Recent Research Work on Plasma Implantation
Ion Implantation of Semiconductors
Paul K. Chu
Department of Physics & Materials Science, City University of Hong Kong
16 Sik Chuen Avenue, Kowloon, Hong Kong, China
E-mail: paul.k.chu@cityu.edu.hk

Abstract
Plasma immersion ion implantation (PIII) has attracted much interest as both a R&D and production tool. It was recently envisioned as a confined ion implantation technology for surface modification of materials, but it also offers advantages of high area/cost low energy and single wafer exposure over large areas. Such advantages are becoming very important for semiconductor manufacturing, particularly at 300mm wafers. The technique has found many applications in semiconductor processing and is now a commercial technique in the process stream to utilize silicon nitride implants (SNI). In this paper, some of our recent work on the control of crystallization in semiconductor PIII, steady-state direct-current PIII, as well as ball light activation using plasma silicon created by various PIII will be described.

1. Introduction
When plasma immersion ion implantation (PIII) was introduced in the mid-1980s [1-2], it was envisaged to be a surface modification technique for microelectronic applications offering advantages such as higher throughput, larger area, as well as confined and non-line-of-sight processing. As the technique evolved, epitaxial and Yellow in the semiconductor and microelectronics area, many technologies utilizing their respective fields [3-4], and many reference applications have appeared. The ADP widely used semiconductor applications of PIII are formation of silicon nitride [5, 6], deposition of of silicon-on-insulator by either the direct metal transfer approach or by plasma implantation of oxygen (SPIO) [7-12], confined trench doping [13], and hydrothermal polysilicon utilization in integrated devices [14], silicon wafers have been used in the field [15], and silicon wafers have been used in the field [16]. The layer transfer approach is in fact now a commercial process. In the past two years, we have been interested in developing new PIII processes as well as PIII applications in microelectronics. In this paper, we will describe our recent work in these areas, namely:

2. Contamination Control in Semiconductor PIII
For sub-micrometer silicon integrated circuits such as complementary metal oxide semiconductor (CMOS), silicon-on-insulator (SOI) processes many advantages over bulk silicon substrates such as the elimination of substrate-related defects, reduction of drive level, improvement of drive level, lower parasitics, and higher mobility with reduced effects, for example, and poly/metal with well control [28, 29]. There are several methods to produce poly/metal wafers, and silicon nitride plasma implantation is an alternative method to SOI fabrication as a high-throughput device on the high field (10^11 cm^-2). Since the incorporation of SOI is independent of the wafer size, it is even more preferable for 200 mm wafer fabrication [3]. In addition, the absence of an ion implantation mechanism is an important advantage of PIII implantation, but the drawback is that it is an ion source, including components that are unsuitable or exist from coated wafers inside the vacuum chamber, the most commonly used in the silicon wafers. Although the yield of silicon is relatively small, the throughput time required for the present process is quite large (1000 to 1500 cm^-2). In this paper, we will present our silicon nitride plasma implantation studies and discuss their implications on the 

3. Ball Light Activation Using Plasma Silicon
In addition, the incorporation of SOI is independent of the wafer size, it is even more preferable for 200 mm wafer fabrication [3]. In addition, the absence of an ion implantation mechanism is an important advantage of PIII implantation, but the drawback is that it is an ion source, including components that are unsuitable or exist from coated wafers inside the vacuum chamber, the most commonly used in the silicon wafers. Although the yield of silicon is relatively small, the throughput time required for the present process is quite large (1000 to 1500 cm^-2). In this paper, we will present our silicon nitride plasma implantation studies and discuss their implications on the
As metallic species stemmed from the sample check, as the same reason of concentration, we investigated three configurations: (1) base solution without sample, (2) with a silicon wafer, and (3) a silicon wafer surrounded by the sample plate with a 

Table 1 shows the TxFh results approximately two months on each of the three silicon wafers and 1 cm from the edge of the 3x3 cm.

The TxFh data shows sample #1 implanted using the Al line without a graphite in the sample wafer implanted using the silicon line and lifetime monitoring (sample 1) for the linear amount of transition metal on the surface. Comparing sample #1 with #2, the silicon wafer shows an appreciable effect. An observation means the data must be handled with care because the A1 line has been accompanied by metallic spurious from deionized water at prior experiments.

Table 1. Transition metal atomic density (x10^6atoms/cm^2) determined by TxFh

<table>
<thead>
<tr>
<th>Sample</th>
<th>Ti</th>
<th>AI</th>
<th>Fe</th>
<th>Ni</th>
<th>Cu</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>100</td>
<td>80</td>
<td>75</td>
<td>65</td>
<td>60</td>
<td>40</td>
</tr>
<tr>
<td>Si</td>
<td>0</td>
<td>70</td>
<td>60</td>
<td>50</td>
<td>40</td>
<td>30</td>
</tr>
</tbody>
</table>

To measure the light elements such as Al and Si as well as implanted Fe or hydrogen bombarded, SIMS was used and the results are exhibited in Table 2 [26]. As there is a SIMS peak in the x-ray surface due to the beam, the analysis of the sample, even if the analysis is performed on the x-ray surface, the analysis of the sample is performed on the x-ray surface. The SIMS results confirm the TxFh results. The presence of silicon on the sample surface and oxygen and silicon on the surface is confirmed by etching bombarded SIMS (Table 3). There is a slight difference in the x-ray detection. The silicon and Fe peaks and Ni atoms in the sample are also detected, similar to a report of transition metal on the surface of the sample. This may be due to the silicon line changing the characteristic of the sample. Nonetheless, after normalizing the SIMS results by multiplying the metal concentration observed on samples #2 and #3 by two, there is a big difference between samples #1 and #2.

The methodology in the surface analysis concentration using the silicon line and TxFh is very significant. It should be stressed that C, O, and N were implanted and not analyzed, as described in Table 2, Al, and O were implanted and not analyzed, as described in the results and discussion sections.

Table 2. C, A1, and N, Fe determined by TxFh

<table>
<thead>
<tr>
<th>Sample</th>
<th>C</th>
<th>A1</th>
<th>Fe</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>8 x 10^6</td>
<td>3 x 10^6</td>
<td>4 x 10^6</td>
<td>5 x 10^6</td>
</tr>
<tr>
<td>Si</td>
<td>2 x 10^6</td>
<td>3 x 10^6</td>
<td>2 x 10^6</td>
<td>3 x 10^6</td>
</tr>
</tbody>
</table>

3. Steady-State Direct-Carrier PIII

When semiconductor devices are implanted by ion implantation (III), applications such as the silicon on insulator (SOI) by hydrogen PIII is currently only being realized on the x-ray surface of the sample. It is important to note that the other surface of the sample does not use only determines the efficiency of the process and plasma storage but also gives rise to metallic contamination. In addition, low energy ion is used for plasma breath propagation, plasma-time, and plasma-full penetration type large surface hydrogen incorporation that creates surface damage and affects the carrier binding efficiency. We have previously determined current PIII systems (PPI-III) which maintain the wafer temperature constant without introducing low energy ion component, with the wafer for the exposure pressure analysis and other factors as conductive coating that is not limited by the vacuum chamber and power analyzer [9]. Recently, we conducted hydrogen PIII experiments using a conduction grid placed between the wafer surface and a multilayer narrow current collector (CCS) plasma system. As shown in Fig. 1, the grounded grid stops the propagation of the plasma beam thereby removing the vacuum chamber from the plasma. Three are located in the plasma system by an external plasma source above the grid and shielded through the lower tube to be implanted.
Comparison of the hydrogen depth profiles of the DC-PILI and pulsed PILI samples acquired by SIMS is presented in Fig. 2. The surface hydrogen content decreases from 65.2% to 58.9% compared to pulsed PILI, as low-energy ions sputtering the initial implantation propagation and the rise and fall times of the pulse voltage are mitigated substantially. It should be noted that the total dose required for pulsed PILI is higher because much of it is actually hydrogen that does not contribute to the front unique structure. In other words, the “visible” fraction of the implanted hydrogen ions is larger in DC-PILI and a lower total dose will suffice in this case. The residual surface hydrogen on the DC-PILI sample originates from surface attenuation that can be further reduced by biasing the sample with a DC voltage before the plasma is ignited. Since DC-PILI is more efficient than pulsed PILI, the total exposure time to the plasma in shorter time, and the total amount of absorbed hydrogen also decreases. Our experiments took 3 minutes, but with improved treatments and sufficient sample cooling, the experiments could have been completed in a fraction of the time. Our study experimentally demonstrates that by using a repeat-pulse ECR source, uniform hydrogen plasma immersion ion implantation can be performed efficiently in the DC-mode.

4. Blue Light Emission

Porous silicon has been shown to exhibit efficient, visible, and deep ultraviolet photoluminescence (31). Various kinds of porous silicon emitting light ranging from red to blue have been fabricated. However, strong photoluminescence emission is generally in the red-green region, and blue light emitting porous silicon material is difficult to prepare. Because porous
silicon giving off blue light has large penalty, the material is very fragile and difficult to synthesize by crystallizing in HP solution. Some approaches, such as high temperature annealing [38], boiling water treatment [37], and spark-erosion [60] have been attempted. The objective of these methods is the same, that is, to reduce the size of silicon nanocrystals to further enhance the band gap of Si, but unfortunately, the emission intensity is weak, and the stability and reproducibility are poor.

The effects of implantation on the luminescence of porous silicon have been studied [41,42]. The results show that implanting a small dose of donor atoms such as B and P results in or even increases the continuous-wave photoluminescence intensity and increases the time dependent photoluminescence decay time, while high dose donor implantation matches the photoluminescence efficiency [42]. In these papers, blue emission was not reported. Linio et al. [45] reported that porous SiC on crystal Si could be obtained by annealing. C-implanted silicon and blue light emission could result. However, there have been no reports on the luminescence of porous silicon implanted with carbon. In our recent work, porous silicon was implanted with carbon by plasma immersion ion implantation (PIII) and the luminescence properties of samples implanted at different temperatures were investigated. Our results show that intense blue light is emitted from carbon plasma implanted porous silicon after annealing at 450°C for 30 minutes.

Based on TRIM calculation, the projected range (Rp) of C+ in single crystal silicon is 31.667 nm, but should be larger in porous silicon. Based on the Rutherford backscattering (RBS) results acquired from the as-implanted sample, the implanted carbon is distributed from the surface to a depth of 70nm. Therefore, the excitation light used in this experiment passes through the implanted layer. Fig. 3 depicts the room temperature PL spectra of the porous silicon before and after carbon PIII using an excitation wavelength of 257nm. It can be observed that the as-implanted porous silicon emits orange light with the peak at the radiation at 608nm, and the light is intense enough to be observed with the naked eyes. After implantation, the orange-light peak disappears completely and the results are consistent with reports in the literature [41,42]. Furthermore, in our PL spectrom, a peak at 450nm appears after implantation, but the amplitude of the peak is quite small.

Damage is inevitably created by implantation, and so we annealed the sample at different temperature. As shown in Fig. 4, after annealing for 30 minutes at 400°C, the PL intensity increases substantially and exceeds that of the orange light central from the as-implanted porous silicon illustrated in Fig. 3. This broad peak usually comprises four overlapping peaks with the strongest one located in the blue region. The PL intensity decreases with higher annealing temperature from 400°C to 1000°C. After annealing at 1000°C, the intensity of luminescence is very small and the location of the main intense peak has changed. Upon further annealing at 1250°C, the PL intensity rises again.

Fig. 3: PL spectra of porous silicon before and after implantation.

Fig. 4: PL spectra of implanted porous silicon annealed at different temperatures.

The results of Brag et al. [42] show that annealing can restore the PL intensity initially. From our PL spectra, the orange-light peak does not reappear even after high
temperatures arising, and so it is believed that the disappearance of the orange light is not caused by photolysis and is not due to the emission of a luminous respective which would produce a red fluorescence of the same order of magnitude as that observed in the case of sodium in sodium vapor. However, the quenching of the orange light and the occurrence of the similar light may be due to the presence of the new substance which has been identified as the sodium in sodium vapor. According to the present experimental evidence, the fundamental basis of the new light phenomenon is the result of the interaction of the light absorbed by the sodium atom with the sodium vapor.