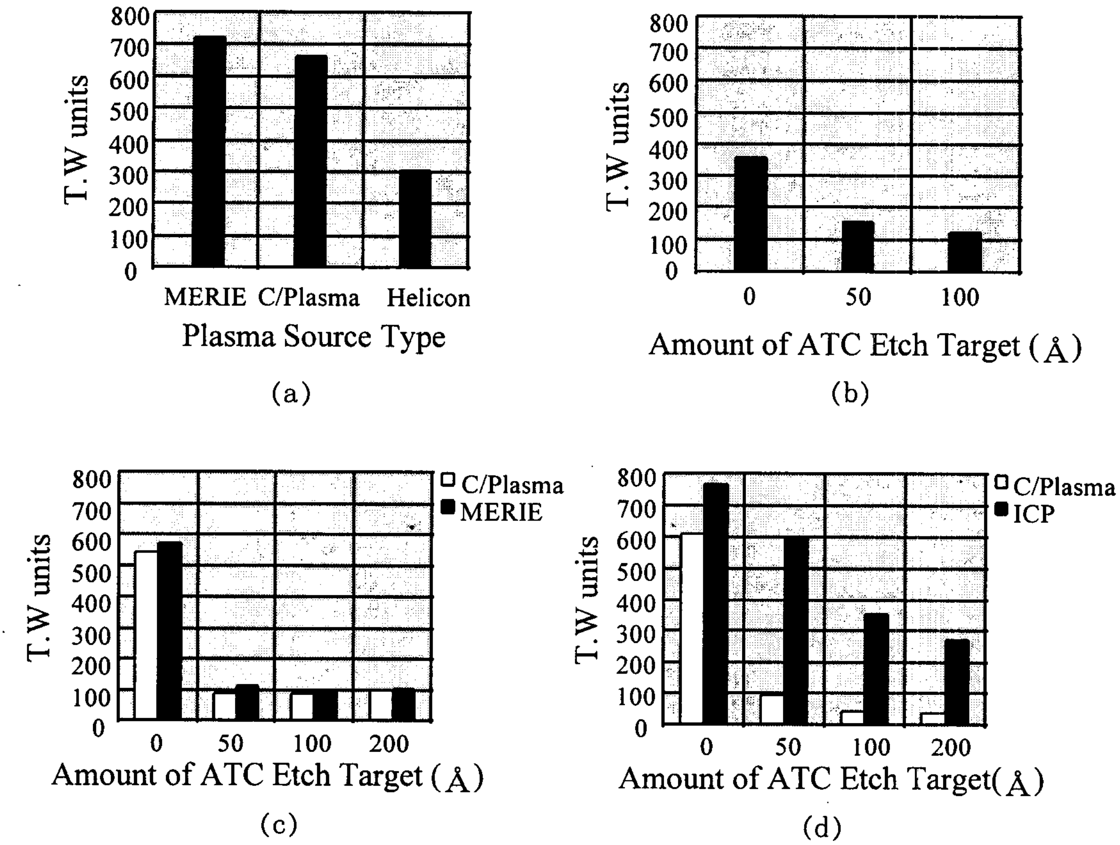

Fig. 1 Results of Therma-Wave Measurements.

source had the smallest ion damage after LOCOS etching process. The other hand, MERIE and conventional plasma typers have similar ion damage level. The therma-wave measured values of MERIE type was decreased in half additional 500Å silicon etch and some ATC (after treatment chamber) etch in Fig. 1(b). Fig. 1(c) shows the comparison of ion damage level of conventional plasma and MERIE type after LDD etching process. The damage status of those types were similar level, however, the damages were decreased after ATC etch. And the ion damage was not effected by the amount of ATC etch quantities. Fig. 1(d) shows the comparison of ion damage level of conventional plasma and MERIE type after contact etching process. The damage level of the conventional plasma type was dramatically decreased after ATC etch. That type was not effected by the ATC etch quantities, but the ICP type has decreased the ion damage level by the ATC etch quantities. From this experiment, it is concluded that the ATC etching process can cure the ion damage due to plasma. Light etching treatment process make the broken dangling bond to be stable in the damaged silicon surface. That is why the light or ATC etching processes are used after plasma etching processes in manufacturing semiconductors.

Life Time Measurements Result

Life time measurements show the contaminants level after plasma etching processes and the measured values of them are presented by recovery percentages. The plasma contaminants status is low, if the recovery percentage is high after plasma etching processes. In Fig. 2(a), life time recovery was measured for MERIE, conventional plasma, and helicon sou-rce plasma types after LOCOS etching process. From this measurements, MERIE and conventional plasma types were recovered above 10%, but helicon source plasma was recovered only 1%. As result, helicon source plasma has more contaiminants induced by plasma than MERIE or conventional plasma type. Fig. 2(b) shows life-time recovery results according to amount of ATC etch quantities after LOCOS and silicon etching processes in MERIE plasma type. Before ATC etch life time recovery was 15%, but after that treatment it was increased to 25%. For LDD etching process, however, the amount of ATC etch quantities devote a lot to life time recovery in MERIE and conventional plasma type as shown in Fig. 2(c). According to the amount of ATC etch quantities, life time recovery was increased for conventional plasma type, but no trend was shown for MERIE plasma type. In Fig. 2(d), recovery was 10 to 60% for conventional plasma type, however, recovery

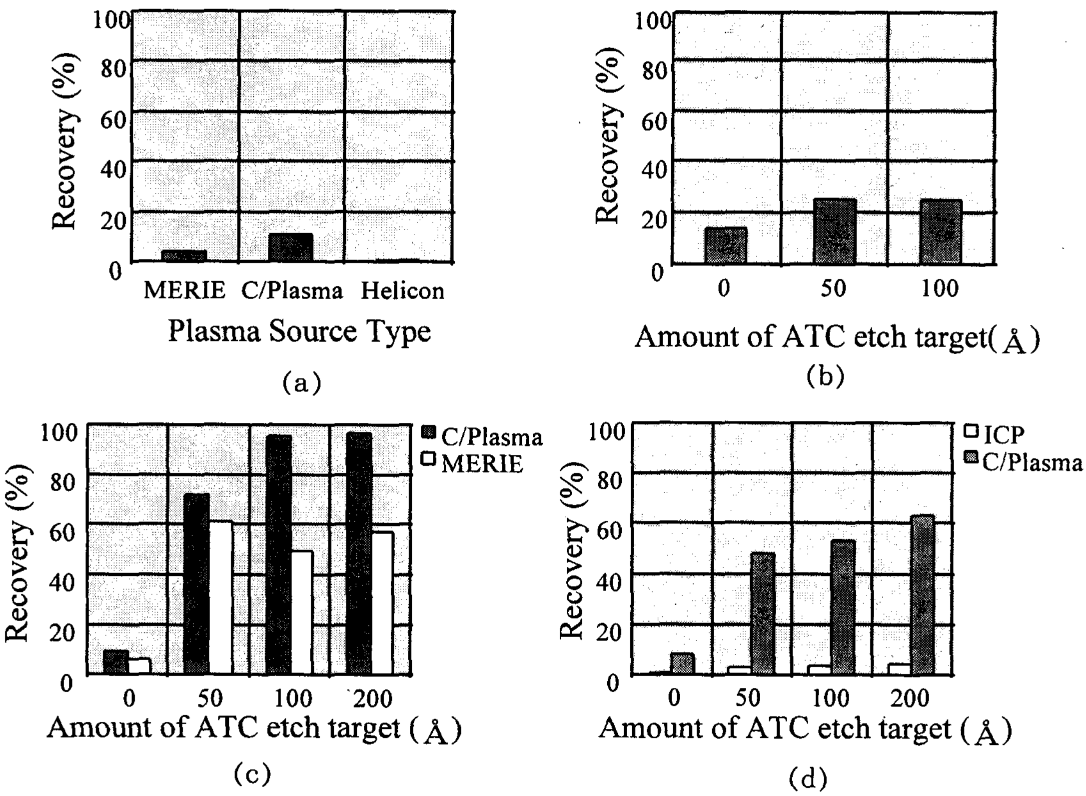

Fig. 2 Results of Life-Time Measurements.

was not effected by the amount of ATC etch quantities in ICP type after contact etching process. This mea-ns that surface polymerization could occur by high density plasma reactiom or more contaminants could exist for ICP type etcher. From thest measurements, it is concluded that the ATC etch could be helpful for the life-time recovery of some plasma damage processes.

SCA (Surface Charge Analyzer) Measurements Result

Surface charge analyzer can show the amount of electric charges in the interface of two different materials. The results of this analyzer also can inform about how many damaged dangling bonds or contaminants induced by plasma reaction in the interface of two materials. In Fig. 3, the amount of electric charge changes were compared in the interface of oxide and silicon before and after hydrogen annealing. In this experiment, the annealing temperature was 420℃ and time was 20 minutes. Reference wafer, which was not done by plasma processing, decreased the amount of electrical charges at surface via hydrogen annealing. Measurements also done for ICP and conventional plasma types. The experiments were performed for 50Å and 200Å ATC etch and were compared for each plasma sources. All type had similar trends, however, conventional plasma type had better result after annealing process. From these measurements, ICP had more defects which could be damaged dangle bonds, contaminants, or etched by-products due to plasma reaction than conventional type as shown as the life time measurements.

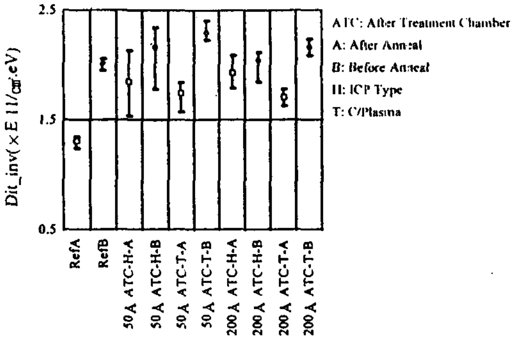

Fig. 3 Electrical Charge Changes in the Interface of Oxide and Silicon before and after.

TRXF(Total Reflection X-ray Fluorescence) Measurements Result

From TRXF measurements, the metal contaminants status can be obtained after plasma processing. Some TRXF experiments were done for several plasma types after LOCOS and contact etching processes in Fig. 4. In Fig. 4 (a), oxide strip was performed by 1 : 20 BHF after LOCOS etching process, and metal contaminants were measured by TRXF. Helicon plasma source had many Ni contaminants compared to other materials, Fe, Cu, etc, and it had more contaminants than other plasma sources, MERIE and conventional plasma type. Metal contaminants could be obtained by process chamber wall or originally the different plasma sources. After contact etching process, ICP and conventional plasma type were compared for metal contamination in Fig. 4(b). Conventional plasma type had similar trend and metal quantities with LOCOS etching process, but ICP type had more metal contaminants than conventional plasma type, especially, many Cu atoms were appeared. From this TRXF measurements result, it is concluded that the high density plasms (HDP) types, like as, ICP or helicon source, had more opportuni ties to

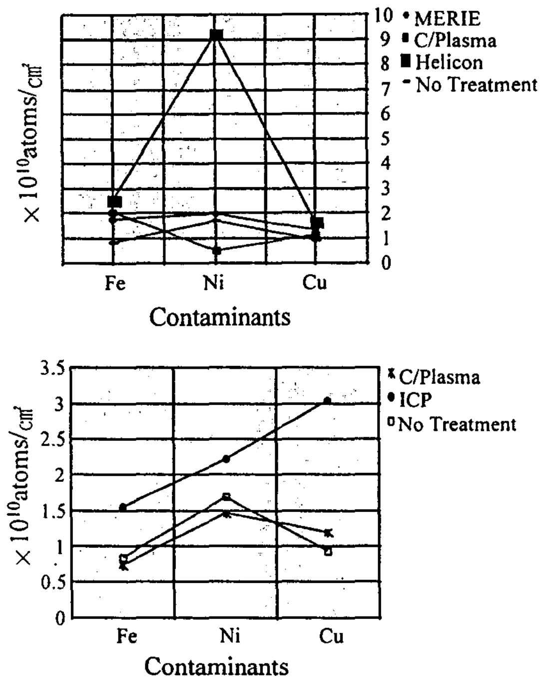

Fig. 4 Comparison of Plasma Contaminants for ICP and Conventional Plasma Sources.

get contaminants. This could be processing chamber wall problem or the plasma reaction mechanisms were different compared to other plasma types.

Refresh Time Measurements Result

Refresh time was compared for ICP and conventional plasma type after contact etching process. Usually refresh time should have a regular distribution histogram after some plasma processes. In Fig. 5, conventional plasma type had a regular distribution, however, ICP type had 10~20m/sec refresh time shift after contact etching process. From this result, it is estimated that the amount of charges which existed in substrate were decreased because of current leakage phenomena by certain contaminants. That could make refresh time short or shift in semiconductor devices.

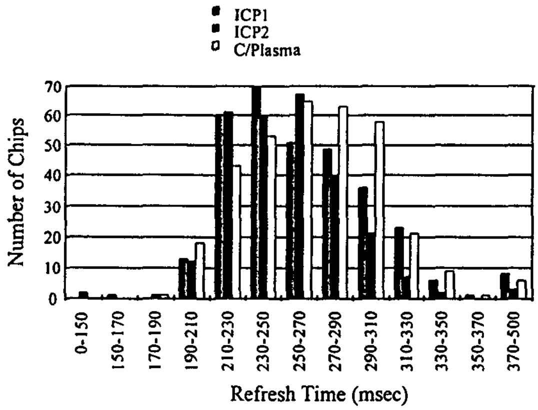

Fig. 5 Comparison of Refresh Time after Contact Etching Process.

CONCLUSIONS

Plasma etching system which had low lifetime recovery values and high therma-wave values had decreased refresh time as characteristics of semiconductor devices after contact etching process. Also the optimum amount of ATC etch after LOCOS and silicon, and LDD ething processes was 50Å. In metal contamination, ICP or helicon source plasma type system had more contaminants than the other plasma source system. Further, it is recommended that investigations for plasma damage mechanism are required and metal contaminants are controlled carefully during plasma processing.

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