Published in final edited form as:

J Mater Chem. 2010 ; 20(18): 3590–3594. doi:10.1039/c0jm00493f.

Photocatalytic Properties of Porous Silicon Nanowires

Yongquan Qu^a, Xing Zhong^a, Yujing Li^b, Lei Liao^a, Yu Huang^{b,c}, and Xiangfeng Duan^{*,a,c}

^aDepartment of Chemistry and Biochemistry, University of California, Los Angeles, CA 90095

^bDepartment of Materials Science and Engineering, University of California, Los Angeles, CA 90095

^cCalifornia Nanosystems Institute, University of California, Los Angeles, CA 90095

Abstract

Porous silicon nanowires are synthesized through metal assisted wet-chemical etch of highly-doped silicon wafer. The resulted porous silicon nanowires exhibit a large surface area of 337 m²·g⁻¹ and a wide spectrum absorption across the entire ultraviolet, visible and near infrared regime. We further demonstrate that platinum nanoparticles can be loaded onto the surface of the porous silicon nanowires with controlled density. These combined advancements make the porous silicon nanowires an interesting material for photocatalytic applications. We show that the porous silicon nanowires and platinum nanoparticle loaded porous silicon nanowires can be used as effective photocatalysts for photocatalytic degradation of organic dyes and toxic pollutants under visible irradiation, and thus are of significant interest for organic waste treatment and environmental remediation.

1. Introduction

Porous materials have attracted considerable interest due to the potential applications in broad areas including catalysis, integrated optics, energy harvesting and biotechnology.¹⁻⁶ For example, porous materials are widely used as supports for catalysts because of the abundant pores, large surface areas and the ease of recycling compared to nanopowders. Recently, porous materials have also been regarded as a promising candidate in solar energy harvesting with the development of synthetic routes to new types of porous materials, especially porous TiO₂.^{1,7-10} TiO₂ is one of the most widely used photocatalysts because of its exceptional stability towards chemical and photochemical corrosion. Previous investigations have recognized porous TiO₂ as a promising photocatalyst material for total destruction of common organic pollutants.¹¹⁻¹⁵ However, the effective photoexcitation of TiO₂ requires the irradiation in the ultraviolet (UV) region due to its large band gap (3.2eV), which leads to a merely 5% of solar energy absorption.^{16,17} Considerable efforts have been devoted to improving TiO₂ photocatalytic performances in the visible light range. Such efforts include nitrogen, phosphate or fluorine doping, transition metal ions doping and surface modification with dyes or quantum dots.^{11-15,18-25} However, significant challenges remain to render the absorption of the modified TiO₂ materials spanning across the entire visible light range.

Recently, synthetic approaches toward single crystal porous silicon nanowires (SiNWs)^{26,27} have been developed. Such nanowires are obtained through a metal-assisted electroless wet chemical etching approach, and exhibit a broad visible emission centered around 650 nm. The emission in the visible range could be attributed to the deep quantum confinement and/or complex surface electronic states in the porous SiNWs. These studies suggest excitons generated within the porous SiNWs could be energetic enough to drive applicable photoelectrochemical reactions.^{26,28} Compared to TiO₂, the overall absorption of the porous SiNWs is much broader as it spans over the entire spectral range from UV to visible and near infrared (IR). In this study, we show that platinum nanoparticles (PtNPs) can be loaded onto porous SiNWs with controlled density and demonstrate that the porous SiNWs and the PtNP loaded porous SiNWs can be used as effective photocatalysts for the photodegradation of indigo carmine (IC) and 4-nitrophenol (4NP) with visible light.

2. Experimental

2.1 Synthesis of Porous Silicon Nanowires

Porous SiNW arrays were synthesized through a two-step method involving the deposition of silver particles on the bare silicon surface followed by wet chemical etching. Briefly, pieces of the commercially available n-type Si (100) wafers with resistivity of 0.008 – 0.02 Ω -cm were used as the starting materials. The silicon pieces were cleaned by sonication in acetone and isopropanol and dried by nitrogen blow. The cleaned silicon pieces were immersed into a buffered oxide etchant (BOE) for 2 minutes to remove the native oxide layer and then immediately soaked into a solution containing 0.005 M AgNO₃ and 4.8 M HF for 1 minute at room temperature. The color of the Si surface turned from dark to colorful, indicating the formation of silver nanoparticles on surface. The silver-deposited Si pieces were rinsed with de-ionized water to remove extra silver ions and then immediately immersed into an etching bath containing 4.8 M HF and 0.3 M H₂O₂ for 60 minutes. The silver metal was removed from the nanowires by immersing the Si pieces into the concentrated nitric acid for an hour.

2.2 Synthesis of Platinum Nanoparticles

For the synthesis of PtNPs, 0.05 mmol of K₂PtCl₄ and 1 mmol of poly(vinylpyrrolidone) (in terms of repeating units) were dissolved in 10 ml of ethylene glycol in a round bottom flask at room temperature.²⁹ The mixture was heated to 180 °C for 30 min with vigorous magnetic stirring. The solution was naturally cooled down to room temperature and 40 ml of acetone was added to precipitate out the PtNPs that were collected by centrifugation at 5000 rpm. The collected PtNPs were then re-dispersed in 5 ml of ethanol and precipitated out by 45 ml of hexane. The process was repeated for three times to thoroughly wash the nanoparticles. The final PtNPs were dissolved in 10 ml of ethanol for characterization and subsequent reactions.

2.3 Formation of Pt loaded Porous Silicon Nanowires

The porous SiNWs were first treated with aminopropyltrimethoxy silane (APTMS). Typically, 3 mg of porous SiNWs were dispersed in 10 ml of 1% APTMS in ethanol. The mixture was refluxed for 2 hours and then centrifuged and washed with ethanol for three times. The APTMS modified porous SiNWs were re-dispersed in 5 ml of ethanol and mixed with various amount of PtNPs for 2 hours under vigorous stirring. The product was centrifuged and washed with ethanol for three times. The Pt loaded porous SiNWs were dried under vacuum for 2 hours.

2.4 Characterization of the Porous Silicon Nanowires

The as-etched samples were inspected with a scanning electron microscope (SEM) (JEOL 6700) at 10 kV of electron acceleration voltage. Transmission electron microscopy (TEM) imaging of the porous SiNWs and the PtNP loaded porous SiNWs was conducted on Phillips CM120 with a 120 kV operation voltage. The high resolution TEM (HRTEM) were collected on FEI Titan with a 300 kV operation voltage. The surface area was measured by the BET method using a Micromeritics ASAP 2020 apparatus (Micromeritics, Norcross, GA). Multipoint isotherms in the P/P^0 relative pressure range of 0.01 – 1.0 were measured by nitrogen adsorption at 77K. The sample was degassed overnight at 250 °C before the BET measurements.

2.5 Photocatalytic Ability of Porous Silicon Nanowires

Indigo carmine (IC) photocatalytic degradation reaction was carried out using 0.3 mg/mL of the porous SiNWs or PtNP-pSiNW dispersed in 100 μ M of IC aqueous solution. The mixture was irradiated under a 300 W xenon lamp. The photocatalytic reaction was carried out in a glass container so that the UV portion of the Xe light is significantly reduced by glass absorption (ESI, Fig. S1 †). The IC degradation was monitored by a Beckman DU-800 UV-vis spectrophotometer. The degradation of 4-nitrophenol (4NP) was performed with the same procedure as the IC degradation. The concentration of 4NP was determined by UV-vis spectrophotometer. All photocatalytic reactions were carried out under ambient conditions. The reaction system was cooled by strong air blowing, with the temperature of solution kept below 35 °C during the measurements.

3. Results and Discussion

Microstructure characterizations of the porous SiNWs were summarized in Fig. 1. SEM image shows high density vertical array of well-aligned porous SiNWs can be readily achieved with the diameters on the order of 100 nm and length on the order of 10 μ m (Fig 1(a)). The TEM image clearly shows porous structure of the resulting SiNWs (Fig. 1(b)).

Incorporating selected metal nanoparticles onto semiconductor photocatalysts can enhance the photocatalytic activity because the difference in their Fermi levels can introduce a Schottky barrier between the metal and the semiconductor.¹⁶ The built-in potential within the Schottky barrier can facilitate the separation of photogenerated electron-hole pairs. Furthermore, properly selected metal nanoparticles can also function as the catalysts to facilitate certain redox reactions. To this end, we have prepared PtNPs and loaded them onto the porous SiNWs. Specifically, PtNPs with 3-4 nm diameters were synthesized using poly(vinylpyrrolidone) (PVP) as the capping ligands²⁹ (ESI, Fig. S2 †). The as-synthesized PtNPs typically have negative surface charges originated from PVP ligands, and cannot be readily attached onto porous SiNWs that also have negative surface charges. To facilitate the attachment of PtNPs onto porous SiNWs with sufficient yield, the porous SiNWs were functionalized with APTMS to render positively charged surface. The PtNPs can then be loaded onto functionalized porous SiNWs through electrostatic force. Controlled densities of PtNPs on porous silicon nanowires were achieved by adding various amounts of PtNPs into a fixed volume of porous SiNW suspension. It should be noted that density of PtNPs eventually saturates and reach an adsorption/desorption equilibrium when the positive surface charges on porous SiNWs are mostly compensated by the negative charges on PtNPs. In this way, we have prepared three photocatalyst samples with variable densities of PtNPs by adding 250 μ L, 500 μ L and 1000 μ L of PtNP solution into 2 ml of ethanol

[†]Electronic Supplementary Information (ESI) available: [details of any supplementary information available should be included here]. See DOI: 10.1039/b000000x/

dispersion containing 3.0 mg porous SiNWs, and named these samples as PtNP-pSiNW-A, PtNP-pSiNW-B and PtNP-pSiNW-C, respectively. TEM studies clearly show that PtNPs are well anchored on the porous SiNWs with increasing densities (Fig. 1(c-e)). The HRTEM image further illustrates good conjugation between the PtNPs and the porous SiNWs (Fig. 1(f)). Energy dispersive X-ray (EDX) spectrum also confirms the conjugation between PtNPs and porous SiNWs (ESI, Fig. S3 †).

Nitrogen gas adsorption/desorption isotherm measurements were used to determine surface areas, average pore size and pore volume of the porous SiNWs. The porous SiNWs, which were prepared by immersing the wafer in an etching solution containing 0.3 M H₂O₂ and 4.8 M HF for 60 minutes were carefully scratched off from half of a 4-inch wafer with a razor blade. The mass of the porous SiNWs was determined after the samples were degassed overnight at 250 °C. A typical adsorption/desorption isotherm for 20.1 mg of the collected porous SiNWs is shown in Fig. 2. The standard multipoint Brunauer-Emmett-Teller (BET) analysis of the porous SiNWs yields an exceptionally high surface area of 337 m²·g⁻¹, which is comparable to the recently reported ptype mesoporous silicon nanowires (342 m²·g⁻¹)²⁶ and mesoporous TiO₂ nanostructures (50 - 300 m²·g⁻¹).¹¹⁻¹⁵ An average pore diameter of 14.0 nm is calculated based on the Barret-Joyner-Halenda (BJH) model. The total pore volume is 1.184 cm³/g at P/P⁰ = 0.97 for the porous SiNWs. The high surface area and large pore volume suggest that the semiconducting porous SiNWs will be a peculiar and promising material for energy harvesting and photocatalysis purposes.

Traditional metal oxide photocatalysts such as TiO₂ and ZnO only absorb a small portion of the solar spectrum because of their large band gaps. Significantly, our study shows the absorption spectrum of the porous SiNWs spans across the entire UV, visible light and near IR range (Fig. 3(a)). Therefore, the photocatalytic reactions based on porous silicon nanostructures could be effectively carried out under visible light or even under near IR light. To evaluate the photocatalytic activity of the porous SiNWs, two sets of experiments were carried out for the photodegradation of indigo carmine (IC) and 4-nitrophenol (4NP).

Under light irradiation, the electron-hole pairs are generated in the porous-SiNWs and then separated, which further react with the dissolved O₂ and water to produce reactive oxygen species (ROS) such as hydroxyl radicals (OH[•]), superoxide (O₂^{•-}), singlet oxygen (¹O₂), and peroxide (H₂O₂). ROS are strong oxidants and known as nonselective oxidizing agents for organic pollutants.³⁰ They can oxidize IC into CO₂, H₂O, HNO₃ and sodium sulfate. The reactions are listed as follows:

The photodegradation of IC was carried out in a photocatalyst dispersion of 0.3 mg/ml under the irradiation of a 300 W xenon light. The change of IC concentration ([IC]) is monitored as a function of reaction time. When the fresh photocatalyst sample PtNP-pSiNW-C was used in the reaction, the change of the [IC] clearly shows three distinct reaction stages: slower reaction rate at the beginning (12.2% degraded IC within 15 minutes), faster reaction rate in the middle (70.3% degraded IC within the subsequent 45 minutes), and slower reaction rate again in the end (ESI, Fig. S4 †). The initial slower reaction rate could be attributed to the simultaneous photodegradation of IC and other absorbed organic species including PVP ligand on PtNP surfaces. After 30 minutes when PVP and other absorbed organic molecules were exhausted, the change of [IC] could be greater than that at the initial stage. When the

[IC] dropped to a very low concentration, the ROS have a lower probability to be captured by the IC molecules, leading to a slower degradation rate.

To remove this initial slow reaction stage and more accurately estimate the catalytic activity of various PtNP-pSiNW photocatalysts, all catalyst samples were exposed to light irradiation for 1 hour before photodegradation of IC and 4NP. The photocatalytic activity of the four catalysts on the degradation of IC is compared in Fig. 3(b). After 60 minutes of irradiation, the percentages of degraded IC are 37.2%, 51.1%, 62.2% and 86.9% for porous SiNWs, PtNP-pSiNW-A, PtNP-pSiNW-B and PtNP-pSiNW-C, respectively. In contrast, only 4.7 % of IC molecules were degraded with the same irradiation conditions without the PtNP-pSiNW photocatalysts. Our results clearly demonstrate that porous SiNWs can function as effective photocatalysts in the visible irradiation range and that the Pt-loaded porous SiNWs are much more efficient photocatalysts than the porous SiNWs only. This catalytic enhancement by PtNPs could be attributed to their ability to facilitate electron-hole separation and to promote electron transfer process in catalytic photodegradation reaction.

It is important to compare the photocatalytic activity of the porous SiNW samples with more commonly used TiO₂ nanoparticles. To this end, we have carried out a series of control experiments using 5 nm anatase TiO₂ nanoparticles³¹ (ESI, Fig. S5 †) and P25 TiO₂ nanoparticles under same conditions with same weight concentration. Under visible light, our studies show that porous SiNWs show photocatalytic activity higher than anatase TiO₂ nanoparticles but lower than P25 TiO₂ nanoparticles (ESI, Fig. S6(b) †). This difference can be largely attributed to the absorption properties of these three samples, with the P25 TiO₂ nanoparticles showing largest overall absorption, and porous SiNWs next, and anatase TiO₂ nanoparticles least (ESI, Fig. S6(a) †). Despite a band gap in the visible range (1.4-2.5 eV), the relatively low absorption of porous SiNWs may be attributed to the low intrinsic absorption coefficient of silicon compared to TiO₂.^{32,33} In the IR regime, the porous SiNWs show best absorption and best photocatalytic activity among three photocatalysts (ESI, Fig. S6 (c) †). In addition to the band gap and absorption properties, it should be noted that the relative alignment of the conduction and valence band edge vs. redox potentials may also affect the photocatalytic activity. Future studies to determine the relative band edge alignment of porous SiNWs and its impact on the photocatalytic activity may offer clues for additional improvement.

The photocatalytic stability of the porous SiNWs was also evaluated by recycling the porous SiNWs for multiple cycles of reactions (squares, in Fig. 3(c)). The concentration of the catalysts was controlled at 0.3 mg/mL in 100 μ M IC solution. After 2.5 hours of light irradiation, the catalysts were recovered by centrifugation and redispersed in a fresh IC solution for the next cycle of test. The catalysts show stable photocatalytic behavior after 10 cycles of reactions, demonstrating the high photostability of the porous SiNWs. A similar experiment was carried out to test the life time of the PtNP-pSiNW-C sample (circles in Fig. 3(c)). The mixture was exposed under the light irradiation for 90 minutes with near complete IC degradation for each cycle. The PtNP-pSiNW-C catalyst also showed similar photocatalytic stability.

Photocatalyst is of significant interest in photodegradation of organic pollutant for waste treatment in environment. For example, ROS can oxidize 4-nitrophenol (4NP) into CO₂ and H₂O. To this end, we have explored the porous SiNWs and PtNP-pSiNW-C as the photocatalysts to degrade 4NP to evaluate their photocatalytic ability in organic waste treatment (Fig. 3(d)). 18.8 % and 66.0% of the 4NP were degraded after 90 minutes of light irradiation with the porous SiNWs and the PtNP-pSiNW-C, respectively. The results further demonstrate the photocatalytic ability of the porous SiNWs in degrading organic species and confirm that PtNP loading can promote photocatalytic activity. Reactions with the catalysts

exposed to xenon light for 1 hour also show a catalytic behavior with an initial slow degradation rate followed by a faster and then another slow reaction rate. This could be attributed to the variable amount of 4NP molecules absorbed on the surface of the porous SiNWs, which determines the degradation rate. Previous studies on the photodegradation of 4NP catalyzed by TiO₂ particles show that the amount of absorbed 4NP molecules on the catalysts is related to the pH values: a lower pH value often leads to higher 4NP molecules absorption.¹¹ The optimal pH for 4NP absorption on TiO₂ surface is 4.0. In the case of porous SiNWs, a thin layer of silicon oxide forms on the surface with abundant (SiO)₃Si-OH groups.^{34,35} The pK_a of such silica surface is 4.5,³⁶ similar to that of the TiO₂ surface (pK_a~4.95).³⁷ In porous SiNWs catalyzed photodegradation of 4NP, the starting solution has a pH value of 7.18 due to the pK_a value of 7.08 for 4NP. The initial amount of the absorbed 4NP molecules is limited by this pH value. As the reaction proceeds, CO₂ and HNO₃ are generated, which reduces the pH value of the reaction solution to 5.71 after 60 minute reaction. The lower pH value favors the adsorption of 4NP molecules on the catalysts and thus accelerates the degradation rate. The slow reaction rate at the final stage could be attributed to the lower concentration of 4NP in the reaction solution. Compared to the porous SiNWs, reactions involving the PtNP-pSiNW-C catalysts display a shorter period of the initial slower stage because the PtNPs accelerate the degradation reaction and lead to a lower pH value within a shorter time duration.

Conclusions

In conclusion, we have shown that porous SiNWs can be synthesized with a large surface area (337 m².g⁻¹) and broad spectrum absorption throughout the entire spectral regime from UV to near IR range. We have further shown that PtNPs can be loaded onto porous SiNWs with controllable density. The combined advancements allow us to explore porous SiNWs as efficient and stable photocatalysts for the photodegradation of organic dyes such as IC and toxic pollutants such as 4NP, which may have significant interest for organic waste treatment and environmental remediation.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

We acknowledge support by the NIH Director's New Innovator Award Program, part of the NIH Roadmap for Medical Research, through Grant 1DP2OD004342-01. We acknowledge Electron Imaging Center for Nanomachines (EICN) at UCLA for support for TEM. We acknowledge Yuanyuan Ma and Professor Alexandra Navrotsky at UC Davis for the BET measurements.

references

1. Davis ME. Nature. 2002; 417:813–821. [PubMed: 12075343]
2. Sanchez C, Lebeau B, Chaput F, Boilot JP. Advanced Materials. 2003; 15:1969–1994.
3. Bartl MH, Boettcher SW, Frindell KL, Stucky GD. Accounts of Chemical Research. 2005; 38:263–271. [PubMed: 15835873]
4. Seayad AM, Antonelli DM. Advanced Materials. 2004; 16:765–777.
5. Taguchi A, Schuth F. Microporous and Mesoporous Materials. 2005; 77:1–45.
6. Slowing, Vivero-Escoto JL, Wu CW, Lin VSY. Advanced Drug Delivery Reviews. 2008; 60:1278–1288. [PubMed: 18514969]
7. Hagfeldt A, Gratzel M. Accounts of Chemical Research. 2000; 33:269–277. [PubMed: 10813871]
8. Zukalova M, Zukal A, Kavan L, Nazeeruddin MK, Liska P, Gratzel M. Nano Letters. 2005; 5:1789–1792. [PubMed: 16159225]

9. Boettcher SW, Fan J, Tsung CK, Shi QH, Stucky GD. *Accounts of Chemical Research*. 2007; 40:784–792. [PubMed: 17461540]
10. Coakley KM, McGehee MD. *Applied Physics Letters*. 2003; 83:3380–3382.
11. Li SX, Zheng FY, Liu XL, Wu F, Deng NS, Yang JH. *Chemosphere*. 2005; 61:589–594. [PubMed: 16202814]
12. Wang C, Li J, Mele G, Yang GM, Zhang FX, Palmisano L, Vasapollo G. *Applied Catalysis B-Environmental*. 2007; 76:218–226.
13. Ibhadon AO, Greenway GM, Yue Y, Falaras P, Tsoukleris D. *Applied Catalysis B-Environmental*. 2008; 84:351–355.
14. Liu JK, An TC, Li GY, Bao NZ, Sheng GY, Fu JM. *Microporous and Mesoporous Materials*. 2009; 124:197–203.
15. Shao GS, Wang FY, Ren TZ, Liu YP, Yuan ZY. *Applied Catalysis B-Environmental*. 2009; 92:61–67.
16. Yoo KH, Kang KS, Chen Y, Han KJ, Kim J. *Nanotechnology*. 2008; 19:505202. [PubMed: 19942763]
17. Zhang HJ, Chen GH, Bahnemann DW. *Journal of Materials Chemistry*. 2009; 19:5089–5121.
18. Rodrigues S, Ranjit KT, Uma S, Martyanov IN, Klabunde KJ. *Advanced Materials*. 2005; 17:2467–2471.
19. Kapoor PN, Uma S, Rodriguez S, Klabunde KJ. *Journal of Molecular Catalysis a-Chemical*. 2005; 229:145–150.
20. Usseglio S, Damin A, Scarano D, Bordiga S, Zecchina A, Lamberti C. *Journal of the American Chemical Society*. 2007; 129:2822–2828. [PubMed: 17305337]
21. Luo HM, Takata T, Lee YG, Zhao JF, Domen K, Yan YS. *Chemistry of Materials*. 2004; 16:846–849.
22. Chatterjee D, Dasgupta S. *Journal of Photochemistry and Photobiology C-Photochemistry Reviews*. 2005; 6:186–205.
23. Ratanatawanate C, Tao Y, Balkus KJ. *Journal of Physical Chemistry C*. 2009; 113:10755–10760.
24. Li L, Tsung CK, Yang Z, Stucky GD, Sun LD, Wang JF, Yan CH. *Advanced Materials*. 2008; 20:903–908.
25. Baker DR, Kamat PV. *Advanced Functional Materials*. 2009; 19:805–811.
26. Hochbaum AI, Gargas D, Hwang YJ, Yang PD. *Nano Letters*. 2009; 9:3550–3554. [PubMed: 19824705]
27. Qu YQ, Liao L, Li YJ, Zhang H, Huang Y, Duan XF. *Nano Letters*. 2009; 9:4539–4543. [PubMed: 19807130]
28. Kang ZH, Tsang CHA, Wong NB, Zhang ZD, Lee ST. *Journal of the American Chemical Society*. 2007; 129:12090–12091. [PubMed: 17880086]
29. Tsung CK, Kuhn JN, Huang WY, Aliaga C, Hung LI, Somorjai GA, Yang PD. *Journal of the American Chemical Society*. 2009; 131:5816–5822. [PubMed: 19341296]
30. Konstantinou IK, Albanis TA. *Applied Catalysis B-Environmental*. 2004; 49:1–14.
31. Ao Y, Xu J, Fu D, Shen X, Yuan C. *Colloids and Surface A: Physicochem. Eng. Aspects*. 2008; 312:125–130.
32. Reyes-Coronado D, Rodríguez-Gattorno G, Espinosa-Pesqueira ME, Cab C, de Coss R, Oskam G. *Nanotechnology*. 2008; 19:145605. [PubMed: 21817764]
33. Bücher K, Bruns J, Wagemann HG. *Journal of Applied Physics*. 1994; 75:1127–1132.
34. Luhmer M, dEspinose JB, Hommel H, Legrand AP. *Magnetic Resonance Imaging*. 1996; 14:911–913. [PubMed: 8970108]
35. Legrand AP, Taibi H, Hommel H, Tougne P, Leonardelli S. *Journal of Non-Crystalline Solids*. 1993; 155:122–130.
36. O'Reilly JP, Butts CP, I'Anson IA, Shaw AM. *Journal of the American Chemical Society*. 2005; 127:1632–1633. [PubMed: 15700985]
37. Wang CY, Liu CY, Zheng X, Chen J, Shen T. *Colloids and Surfaces a-Physicochemical and Engineering Aspects*. 1998; 131:271–280.

Fig. 1. haracterization of the porous SiNWs and PtNP loaded porous SiNWs. (a) SEM image of the cross section of the as-etched porous SiNWs. (b) TEM image of a typical porous SiNW. (c) TEM image of the PtNP-pSiNW-A. (d) TEM image of the PtNP-pSiNW-B. (e) TEM image of the PtNP-pSiNW-C. (f) HRTEM image of the PtNP-pSiNW-C. The scale bar is 10 μm for A, 2 nm for F, and 100 nm for all others.

Fig. 2.
ypical nitrogen adsorption/desorption isotherms of the porous SiNWs

Fig. 3.

hotocatalytic properties of the porous SiNWs and Pt loaded porous SiNWs. (a) Absorption spectrum of the porous SiNWs. The concentration of porous SiNWs was set at 0.1 mg/ml. (b) IC degradation catalyzed by the porous SiNWs and Pt loaded porous SiNWs. Squares represent the IC under the light irradiation without photocatalysts. Stars, down-triangles, circles and right-triangles represent the catalytic behaviour of the porous SiNWs, PtNP-pSiNW-A, PtNP-pSiNW-B and PtNP-pSiNW-C, respectively. The concentration of all catalysts was set at 0.3 mg/ml. (c) Photocatalytic stability of the porous SiNWs and PtNP-pSiNW-C. Squares and circles represent the catalytic behaviour of the porous SiNWs and the PtNP-pSiNW-C, respectively. The activity of each photocatalyst is represented by the percentage of IC degraded in a given reaction. (d) 4NP degradation catalyzed by the porous SiNWs and PtNP loaded porous SiNWs. Squares represent the 4NP without photocatalysts. Circles and up-triangles represent the catalytic behaviour of the porous SiNWs and the PtNP-pSiNW-C, respectively.