Effects of Silicon Dioxide Layer on Optoelectronic Characteristics of FeO/PSi Heterostructures

Jasim A. Yaseen

Department of Materials Engineering, College of Engineering, Thi Qar University, Nasiriyah, IRAQ

Abstract

In this study, the influence of silicon dioxide (SiO_2) layer on the optoelectronic performance of SiO_2/FeO/porous silicon (PSi) heterojunction photodetectors was studied. Devices with FeO thickness of 300 nm were fabricated and evaluated in terms of dark current, photocurrent, sensitivity, spectral responsivity, external quantum efficiency (EQE), specific detectivity (D^*), noise-equivalent power (NEP), and temporal response. The results reveal that the deposition of SiO_2 layer plays a decisive role in charge transport, carrier recombination, and optical absorption. The highest values of responsivity, EQE, and specific detectivity were 0.381 A/W, 0.861%, and 6.858×10^{13} Jones, respectively, at ~550 nm along with the lowest NEP (~2.62×10^{-12} W).

Keywords: Photodetectors; Heterojunctions; Iron oxide; Porous silicon
Received: 11 June 2025; **Revised:** 19 July 2025; **Accepted:** 26 July 2025; **Published:** 1 October 2025

1. Introduction

Heterostructures and the resulting heterojunctions are foundational concepts in modern photonics and optoelectronics, representing a paradigm shift from traditional single-material (homojunction) devices [1]. A heterostructure is formed by layering two or more different crystalline semiconductor materials with distinct band gaps, lattice constants, or electron affinities. This is typically achieved through highly controlled epitaxial growth techniques like molecular beam epitaxy (MBE) or metal-organic chemical vapor deposition (MOCVD). These fabrication methods allow for atomic-layer precision, ensuring a nearly perfect interface - the heterojunction - which is critical for device performance [2,3]. The primary advantage of a heterojunction is the ability to precisely engineer the electronic potential landscape, specifically the conduction band and valence band offsets at the interface. These offsets, which can be tailored to be staggered (Type I), straddling (Type II), or broken (Type III), enable the spatial separation and confinement of charge carriers (electrons and holes), a phenomenon known as carrier confinement or band gap engineering. This confinement is leveraged in several key applications [4-6]. In photonics, the most significant application is the double heterostructure (DH) laser diode. Here, a thin, narrow-bandgap active layer is sandwiched between two wider-bandgap cladding layers [7]. The large bandgap difference confines both the emitted photons (due to the difference in refractive index) and the charge carriers to the active layer, dramatically increasing the probability of radiative recombination and resulting in low-threshold, high-efficiency light emission - a breakthrough that made fiber-optic communication possible. Furthermore, by confining carriers to two dimensions, the structure can evolve into a quantum well (QW), which leads to sharper density of states and even higher efficiency. In optoelectronics, heterojunctions are vital for photodetectors and solar cells [8]. The heterojunction's built-in electric field, created by the band bending at the interface, efficiently separates photogenerated electron-hole pairs. In solar cells, this separation across the junction (e.g., amorphous silicon and crystalline silicon) reduces recombination loss and increases the collection efficiency of the device. Moreover, different bandgaps can be stacked to create tandem solar cells, which absorb a broader spectrum of light, leading to world-record power conversion efficiencies [9,10]. The ability to combine disparate material properties—for instance, high electron mobility in one layer and desirable optical properties in another—is the core advantage. For example, the high electron mobility transistor (HEMT), a purely electronic device, uses a heterojunction to separate electrons from their parent donor atoms, achieving extremely fast switching speeds [11]. Ultimately, heterostructures enable the independent control over electrical and optical processes within a single monolithic device, making them indispensable for high-speed fiber-optic networks, advanced display technologies, and high-efficiency energy harvesting [12].

Depositing a layer of silicon dioxide (SiO_2) on porous silicon (PSi)-based heterostructures significantly modifies their optoelectronic characteristics, primarily due to changes in surface passivation, quantum confinement, and charge transport [1-3]. PSi itself, with its high surface area and quantum confinement effects, exhibits strong photoluminescence (PL) in the visible spectrum. However, its unstable surface, prone to oxidation and environmental degradation, often leads to a decrease in PL efficiency and device reliability [4-6]. The SiO_2 layer acts as an excellent passivating agent, effectively reducing the density of non-radiative recombination centers, such as dangling bonds and surface defects, on the PSi nanostructures. This passivation enhances the quantum efficiency and intensity of the PL signal by suppressing competing non-radiative pathways [7,8]. Furthermore, the wide bandgap of SiO_2 (~9 eV) provides a large energy barrier for carriers, confining them within the PSi layer. This enhanced carrier confinement intensifies the quantum confinement effect, which can lead to a blue-shift in the emission spectrum and further boost the PL efficiency [9-11]. The presence of the SiO_2 layer also impacts the electrical properties of the heterostructure. It serves as a high-quality dielectric layer, reducing leakage currents and improving the insulation between the PSi and any subsequent metallic or semiconducting layers. This is crucial for applications in light-emitting diodes (LEDs) and photodetectors, where low leakage current is essential for efficient operation [12-14]. The interface between the PSi and the SiO_2 layer is a critical factor; a high-quality, defect-free interface ensures minimal interface states that could act as charge trapping sites, which would otherwise degrade the device performance. Therefore, the deposition technique (e.g., thermal oxidation or plasma-enhanced chemical vapor deposition) and process parameters must be carefully controlled to achieve a uniform, conformal, and low-defect SiO_2 layer [15-17]. The strategic deposition of SiO_2 on PSi-based heterostructures serves a dual role: it passivates the surface to improve PL efficiency and provides a stable dielectric layer to enhance electrical performance, making it a crucial step for fabricating reliable and high-performance optoelectronic devices. This approach transforms the unstable PSi into a robust platform for advanced photonic and electronic applications.

2. Experimental Work

Figure (1) shows a scheme of the SiO_2/FeO/PSi heterostructures fabricated in this work. The fabrication of the FeO/PSi heterostructures was described in details in reference [18]. The SiO_2 layer with 500 nm thickness was deposited by spin coating method.

3. Results and Discussion

Based on the typical effects of a dielectric layer, figure (2) would likely show a significant increase in the spectral responsivity of the FeO-PSi heterostructure after the deposition of the 500nm SiO_2 layer. This improvement stems from two main factors: surface passivation and enhanced charge transport. The SiO_2 layer effectively reduces surface defects and dangling bonds on the porous silicon, which are major sources of non-radiative recombination. By passivating these defects, the layer ensures that more photogenerated carriers contribute to the photocurrent, directly boosting the responsivity. Furthermore, the 500nm-thick SiO_2 layer acts as a high-quality insulating film, reducing leakage currents and improving the efficiency of carrier collection, thereby leading to a higher overall photoresponse.

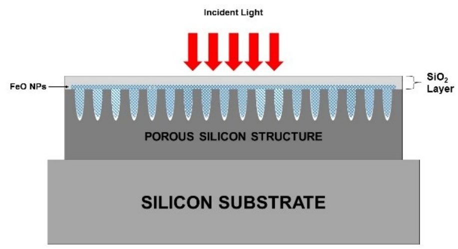

Fig. (1) Scheme of the SiO_2/FeO/PSi heterostructures fabricated in this work

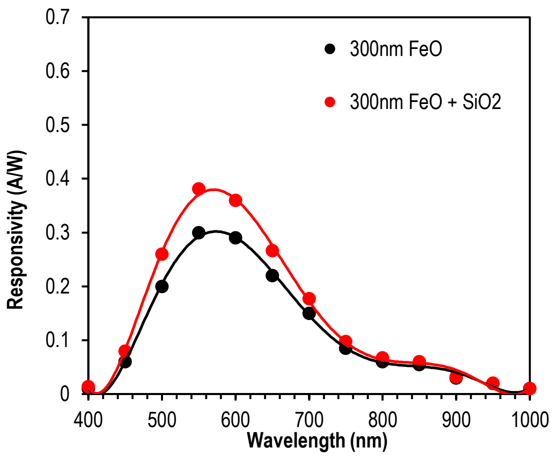

Fig. (2) Effect of depositing 500nm thick SiO_2 layer on spectral responsivity of the FeO/PSi heterostructure

As can be shown in Fig. (3), The primary role of the SiO_2 layer is surface passivation. Porous silicon has a very high surface-to-volume ratio, which means it has a lot of dangling bonds and defects that act as non-radiative recombination centers. Depositing a high-quality SiO_2 layer, especially one that is 500 nm thick, effectively passivates these defects, significantly reducing recombination losses. This results in more photogenerated carriers being collected, thereby increasing the overall EQE. The SiO_2 layer also serves as a crucial dielectric and can act as an anti-reflection coating, reducing optical losses from reflection and allowing more photons to be absorbed by the PSi layer, which further enhances the external quantum efficiency.

Figure (4) shows how the SiO_2 layer deposited on FeO/PSi heterostructure significantly enhances its specific detectivity (D^*) by simultaneously improving the signal and suppressing the noise. The SiO_2 layer acts as a passivation layer, reducing surface defects and dangling bonds on the porous silicon. This minimizes non-radiative recombination, thereby increasing the responsivity (R) by allowing more photogenerated carriers to be collected. Critically, the

SiO_2 also acts as a high-quality dielectric, which significantly reduces the dark current density by suppressing leakage paths. Since specific detectivity is inversely proportional to the square root of the dark current, a smaller dark current leads to a higher D^*. The combined effect of increased responsivity and reduced dark current leads to a substantial improvement in the overall specific detectivity.

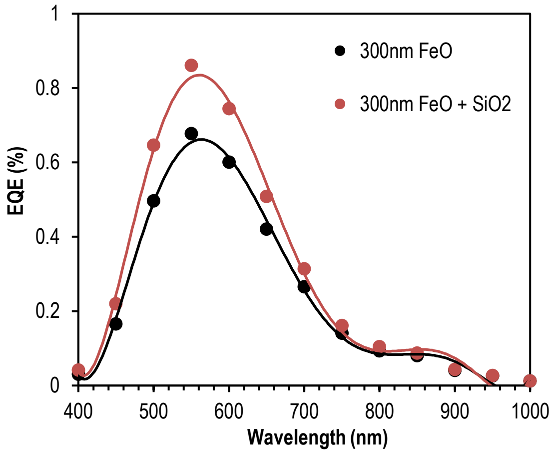

Fig. (3) Effect of depositing 500nm thick SiO_2 layer on external quantum efficiency (EQE) of the FeO/PSi heterostructure

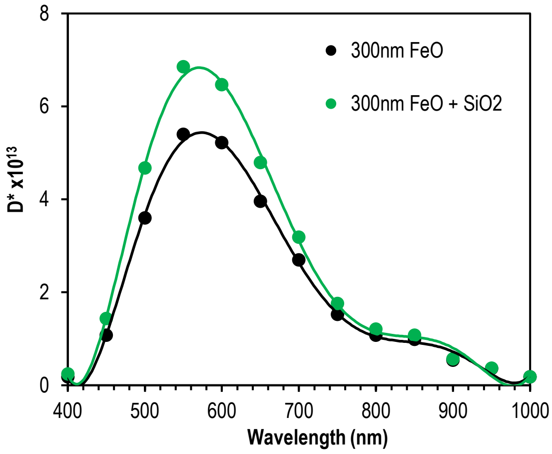

Fig. (4) Effect of depositing 500nm thick SiO_2 layer on specific detectivity (D^*) of the FeO/PSi heterostructure

Depositing a 500 nm thick SiO_2 layer on an FeO/PSi heterostructure significantly reduces the noise-equivalent power (NEP), a key metric for detector sensitivity. NEP is the minimum optical power needed for the signal-to-noise ratio to equal one. A lower NEP is better. The SiO_2 layer has a dual-beneficial effect: it increases responsivity by passivating surface defects and minimizing non-radiative recombination, and it reduces noise by acting as a high-quality dielectric. This dielectric property dramatically suppresses the dark current, which is a primary source of noise. The combination of increased signal (responsivity) and decreased noise (dark current) leads to a substantial reduction in the NEP, making the heterostructure a more sensitive photodetector.

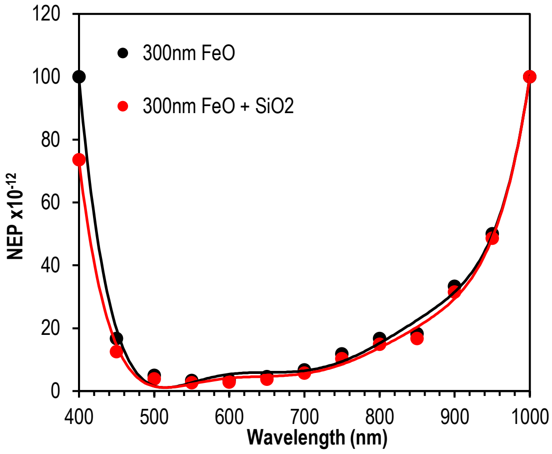

Fig. (5) Effect of depositing 500nm thick SiO_2 layer on noise equivalent power (NEP) of the FeO/PSi heterostructure

4. Conclusions

Based on the provided results, the key conclusion is that the deposition of a 500 nm thick SiO_2 layer on an FeO/PSi heterostructure significantly improves its performance as a photodetector. This enhancement is a result of a dual-beneficial effect on the device's signal and noise characteristics. The SiO_2 layer primarily functions as a high-quality passivation layer and a dielectric insulator. By passivating the surface of the porous silicon, the SiO_2 layer reduces dangling bonds and defects that act as non-radiative recombination centers. This ensures that a greater number of photogenerated carriers are successfully collected, which directly increases the responsivity and external quantum efficiency (EQE) of the device. The layer's dielectric properties are crucial for suppressing leakage currents and reducing the dark current. Since dark current is a primary source of noise, its reduction directly leads to a decrease in device noise.

References

[1] M. Henini, **"Handbook of Thin-Film Deposition Processes and Techniques"**, 2nd ed., William Andrew Inc. (2001), vol. 31, no. 3.

[2] S. Eränen, "Silicon Dioxides", in **Handbook of Silicon Based MEMS Mater. Technol.**, (2010) pp. 137–148.

[3] K. Pradhan et al., "Exploration of impact of ammonia concentration on the surface morphology, optical and wettability performance of SiO_2 thin film", *J. Mater. Sci. Mater. Electron.*, 36(5) (2025) 1-14.

[4] L.A.J. Garvie et al., "Bonding in alpha-quartz (SiO_2): A view of the unoccupied states", *Am. Mineral.*, 85(5-6) (2000) 732-738.

[5] N. Li and W.Y. Ching, "Structural, electronic and optical properties of a large random network model of amorphous SiO_2 glass", *J. Non. Cryst. Solids*, 383 (2014) 28-32.

[6] D.A.P. Wardani et al., "Functional Groups, Band Gap Energy, and Morphology Properties of Annealed Silicon Dioxide (SiO_2)", *Egypt. J. Chem.*, 66(3) (2023) 529-535.

[7] C.A. Banciu et al., "Comparative study of the

hydrophobic properties of silicon dioxide particles functionalized with different agents", *J. Optoelectron. Adv. Mater.*, 25(1-2) (2023) 89-95.
[8] S.W. Glunz and F. Feldmann, "SiO_2 surface passivation layers – a key technology for silicon solar cells", *Sol. Ener. Mater. Sol. Cells*, 185 (2018) 260-269.
[9] T. Oyama et al., "A new layer system of anti-reflective coating for cathode ray tubes", *Thin Solid Films*, 351(1-2) (1999) 235-240.
[10] V. Bhatt and S. Chandra, "Silicon dioxide films by RF sputtering for microelectronic and MEMS applications", *J. Micromech. Microeng.*, 17(5) (2007) 1066-1077.
[11] T.S. Chen et al., "The effect of the native silicon dioxide interfacial layer on photovoltaic characteristics of gold/p-type amorphous boron carbon thin film alloy/silicon dioxide/n-type silicon/aluminum solar cells", *Sol. Ener. Mater. Sol. Cells*, 137 (2015) 185-192.
[12] H. Jung et al., "Growth characteristics and electrical properties of SiO_2 thin films prepared using plasma-enhanced atomic layer deposition and chemical vapor deposition with an aminosilane precursor", *J. Mater. Sci.*, 51(11) (2016) 5082-5091.
[13] M. Yu et al., "Comparative study of the characteristics of Ni films deposited on SiO_2/Si(100) by oblique-angle sputtering and conventional sputtering", *Thin Solid Films*, 516(21) (2008) 7903-7909.
[14] E.S.M. Goh et al., "Thickness effect on the band gap and optical properties of germanium thin films", *J. Appl. Phys.*, 107(2) (2010) 1-5.
[15] V. Jokanovic et al., "Thin films of SiO2 and hydroxyapatite on titanium deposited by spray pyrolysis", *J. Mater. Sci. Mater. Med.*, 19(5) (2008) 1871-1879.
[16] W. Zhang et al., "Preparation of SiO_2 anti-reflection coatings by sol-gel method", *Energy Procedia*, 130 (2017) 72-76.
[17] G. Wang et al., "Preparation methods and application of silicon oxide films", *Int. Conf. Mechatronics, Electron. Ind. Control Eng. MEIC 2014*, pp. 479–483.
[18] J.A. Yaseen, " Influence of FeO Layer Thickness on Characteristics of FeO/Porous Silicon Heterojunction Photodetectors", *Iraqi J. Mater.*, 4(4) (2025) xx-xx.
[19] S. Chen et al., "Vanadium oxide thin films deposited on silicon dioxide buffer layers by magnetron sputtering", *Thin Solid Films*, 497(1-2) (2006) 267-269.
[20] A. Ranjgar et al., "Characterization and Optical Absorption Properties of Plasmonic Nanostructured Thin Films", *Armen. J. Phys.*, 6(4) (2013) 198-203.
[21] I. Safi, "Recent aspects concerning DC reactive magnetron sputtering of thin films: A review", *Surf. Coat. Technol.*, 127(2-3) (2000) 203-218.
[22] K. Pfeiffer et al., "Comparative study of ALD SiO_2 thin films for optical applications", *Opt. Mater. Exp.*, 6(2) (2016) 660.
[23] M.D. Beltrán et al., "Double laser for depth measurement of thin films of ice," *Sensors (Switzerland)*, 15(10) (2015) 25123-25138.
[24] K. Praweerawat, C. Muangphat, and C. Luangchaisri, "The Preparation and Characterization of SiO_2 Films by Spray Coating Technique", *Mater. Today Proc.*, 23 (2018) 696-702.
[25] H.G. Fahad and O.A. Hammadi, "Characterization of Highly-Pure Silicon Dioxide Nanoparticles as Scattering Centers for Random Gain Media", *Iraqi J. Appl. Phys.*, 16(2) (2020) 37-42.