Post thermal annealing effect on optical properties of a-Si:H/SiO_2 multilayer thin films for Bandpass Filter

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Abstract- The a-Si:H/SiO_2 multilayer thin films for Bandpass filter (BPF) have been grown on D263T (SiO_2) substrates using RF-magnetron sputtering deposition with deposition parameters, P= 5X10^{-04}, RF=13.56MHz, t=3168.40s, O_2/H_2 flow rates 280/45 sccm, and thickness of 1800 nm. The transmittance and thickness of the multilayer thin films were measured before annealing treatment. The films were annealed with temperature of 450 and 500°C for 15, 30 and 45 minutes, respectively in vacuum chamber with the pressure of 10^{-2} mbar. The transmittance of the films exhibits a constant value for 920 nm – 960 nm and shows a bandpass filter behavior. Then, the bandpass spectrum slightly shifted to the higher frequency region after 450°C annealing and shifted to the further higher frequency region after 450°C annealing. Meanwhile, the transmittance of the films also significantly shifted to the higher frequency region as the annealing time increases. There were increases in film thickness when annealed at both 450°C and 500°C as annealing time increases. The TFC software simulation results revealed that increase of thickness on the films caused the transmittance shifted to the righter frequency region which was in accordance with our study. Increase of film thickness might be resulted from Si-O variation of SiO_x in the Si/SiO_2 interface. The value x was found to increase which was induced by the more stoichiometric and thicker as the anneal temperature and time increase. The phenomenon was ascribed to the cooperation of hydrogen effusion and reordering of the Si-O bonds of SiO_x networks in the interfaces.

Keywords – a-Si:H/SiO_2 multilayer thin films, annealing, thickness, transmittance, TFC calc.

I. INTRODUCTION

Hidehiko Yoda [1] examined the optical properties of a-Si:H/SiO_2 multilayer films using RF-magnetron sputtering for optical band pass filters (BPFs). Because of high refractive index contrast between a-Si:H and SiO_2, which was defined as the high index of one material divided by the low index of another, total number of layers of an a-Si:H/SiO_2 multilayer could be relatively small to about 27 layers. Goh Boon Tong [2-5] in his study of post-thermal annealing effect on optical, structural, and morphological properties of a-Si:H fabricated by Layer-by-Layer deposition showed that LBL films have a highly ordered film structure with clusters of highly ordered Si nano-structures scattered within the amorphous matrix of film structure which break down when annealed at 200 °C and above as H atoms are released from Si bonds in film structure, reduction of H content in the film also contribute to increase in refractive index of film, decrease in optical energy gap and thickness of film, and a more compact but highly stressed film structure. F.V. Grigoriev [6-8] study post thermal annealing effect of Ion Beam Sputtering deposited SiO_2 thin films and found that the film density is reduced for about 0.15 g/cm3 under annealing with the temperature of 1300 K and was correspond with reduction of refractive index of approximately 0.03. The stress value essentially reduces after annealing at 1300 K and the film thickness increases for 3nm. Mei Jia-Xin [9], step-by-step thermal annealing treatments were performed on a-Si:H/SiO_2 multilayer film fabricated by PECVD and studied by FTIR, it was found that Si-O vibration from interfacial SiO_x was identified: the value x was found to increase (become more stoichiometric and thicker) as the anneal temperature increase, which was ascribed to the cooperation of hydrogen effusion and reordering of the oxygen bond in SiO_x networks. The H atoms bonded in different bonding configurations effused at different temperature due to their different desorption energies. In this study, we fabricated a-Si:H/SiO_2 multilayer thin films for Bandpass Filter using RF-magnetron sputtering deposition technique with total of 19 layers. Then, the films were annealed with temperature 450 and 500 ^{o}C for 15, 30 and 45 minutes respectively and the post thermal annealing effect on optical properties of the films were analyzed.

II. EXPERIMENTAL

The a-Si:H/SiO_2 multilayer thin films for Bandpass Filter was deposited using RF-magnetron sputtering technique, with deposition parameter P= 5E-04, RF=13,56 Mhz, and t=3168,40 s, O_2 & H_2 flowrate 280 and 45 sccm respectively, a total layer of 19 layers and total thickness of 1800 nm. The substrates D263T (SiO_2) with 0.3mm thickness and size of 8 x 8 cm, were ultrasonically cleaned in the 4 Deionized (DI) water tanks and 3 IPA tanks each for 3 min successively. The transmittance of the film was analyzed using UV-VIS Spectrophotometer, and the total thickness of the films were measured using a-step profilometer before annealed. The films were annealed in temperature of 450^{o}C and 500^{o}C for 15, 30 and 45 min respectively in vacuum chamber with pressure 10^{-2} mbar. The transmittance and thickness of the multilayer films were then measured again to analyze the effect of post thermal annealing to the transmittance and thickness of the films. In this study, we added the simulation using TFC calculator to observe the effect of changing in film thickness on the transmittance of the film and compared the simulation results with our study.

III. RESULTS AND DISCUSSION

Figure 1 showed the design of a-Si:H/SiO_2 multilayer film as bandpass filter compared with the as-grown of the film prepared by RF-magnetron sputtering deposition. Before fabricating our bandpass filter multilayer film, we did simulation using TFC calculator, choosing Si:H/SiO_2 as our material (because of high refractive index contrast) and had our multilayer film designated for 920 nm - 960 nm with transmittance over 98%. As revealed, the transmittance of the as-grown films was almost the same with the designated film (red-shifted 2 nm), with the transmittance over 90% for the bandpass filter wavelength. The transmittance was not in accordance with the simulation result because the multilayer films were one-sided coating.

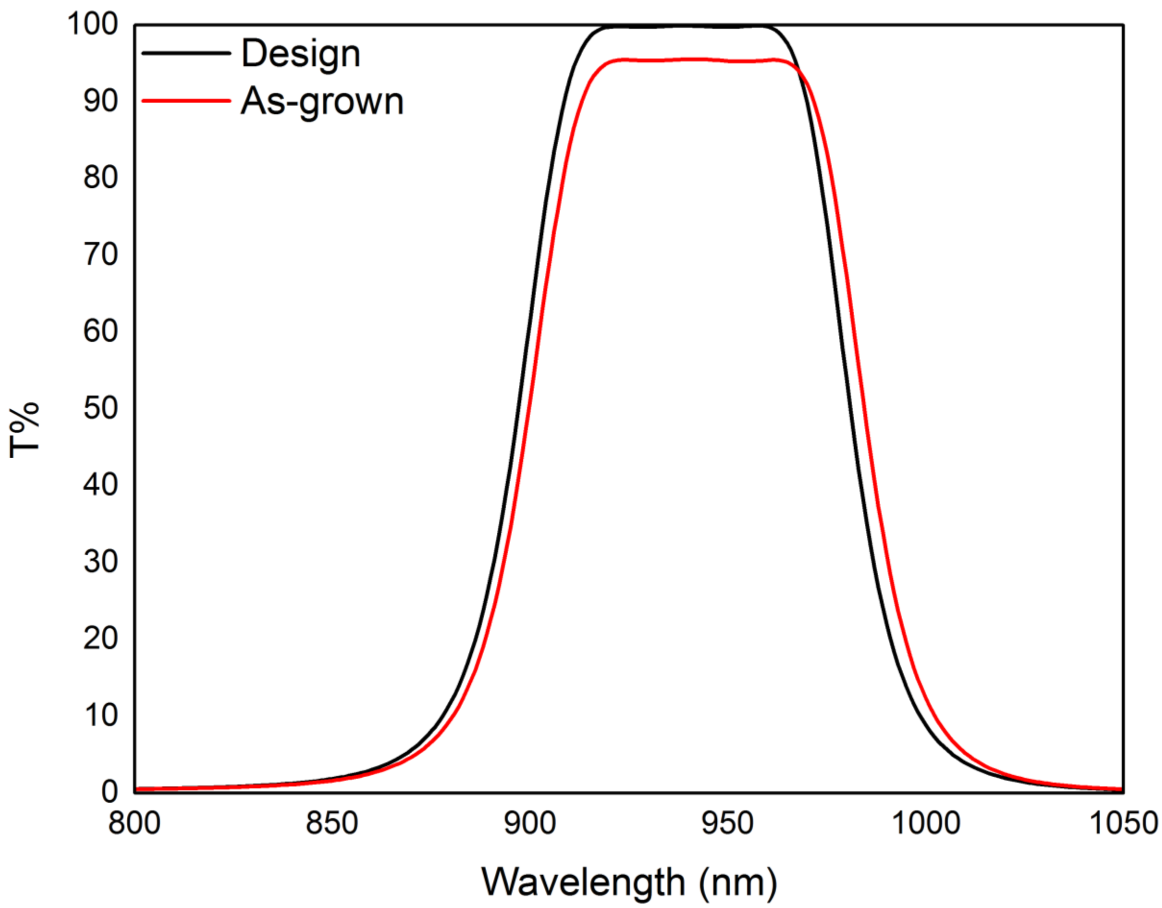

Figure 1. The designated a-Si:H/SiO2 multilayer films for bandpass filter compared with the as-grown of the film.

Figure 2 (a-f) showed the transmittance of the films before and after annealed with temperature of 450^{o}C (a-b-c) and 500^{o}C (d-e-f) for 15, 30 and 45 min respectively. The transmittance of the films for bandpass filter wavelength (920nm–960nm) remained constant (T% > 94%) but gradually shifted to the right (shifted up to 2 nm) when annealed with temperature of 450^{o}C but increase significantly when annealed with temperature of 500^{o}C (shifted up to 4 nm). The red shifted of the films were in accordance with our simulation results which was because of increase in the thickness of the films.

Figure 3 showed the transmittance of the films before and after annealed when annealed for 45 minutes for temperature of 450^{o}C and 500^{o}C. The transmittance of the films remained constant (T% > 94%) for bandpass filter wavelength but shifted to the right as the anneal time increase to 45 minutes. The transmittance of the films red-shifted significantly when annealed with temperature of 500^{o}C (up to 4 nm). The red shifted of the films were in accordance with our simulation results which was because of increase in the thickness of the films.

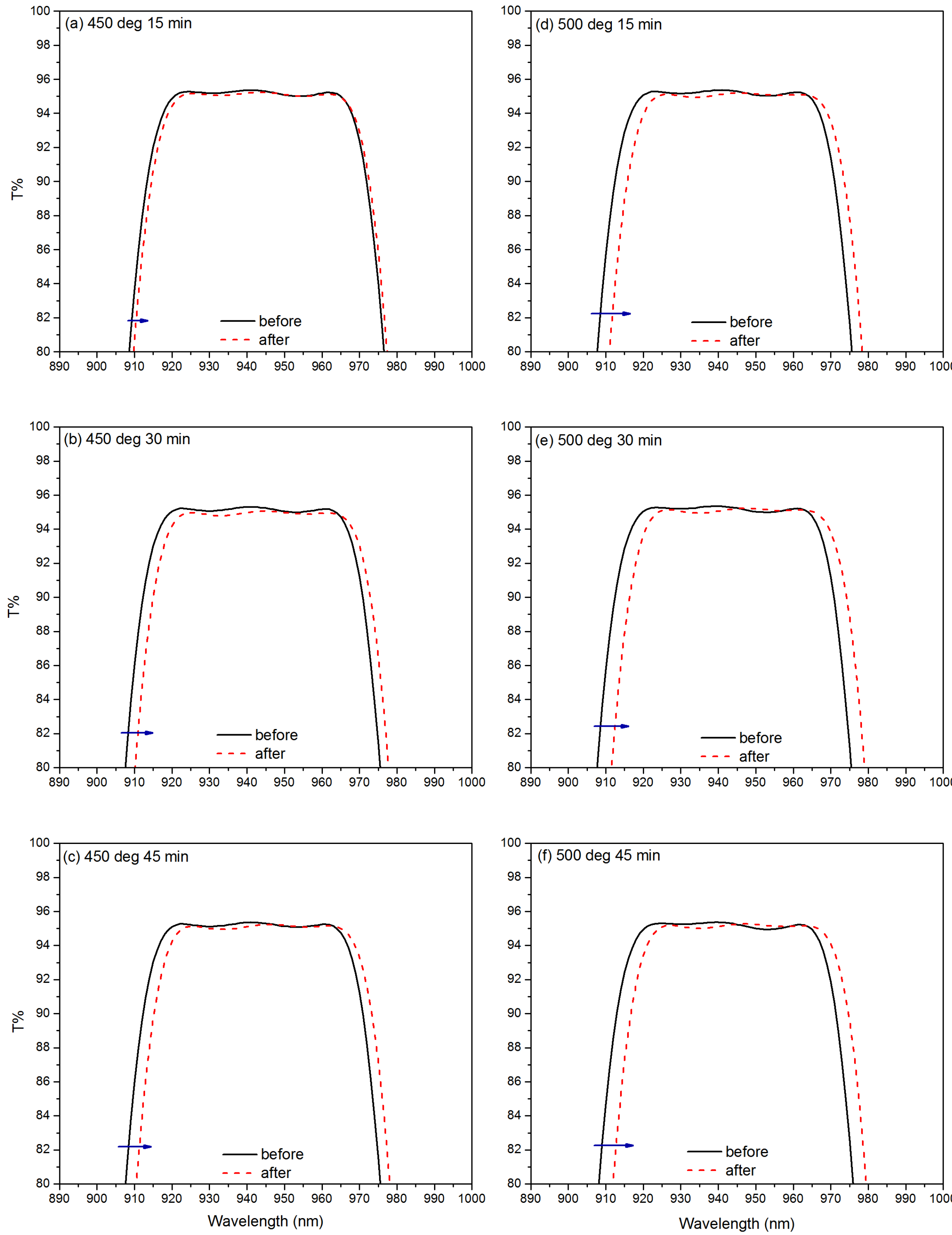

Figure 2. Transmittance graph of the multilayer films as grown and when annealed with temperature of 450ºC (a-c) and 500ºC (d-f) for 15, 30 and 45 minutes, respectively.

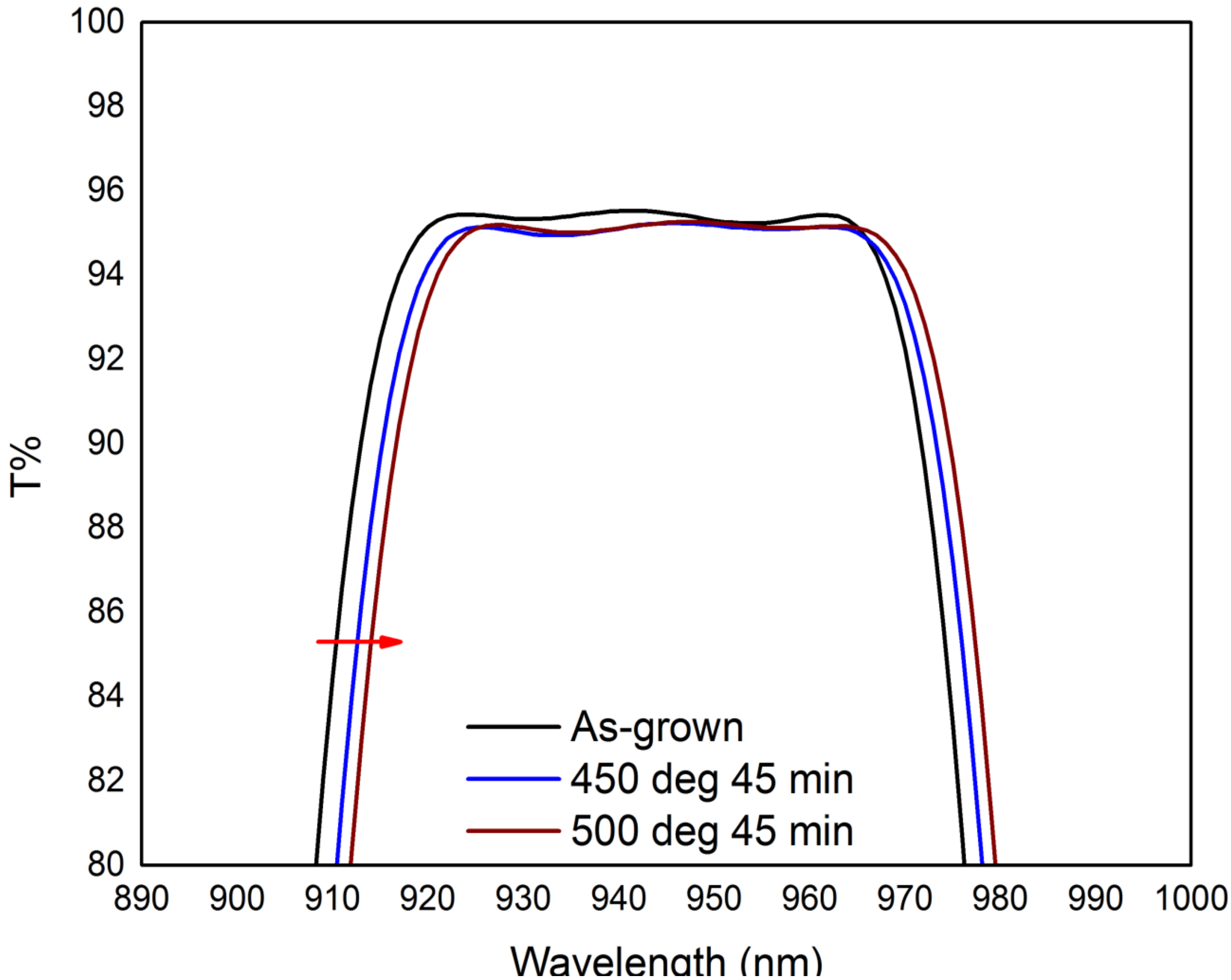

Figure 3. Transmittance graph of the multilayer films as grown and when annealed with temperature of 450°C and 500°C for 45 minutes.

Figure 4 showed difference in thickness before and after annealed with temperature of 450°C (a) and 500°C (b) for 15, 30 and 45 minutes respectively. The graphs revealed that there were an increase of 3% in thickness of the multilayer films (20-60nm thicker than the initial thickness 1800 nm) when annealed with temperature of 450 and 500°C as annealed time increase. The increase in multilayer film thickness might be in accordance with Mei Jia-Xin's paper [9], step-by-step thermal annealing treatments were performed on a-Si:H/SiO_2 multilayer film fabricated by PECVD and studied by FTIR, there were Si-O variation from interfacial SiO_x, the value x was found to increase (become more stoichiometric and thicker) as the anneal temperature and time increase, which was ascribed to the cooperation of hydrogen effusion and reordering of the oxygen bond in SiO_x networks whereas H atoms bonded in different bonding configurations effused at different temperature due to their different desorption energies.

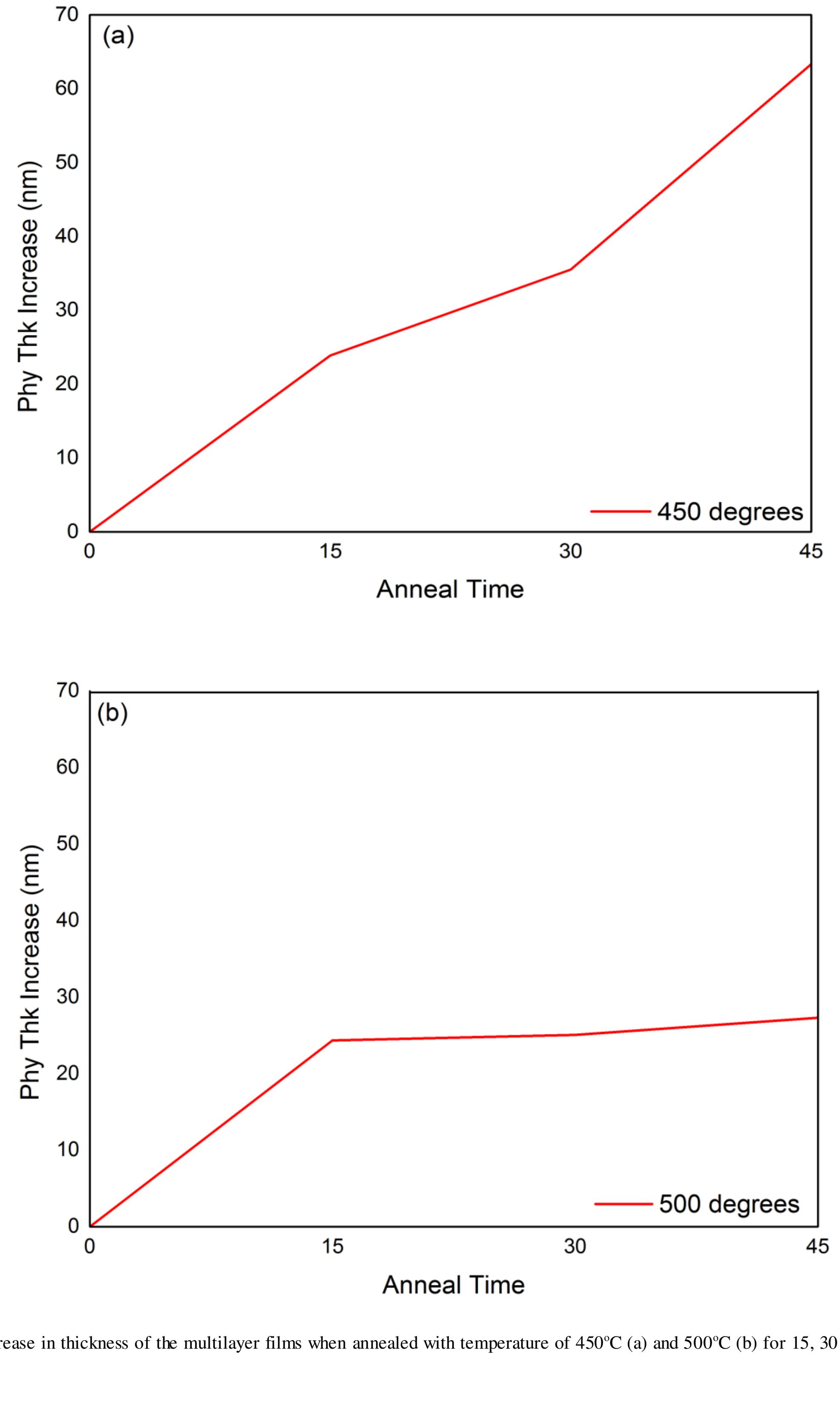

Figure 4. Increase in thickness of the multilayer films when annealed with temperature of 450ºC (a) and 500ºC (b) for 15, 30 and 45 minutes respectively.

Figure 5 showed the simulation results with TFC calculator. Increase in Si:H layers thickness were not bound to happen since H atoms bonded in different bonding configurations effused at different temperature due to their different desorption energies, therefore, we prepared the simulation of SiO_2 thickness difference effect to the transmittance of a-Si:H/SiO_2 multilayer films. Here, SiO2 layers were originally *1, then we did simulation, SiO2 layers *0.98 or *0.995 (decrease thickness) and *1.005 or *1.04 (increase thickness). It was found that as SiO_2 thickness increase, the transmittance of the films shifted to the right, and vice versa. It was also found that if SiO2 layers thickness increase or decrease a lot, then there would be changing in the shape of the transmittance as it was shown in SiO2 layers *1.04 (The shape of the transmittance in the bandpass wavelength was supposed to be flat), and the bandpass wavelength was shifted to undesired wavelength.

Figure 6 showed the simulation of SiO_2 layers thickness increase compared with as-grown and post thermal annealing of a-Si:H/SiO_2 multilayer thin films when annealed with temperature of 500°C for 45 min. The simulation results were in accordance with our post-thermal annealing study, which is increase in SiO_2 layer thickness affect the transmittance of the film shifted to the right. As the reason for the increase in the thickness of the films was already explained above in Mei Jia-Xin [9] report.

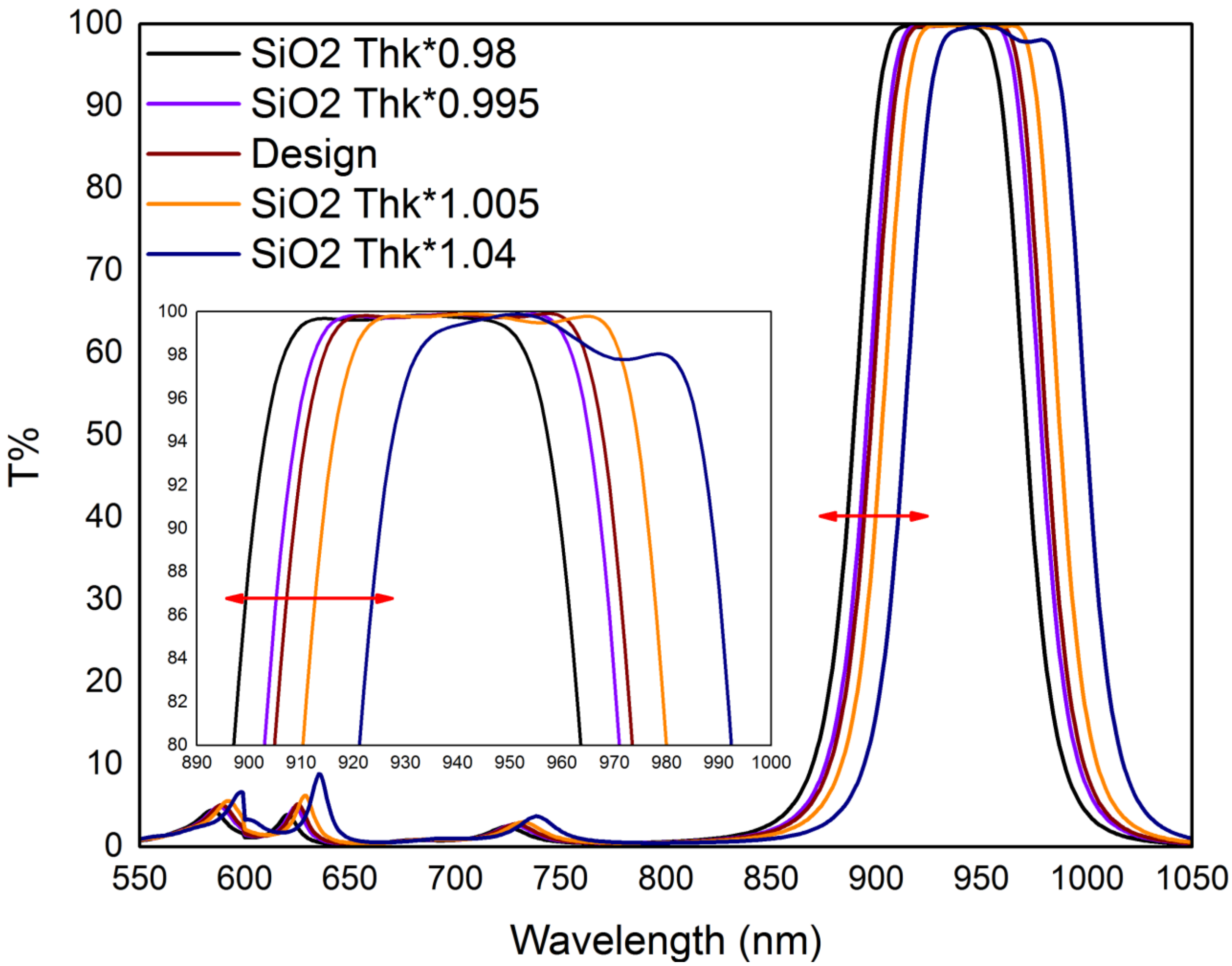

Figure 5. TFC calculator simulation results revealed that increase in thickness of SiO_2 effect the transmittance of a-Si:H/ SiO_2 multilayer films.

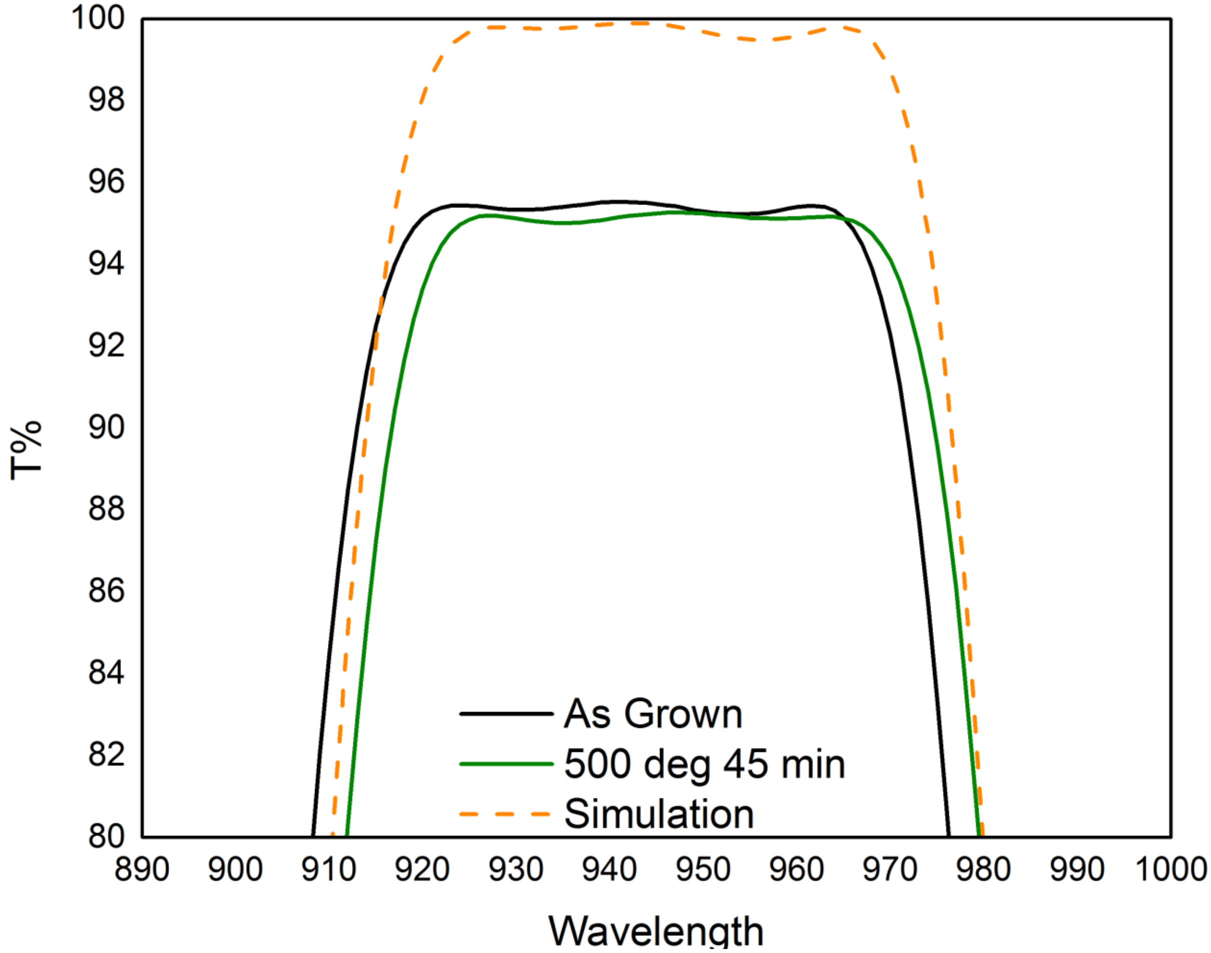

Figure 6. TFC calculator simulation result showed simulation of thickness increase compared with as-grown and post thermal annealing of a-Si:H/SiO_2 multilayer thin films.

IV.CONCLUSION

The effect of post-thermal annealing on the optical properties of RF-sputtered a-Si:H/SiO_2 multilayer thin films for optical bandpass filter are investigated in this study. The transmittance graph remained constant at T% > 94% but gradually shifted to the right (shifted up to 2 nm) when annealed with temperature of 450^{o}C and significantly shifted to the right (shifted up to 4 nm) when annealed with temperature of 500^{o}C. The transmittance of the films was also significantly shifted to the right as the annealed time increase. There were increases for up to 3% (20-60nm thicker than the initial thickness1800 nm) in the thickness when annealed with temperature of 450 and 500^{o}C as annealed time increase. The post-thermal annealing effect of the films, red-shifted of the transmittance and the increase in thickness of the films, were in accordance with the simulation results using TFC calculator, which was prove that increases in thickness of the films will cause the transmittance of the films red-shifted. Whereas the increase of the multilayer films thickness might because of Si-O vibration from interfacial SiO_x, the value x was found to increase (become more stoichiometric and thicker) as the anneal temperature increase, which was ascribed to the cooperation of hydrogen effusion and reordering of the oxygen bond in SiO_x networks whereas H atoms bonded in different bonding configurations effused at different temperature due to their different desorption energies [9].

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