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# Enhanced Visible Light and Electron Field Emission of Porous Silicon Nanowires

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## 1. Introduction

Vertical-aligned Porous silicon nanowires (SiNWs) with a porous-like surface were prepared by a two-step etching process. Strong orange-red light emission at around 670 nm were observed, which is primarily due to a strong enhancement in quantum confinement effect [1] arising from the nano-scaled porous morphologies of SiNWs. The porous SiNWs also demonstrated better field emission (FE) characteristics as compared to those without porous surface (i.e., non-porous SiNWs). A turn-on field intensity ($E_{on}$) of 2.7 V/μm, an emission current density up to 1 mA/cm$^2$ at around 5.83 V/μm, and an enhancement factor (β) [2] of around 3102 were achieved from SiNWs after subjected to a 3-min etching to form porous surface. The changes in wire density, aspect-ratio, and work function of electron emitting from wire to vacuum might be responsible for the improved FE properties.

Silicon nanowires (SiNWs) have been the focus of much attention for having many unique properties, including high electrical conductivity, chemical stability and superior electron FE characteristics [3]. It is expected that SiNWs with good emission characteristics would be a potential applications on vacuum microelectronic and flat panel displays. Various techniques including chemical physical deposition, laser ablation, thermal evaporation, and electroless etching methods [4], etc., have been proposed to fabricate SiNWs. In this study, a two-step etching method was proposed for the fabrication of vertical-aligned porous SiNWs to further enhance quantum confinement effect. Improved photoluminescence (PL) and FE properties were obtained from the prepared porous SiNWs as compared to the non-porous SiNWs.

## 2. Experiments

Figure 1 illustrates key fabrication processes flow of porous SiNWs. P-type Si (100) wafers were wet etched first using an HF/$AgNO_3$ solution at 50$^o$C for 1 hour. As shown in Figs. 1(a)-1(c), after the etching process, the samples were dipped into $HNO_3$ for 10 s and rinsed in DI water to detach the dendritic silver structures on the surface. To enhance the quantum confinement effect of SiNWs, these samples were undergone a second step wet etching (abbreviated as SE) using a solution of HF/$HNO_3$ at 35°C (Fig. 1(d)).

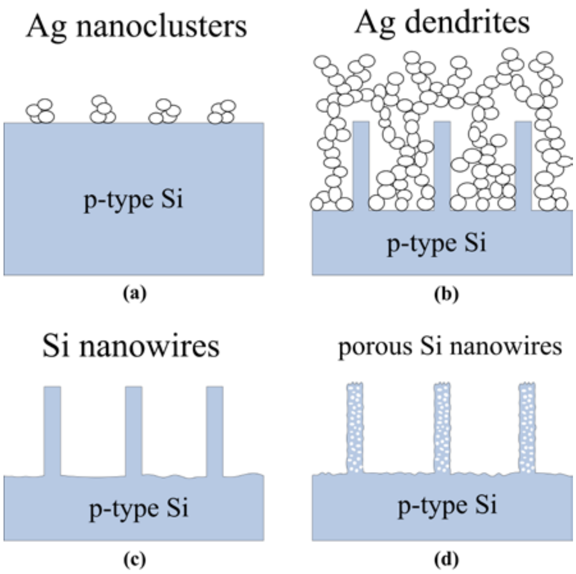


Fig. 1 Key fabrication processes flow of porous SiNWs.

## 3. Results and discussion

Figures 2 and 3 show the SEM images of the prepared samples. Vertical aligned crystalline SiNWs with diameters of about 0.05~2 μm and lengths of about 18~30 μm were formed. Figures 2(b)-2(d) show the SEM images of SiNWs after subjected to SE for 3, 6, and 9 min, respectively. It is seen that the surfaces of SiNWs after a 3-min SE (Fig. 2(b)) showed no obvious change but with a relatively shorter length. While for the samples after SE for 6 and 9 min, the surfaces of SiNWs (Fig. 1(c)) showed porous-like with its length and density further reduced.

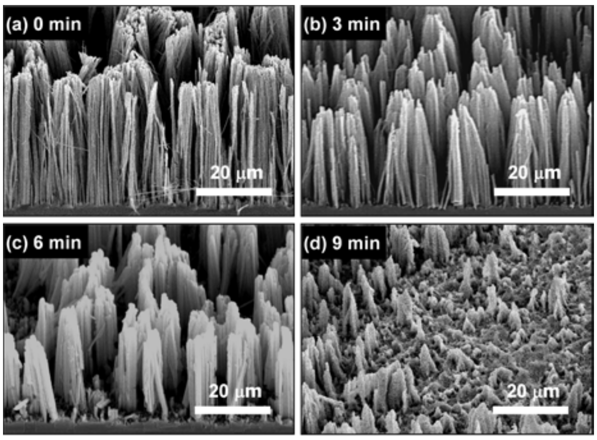


Fig. 2 SEM images of SiNWs without and with SE.

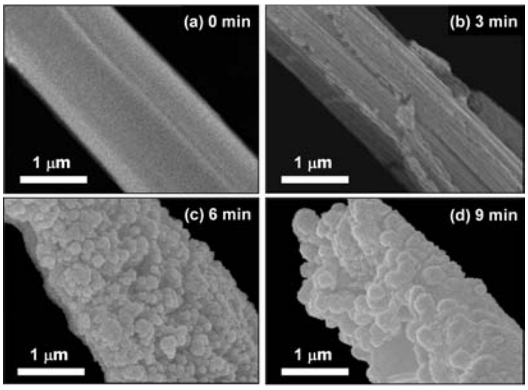

Fig. 3 High magnification SEM images of prepared SiNWs without and with SE for different etching times.

Figure 4 shows the PL spectra of the prepared SiNWs with and without SE as excited by a He-Cd laser (325 nm). The photos of the samples illuminated under sunlight and ultraviolet (UV) light (254 and 366 nm) were shown in Fig. 5. It is interesting to see that all the SiNWs subjected to SE show orange-red light emission in the range of 670~680 nm under UV illumination. Note that the peak wavelength of light emission decreases with increasing the SE time, suggesting the quantum confinement effect of SiNWs could be further enhanced through a longer SE. Our results reveal that the SiNWs with 6-min SE exhibit the highest PL intensity. Such orange-red light emissions might be ascribed to the quantum confinement effect of the SiNWs, which has been enhanced by the SE.

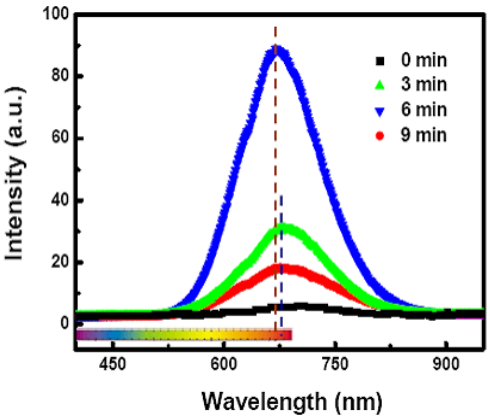

Fig. 4 The PL spectra of SiNWs with and without SE as excited by a He-Cd laser (325 nm).

Figure 6 shows the typical FE characteristics of SiNWs with and without porous-like surface. The inset shows the corresponding Fowler-Nordheim (F-N) plots. Note that the porous SiNWs obtained from 3-min SE etching exhibit the best FE performance (a turn-on field intensity of 2.7 V/μm, an emission current density up to 1 mA/cm$^2$ at around 5.83 V/μm, and an enhancement factor of around 3102) among all samples. The improvement of FE characteristics should be attribute to the fact that a suitable density, tip structure, and work function for electron emission have been modified by the SE etching. It is expected that the visible light emission and FE performance of the porous SiNWs can be further improved once the optimization for the fabrication processes is obtained.

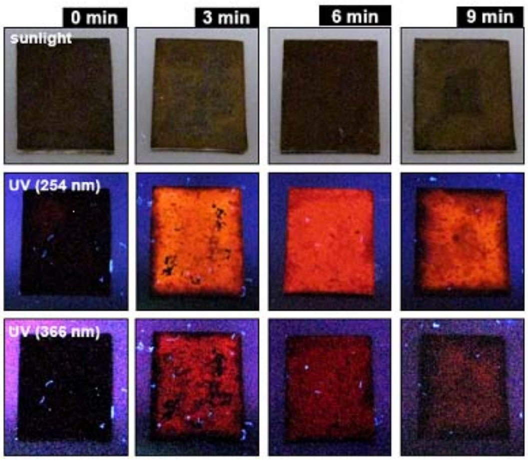

Fig. 5 The photos of SiNWs illuminated under sunlight and UV lights (254 and 366 nm).

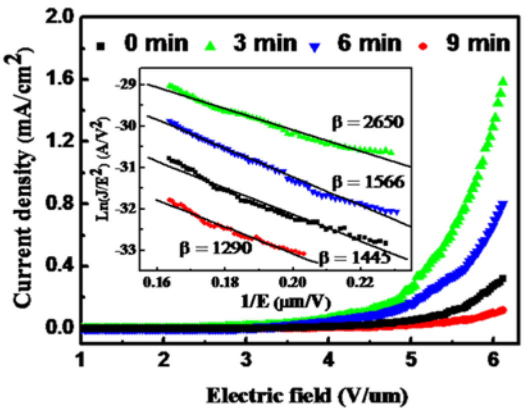

Fig. 6 The J-E curves of the SiNWs with and without SE. The inset shows the corresponding FN plot ((ln(I/V$^2$) vs. 1/V) curves).

## 4. Conclusion

In this study, we have reported the preparation of well ordered vertical aligned porous SiNWs using a two-step etching method. Improved FE (with reduced Eon and improved β and emission current), and strong PL and visible light (orange-red) emission (670 nm) have been demonstrated from the prepared porous SiNWs. It is expected that porous SiNWs with the merits of high aspect-ratio and high surface-to-volume ratio could be a potential material for the applications of FE emitters, UV detectors, and solar cells.

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## Reference


[1] T. Takagahara et al, Physical Review B. **46** (1992) 15578.
[2] B. S. Satyanarayana et al, Appl. Phys. Lett. **71** (1997) 1430.
[3] B. Q. Zeng et al, Appl. Phys. Lett.. **88** (2006) 213108.
[4] K. Peng et al, Adv. Mater. **16** (2004) 73.