# List of figures

**Chapter 2**


| | | |
|---|---|---|
| Fig. 1 | The secondary ion mass spectrometry result and the TRIM-calculated excess Si-atom density in multi-energy Si-ion-implanted $SiO_2:Si^+$ sample as a function of implanting depth. | 30 |
| Fig. 2 | PL spectra of the $SiO_2:Si^+/Si$ samples at (a) as-implanted condition, or annealed at 1100 °C for (b) 30, (c) 60, (d) 180 and (e) 240 min. The inset figure plots the PL spectra of (1) n-type Si substrate (2) 60-min annealed n-type Si substrate (3) $SiO_2/Si$ sample (4) 60-min annealed $SiO_2/Si$ sample and (5) as-implanted substrate. | 30 |
| Fig. 3 | Wavelength evolution of three PL peaks in $SiO_2:Si^+$ samples as-implanted or annealed at 1100 °C for different annealing times. | 31 |
| Fig. 4 | The annealing-time dependent PL intensities at different wavelengths of 415 nm, 455 nm, and 520 nm. | 31 |
| Fig. 5 | C–V hysteresis measurement of MOS diode made on (a) as-implanted $SiO_2:Si^+$ and (b) $SiO_2:Si^+$ annealed at 1100 °C for 3 h. The inset figure shows the NOV defect concentration as a function of annealing time obtained from C–V analysis. | 32 |
| Fig. 6 | Normalized TRPL spectra of $SiO_2:Si^+$ samples at (a) as-implanted condition, or annealed at 1100 °C for (b) 1.5 h, (c) 3 h and (d) 4 h. | 32 |
| Fig. 7 | EPR spectra of the $SiO_2:Si^+$ samples at as-implanted condition, and annealed at 1100 °C for 45, 90 and 180 min. | 33 |
| Fig. 8 | TRPL lifetime and concentrations of NOV and $E'_\delta$ defects in $SiO_2:Si^+$ at different annealing times. | 33 |
| Fig. 9 | CW and pulsed current-voltage measurements of $Ag/SiO_2:Si^+/n\text{-}Si/Ag$ MOS diode with $SiO_2:Si^+$ annealing at 1100 °C for 180 min. | 34 |
| Fig. 10 | The average EL power as a function of pulsed current and voltage. The inset figure shows CW (dashed line) and pulsed (dotted line) current-voltage responses of $Ag/SiO_2:Si^+/n\text{-}Si/Ag$ MOS diode with $SiO_2:Si^+$ annealing at 1100°C for 3hrs. | 34 |
| Fig. 11 | Lifetime testing of $Ag/SiO_2:Si^+/n\text{-}Si/Ag$ MOS diode under pulsed-current EL operation. The inset figure plots the operating condition of the MOS diode and its EL pattern at bias of 3 A. | 35 |
| Fig. 12 | Pulsed EL power as a function of the bias current. The inset figure is the lifetime and decaying rate of the $Ag/SiO_2:Si^+/n\text{-}Si/Ag$ MOS diode under pulsed-current EL operation. | 35 |

Fig. 13 EL patterns at different bias currents of 0.35 A (left), 1.25 A (middle) and 3 A (right). 36

Fig. 14 EL spectra of the $Ag/SiO_2:Si^+/n-Si/Ag$ MOS diode at different bias currents of 0.35 (dash line), 1.25 (dot line) and 3 A (solid line). 36

Fig. 15 Energy band diagrams of the $Ag/SiO_2:Si^+/n-Si/Ag$ structure with metal-oxide barrier potential of $\phi_m = 3.28$ V under reverse bias at 3.7 V (left part) and 5.7 V (right part). Three defect-related irradiative emissions at (a) 415 nm from the WOB defect, (b) 455 nm from the NOV defect and (c) 520 nm from the $E'_\delta$ defect. 37

**Chapter 3**

Fig. 1 PL spectra of 3-h-annealed Si-rich $SiO_x$ films fabricated by PECVD with different $N_2O/SiH_4$ ratios. The inset shows the peak intensity as a function of the $N_2O/SiH_4$ ratio. 83

Fig. 2 Room-temperature PL spectra of annealed Si-rich $SiO_x$ films fabricated by PECVD with different substrate temperatures from 100 to 350°C. The inset shows the peak intensity as a function of substrate temperature. 83

Fig. 3 PL spectra of as-grown sample A7 after annealing at 1100 °C for 1-5 h. 84

Fig. 4 Peak PL intensities of NOV defect and nc-Si, and peak wavelength of nc-Si as a function of the annealing time. 84

Fig. 5 Time-resolved PL traces of sample A7 after annealing at 1100 °C for 1, 2, and 3 h. 85

Fig. 6 PL intensity and peak wavelength as a function of $N_2O$ fluence. 85

Fig. 7 TRPL spectra of nc-Si embedded in PECVD-grown $SiO_x$ samples for different annealing time. 86

Fig. 8 Planar-view HRTEM picture of 15 min-annealed PECVD-grown $SiO_x$ film 86

Fig. 9 Size distribution of nc-Si in the 15 min-annealed PECVD-grown $SiO_x$ film 87

Fig. 10 PL spectra of PECVD-grown $SiO_x$ samples annealed from 15 to 60 min. 87

Fig. 11 Density and size distribution of nc-Si buried in annealed $SiO_x$ film as a function of annealing time. 88

Fig. 12 PL as function of annealing time at different process pressures. 88

Fig. 13 EELS spectra of pure Si, as-grown $SiO_x$ and 30 min-annealed samples. 89

Fig. 14 PL intensity and peak wavelength as a function of substrate temperature. 89

Fig. 15 EL spectra of samples prepared under different substrate temperatures. 90

Fig. 16 EL patterns of ITO/$SiO_x$:nc-Si/p-Si/Al MOSLED. 90

Fig. 17 I-V and P-I curves of ITO/$SiO_x$:nc-Si/p-Si/Al MOSLED. 91

Fig. 18 Plot of $\ln(J_G/E^2)$ as a function of 1/E for three ITO/SiOx:nc-Si/p-Si/Al MOSLEDs with their SiOx grown at (a) 300, (b) 350 and (c) 400°C. Inset: Band structure of ITO/$SiO_x$:nc-Si/p-Si MOSLED. 91

Fig. 19 Internal and external quantum efficiencies as a function of substrate temperature. 92

Fig. 20 Direct tunneling mechanism of MOS diode 92

Fig. 21 Plot of ln(J) as a function of voltage for three different ITO/$SiO_x$:nc-Si/p-Si/Al MOSLEDs with their $SiO_x$ grown at 300, 350 and 400°C and a simulated direct tunneling current (solid line). 93

Fig. 22 Fowler-Nordheim tunneling mechanism of MOS diode. 93

Fig. 23 Thermionic emission tunneling mechanism of MOS diode. 94

Fig. 24 Plot of ln(J) as a function of voltage for three ITO/$SiO_x$:nc-Si/p-Si/Al MOSLEDs with their $SiO_x$ grown at 300, 350 and 400°C and a simulated thermionic current. 94

Fig. 25 Poole-Frenkel tunneling mechanism of MOS diode. 95

Fig. 26 Plot of ln(J/E) as a function of $E^{0.5}$ for three ITO/$SiO_x$:nc-Si/p-Si/Al MOSLEDs with their $SiO_x$ grown at 300, 350 and 400°C and a simulated Poole Frankel tunneling current. 95

Fig. 27 Images of $SiO_{1.25}$ film after $CO_2$ laser annealing at $P_{laser}$ increasing from 3 to 13.5 kW/cm$^2$. 96

Fig. 28 The thicknesses of annealed $SiO_{1.25}$ films as a function of annealing time. 96

Fig. 29 Ablation thickness of $SiO_x$ as a function of $P_{laser}$. Inset: PL spectra of $CO_2$ laser annealed $SiO_{1.25}$ films at $P_{laser}$ = (a)1.5 (b)3 (c)4.5 (d)6 (e)7.5 (f)9 (g)10.5 kW/cm$^2$. 97

Fig. 30 RBS spectrum of the as-grown $SiO_{1.25}$ film on a Si substrate. 97

Fig. 31 Cross-sectional HRTEM images of $SiO_x$ $CO_2$-laser-annealed at $P_{laser}$ = 6 kW/cm$^2$. Inset: the electron diffraction pattern (lower right) of a (111)-plane Si nanocrystal (lower left). 98

Fig. 32 Transmission spectra of Quartz, as-PECVD grown $SiO_{1.25}$ film and the $CO_2$ laser annealed $SiO_{1.25}$ film at $P_{laser}$ = 6 kW/cm$^2$. 98

Fig. 33 Transmission spectra of $CO_2$ laser annealed $SiO_{1.25}$ films at $P_{laser}$ increasing from 6 to 12 $kW/cm^2$. 99
Fig. 34 Reflectance spectra of the quartz substrate, as-PECVD grown $SiO_{1.25}$ film and the $CO_2$ laser annealed $SiO_{1.25}$ film at $P_{laser}$ = 6 $kW/cm^2$. 99
Fig. 35 Reflectance spectra of $CO_2$ laser annealed $SiO_{1.25}$ films at $P_{laser}$ increasing from 6 to 12 $kW/cm^2$. 100
Fig. 36 Refractive index of $CO_2$ laser annealed $SiO_{1.25}$ film as a function of $P_{laser}$. 100
Fig. 37 PL spectra of $CO_2$ laser annealed $SiO_x$ at (a) 6 $kW/cm^2$, (b) furnace-annealing at 1100$^o$C for 30 min and $CO_2$ laser annealed $SiO_x$ at (c) 12 $kW/cm^2$. 101
Fig. 38 Plot of $\ln(J_G/E^2)$ as a function of 1/E for $CO_2$ laser-annealed and furnace-annealed MOSLEDs. 101
Fig. 39 P-I curves of (a) ITO/ $CO_2$ laser RTA $SiO_x$ /p-Si/Al and (b) ITO/ furnace-annealed $SiO_x$ /p-Si/Al MOSLEDs. Inset: Energy band diagram of a highly forward biased ITO/ $CO_2$ laser RTA $SiO_x$ /p-Si/Al MOSLED. 102
Fig. 40 EL spectra of MOSLEDs made by $CO_2$ laser RTA (lower) and furnace-annealed (upper) $SiO_x$. Inset: EL patterns of $CO_2$ laser RTA (lower) and furnace-annealed (upper) MOSLEDs. 102

**Chapter 4**

Fig. 1 Cross-sectional HRTEM photographs and corresponding electron diffraction patterns of Si-rich $SiO_x$ grown at ICP powers of 45 (upper left) and 35 (lower left) watts. (a) The cross-sectional TEM photograph of the $SiO_x$ film PECVD grown at normal ICP power. Inset: the electron diffraction pattern of the PECVD-grown $SiO_x$ film. (b) and (c): the lattice parameter and orientation of the Si nanocrystals in PECVD-grown $SiO_x$ film. (d) The cross-sectional TEM photograph of Si-rich $SiO_x$ film with dense interfacial Si nano-pyramids grown at threshold ICP power. (e) The magnified cross-sectional TEM photograph of the Si-nano-pyramid embedded Si-rich $SiO_x$/Si interface. (f) The magnified TEM photograph for a single Si nano-pyramid and its electron diffraction pattern shown in the inset. (g): The observed orientations for the Si nano-pyramid (upper part) and Si substrate (lower part). (h) and (i): the orientation of the Si nanocrystals in the PECVD-grown Si-rich $SiO_x$ film at threshold ICP-power condition. 127

Fig. 2 The plots of $\ln(I/E^2)$ as a function of $1/E$ for three MOSLED samples with their $SiO_x$ films PECVD grown at different ICP powers. 128
Fig. 3 Threshold F-N tunneling electric field as a function of the area density of Si nano-pyramids. 128
Fig. 4 The energy band diagrams of a highly biased MOSLEDs using $SiO_x$ grown at different PECVD conditions. Left: the $SiO_x$ grown at normal ICP power without Si nano-pyramids but with dense interfacial radiant defects. Right: the $SiO_x$ grown at threshold ICP power with Si nano-pyramids at the $SiO_x$/Si interface. 129
Fig. 5 The I-V and I-P curves of the ITO/$SiO_x$/p-Si/Al MOSLEDs with $SiO_x$ films grown at different ICP powers. Upper: ICP power of 45 W. Middle: ICP power of 40 W. Lower: ICP power of 30 W. 129
Fig. 6 TEM images of nc-Si within the annealed $SiO_x$ film grown without (left) and with (right) interfacial Si nano-pyramids. 130
Fig. 7 EL spectra of ITO/$SiO_x$/p-Si/Al MOSLEDs with (solid) or without (dashed) interfacial Si nano-pyramids. 130
Fig. 8 EL patterns of three MOSLED samples without (upper) and with Si-nano-pyramid concentrations of $\rho=10^9/cm^2$ (middle) and $\rho=10^{11}/cm^2$ (lower). 131
Fig. 9 Output power stability of three MOSLED samples with different Si-nano-pyramid concentrations. 131
Fig. 10 SEM image of Ni nano-dots precipitated from the evaporated Ni film on $SiO_2$/Si with different film thickness. 132
Fig. 11 SEM image of Si nano-pillars formed after ICP-RIE with different RF/Bias power recipes. 132
Fig. 12 Density and average diameter of Si nano-pillars on Si substrate as a function of RF/Bias power ratio in ICP-RIE system 133
Fig. 13 (a) Micro-PL spectrum of as-made Si nano-pillar array. (b) Normalized PL spectra of unprocessed pure Si wafer and etched Si nano-pillar. (c) Si nano-pillar related PL and pure Si PL spectrum. (d) PL spectra of etched Si nano-pillars. 133
Fig. 14 Peak wavelength of Si nano-pillar as a function of rod size. Inset: Plan-view SEM picture of etched Si nano-pillars. 134
Fig. 15 (a) SEM image of Ni nano-dots precipitated from the evaporated Ni film on $SiO_2$/Si. (b) SEM image of Si nano-pillars formed after ICP-RIE with RF/Bias power recipe of 50/100W. (c) Device structure of a silicon nanocrystal based MOSLED on Si nano-pillar array. (d) An ITO/$SiO_x$/Si/Al diode with a circular contact diameter

of 0.8 mm.

Fig. 16 Normalized PL spectra of nc-Si based MOSLEDs (a) without and (b)with Si nano-pillars. Normalized EL spectra of nc-Si based MOSLEDs (c) with and (d) without Si nano-pillars. 135

Fig. 17 I-V and I-P curves of nc-Si based MOSLEDs with/without Si nano-pillars. Inset: EL pattern of nc-Si based MOSLED with Si nano-pillars. 135

Fig. 18 The ratio of the EL power from nc-Si MOSLED made on Si nano-pillar to that made on smooth Si wafer at different biased current. 136