Calculation and Reliability Analysis of Epitaxial Layer Thickness Using Infrared Interferometry Based on the Constant Refractive Index Assumption

Haojun Chen *

SCHOOL OF AEROSPACE ENGINEERING, NORTH UNIVERSITY OF CHINA, Taiyuan, Shanxi, 030051 China

* Corresponding author Email: 18689371223@163.com

Abstract

This study focuses on applying infrared interferometry to calculate the precise thickness of silicon carbide epitaxial layers and conducting reliability analysis of the results. Addressing the complexity of epitaxial layer refractive index variation across infrared spectral wavelengths, this research proposes a key assumption: the refractive index can be treated as constant within specific wavenumber ranges outside the vicinity of the vibrational absorption peak near 1000 cm^{-1}. To validate this hypothesis, experimental data from two incident angles were visualized. Within the specified wavenumber range, minimal reflectance fluctuations and stable interference fringes were observed. The hypothesis's applicability was further confirmed by verifying the proportional relationship between wavenumber increments and order increments through a proof by contradiction approach. Based on literature review, the refractive index was set to 2.55. Subsequently, using the epitaxial layer thickness calculation formula, eight thickness values were selected and computed using the interference order. Calculations revealed average thicknesses of 8.0381 μm and 7.9797 μm for the 10° and 15° incidence angles, respectively. The final determined epitaxial layer thickness was 8.0089 μm. Reliability analysis indicated that the relative error of all calculated results was controlled below 0.4%, and the maximum relative errors under both incidence conditions were extremely close, fully demonstrating the high consistency and reliability of the calculation results.

Keywords

Epitaxial Layer Thickness; Refractive Index Constant Assumption; Relative Error Analysis.

1. Introduction

In the measurement of epitaxial layer thickness in silicon carbide materials, infrared interferometry is an efficient and commonly used technique. Under infrared illumination, reflections and transmissions at the epitaxial layer-substrate interface create interference patterns. By measuring the position of these interference fringes, the epitaxial layer thickness can be determined[1]. However, the refractive index of the epitaxial layer is not a constant; it depends on parameters such as the wavelength of the infrared spectrum, posing challenges for precise thickness calculation. This study focuses on solving how to achieve precise calculation and reliability verification of epitaxial layer thickness under different incident angle conditions using actual experimental data, specifically when considering interference formed solely by single reflection and transmission. Previous research often required presetting refractive index parameters when applying thin-film interference models, lacking sufficient experimental data to support their validity. The innovation of this research lies in proposing the hypothesis of constant refractive index within a specific wavenumber range. Through visualization of experimental data and a refutation approach, this hypothesis provides robust validation for the validity of the refractive index values. The research methodology follows these steps: First, establish and validate the refractive index constant hypothesis; second, based on this hypothesis and thickness calculation formulas, design computational algorithms and solve for thickness using experimental data at different incidence angles (10 degrees, 15 degrees); Finally, the reliability and consistency of the computational results are assessed through relative error analysis[2-3].

2. Model Establishment and Solution

This section focuses on the application of the core model and designs an algorithm for thickness calculation. We have established a process from formulating assumptions to hypothesis testing via reduction to absurdity, then to calculation and solution, and finally to reliability analysis, providing methodological support for thickness calculation and verification. According to optical knowledge, the epitaxial layer exhibits resonance between atoms near a wavenumber of 1000 cm^{-1}, resulting in vibrational absorption peaks. Therefore, the interference fringe orders appearing before 1000 cm^{-1} are not considered in the calculation[4-5].

2.1. Formulation of Assumptions

Since the refractive index of the epitaxial layer is not a constant and is related to parameters such as the doping carrier concentration and the wavelength of the infrared spectrum, this study considers its relationship with the infrared wavelength and assumes that the refractive index is a constant within a specific wavenumber range.

2.2. Hypothesis Testing

Step 1: Visualization processing was performed, and the ima find_min algorithm was used to obtain the minimum points in the reflectivity-wavenumber curve:

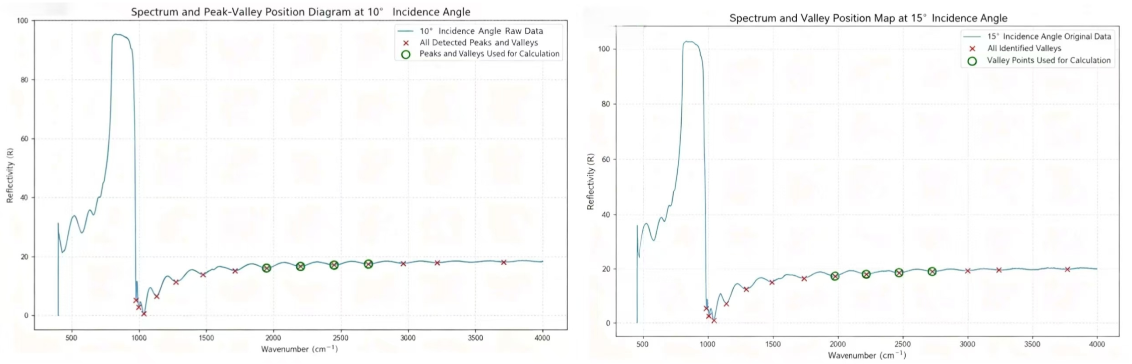

Figure 1. Visualization of data

From the visualized data figure 1, it is found that within the specific wavenumber range of $1000-4000\ \mathrm{cm}^{-1}$, the reflectivity fluctuates around a certain fixed value, which provides favorable conditions for the subsequent determination of fringe orders and reliability analysis. Thus, the proposed assumption is considered reasonable.

Step 2: Starting from the assumption, the refractive index function is set as a constant n_2. At this time, the only unknowns in the formula are the order k and the thickness e. The thickness calculation formula is:

$$e=\frac{(k-\frac{1}{2})\lambda}{2\sqrt{n_2^2-\sin^2 i}}\ (k=1,2,\dots,\text{ where } k \text{ is an integer}) \quad (1)$$

It can be observed that the equation is a proportional relationship, and there is a certain correlation between the order k and the thickness e. By rearranging the formula, we obtain:

$$\mathrm{ev} = \frac{1}{2\sqrt{n_2^2 - \sin^2 i}} \cdot (k - \frac{1}{2}) \tag{2}$$

2.3. Calculation Results

Step 1: Since the order k is an integer, it is not difficult to conclude that the increment of the order, i.e., Δk, is also an integer (Δk is the number of fringes within the range of two wavelengths). When $\Delta k = 1$ is selected, the wavenumber increment fluctuates around a constant, indicating that the two variables approximately have a proportional relationship. This verifies the consistency with the assumption, and thus the assumption is considered valid. Through literature review, we selected $n_2 = 2.55$.

Step 2: Peak and valley points were selected from the visualization graphs for verification. For the same material under the same incident angle and refractive index, it is known that $k_1\lambda_1 = (k_1 + \Delta k)\lambda_2$. Deriving this equation gives:

$$k_1 = \frac{\Delta k \lambda_2}{\lambda_1 - \lambda_2} = \frac{\Delta k \frac{1}{v_2}}{\frac{1}{v_1} - \frac{1}{v_2}} = \frac{\Delta k}{\frac{v_2}{v_1} - 1} \tag{3}$$

Step 3: It is concluded that when $k = 7,8,9,10$ are selected, the deviation from the actual value is small, which further verifies the validity of the assumption. Thus, the refractive index is considered to be a constant $n_2 = 2.55$ within this wavelength band.

By selecting k and establishing simultaneous equations under the two incident conditions:

$$\begin{cases} e_1 = \dfrac{(k - \frac{1}{2})}{2v_1\sqrt{n_2^2 - \sin^2 10^\circ}} \\ e_2 = \dfrac{(k - \frac{1}{2})}{2v_2\sqrt{n_2^2 - \sin^2 15^\circ}} \end{cases} \tag{4}$$

The solutions are as follows:

$$\text{When } k = 7: \begin{cases} e_1 = 8.0291\ \mu m \\ e_2 = 7.9536\ \mu m \end{cases} \tag{5}$$

$$\text{When } k = 8: \begin{cases} e_1 = 8.0683\ \mu m \\ e_2 = 7.9866\ \mu m \end{cases} \tag{6}$$

$$\text{When } k = 9: \begin{cases} e_1 = 8.0369\ \mu m \\ e_2 = 8.0003\ \mu m \end{cases} \tag{7}$$

$$\text{When } k = 10: \begin{cases} e_1 = 8.0183\ \mu m \\ e_2 = 7.9784\ \mu m \end{cases} \tag{8}$$

2.4. Reliability Analysis

Table 1. Absolute difference data table

Incident type \ Fringe order k	7	8	9	10
10°	0.0090	0.0301	0.0012	0.0199
15°	0.0261	0.0069	0.0206	0.0013

Step 1: For an incident angle of 10°, the average thickness is calculated as $\overline{e_1} = 8.0381\ \mu m$; for an incident angle of 15°, the average thickness is $\overline{e_2} = 7.9797\ \mu m$.

Step 2: The absolute differences between the thickness values under the two incident conditions for each order and their respective average values are calculated, as shown in Table 1.

Subsequently, the relative error is calculated using the formula:|Actual value - Actual value| ÷Actual value. Relative error data is shown in table 2.

Table 2. Relative error data table

Incident type \ Fringe order k	7	8	9	10
10°	0.11%	0.37%	0.02%	0.25%
15°	0.33%	0.09%	0.26%	0.02%

Step 3: Based on the above relative error calculations, it is considered that when the relative error is controlled at the 0.5% level, its impact on the accuracy of the final thickness result is negligible. Therefore, the average thickness $\bar{e} = \frac{\overline{e_1}+\overline{e_2}}{2} = 8.0089\ \mu m$ is taken as the calculated value of the epitaxial layer thickness.

2.5. Analysis Results

Based on the establishment, solution, and reliability analysis of the model, considering only the case of a single reflection and transmission, a comprehensive evaluation and summary of the calculated results of the SiC epitaxial layer thickness are presented as follows:

(1) By formulating and verifying the assumption, we solved the key step of determining the refractive index of the epitaxial layer required for thickness calculation. It is confirmed that the reflectivity $n_2 = 2.55$ fluctuates slightly within a specific wavenumber range, and the interference fringes exhibit stability.

(2) By verifying that when the order increment $\Delta k = 1$, the wavenumber increment fluctuates around a specific value, the applicability of the model is further verified.

(3) Relying on the mathematical model constructed combined with the experimental data, the epitaxial layer thicknesses under two different incident angles (10° and 15°) for interference fringe orders 7, 8, 9, and 10 were calculated, yielding eight thickness values. The average thicknesses at incident angles of 10° and 15° are $\overline{e_1} = 8.0381\ \mu m$ and $\overline{e_2} = 7.9797\ \mu m$, respectively, with the final thickness being $\bar{e} = 8.0089\ \mu m$. The difference between the thickness values is less than $0.06\ \mu m$, indicating high consistency, which shows that the algorithm is insensitive to changes and enhances reliability.

(4) Through the reliability analysis of relative errors, it is found that all relative errors are controlled below 0.40%, and the maximum relative errors under the two incident conditions (0.37% at 10° and 0.33% at 15°) are very close. The errors are within an acceptable range and can be ignored in determining the final thickness calculation value.

3. Conclusion

This research successfully completes the calculation and reliability analysis of the thickness of the silicon carbide epitaxial layer. The study first resolves the issue of refractive index setting required for thickness calculation by establishing and validating the key assumption that the refractive index can be considered constant within a specific wavenumber range (away from the vibration absorption peak near 1000 cm^{-1}). Based on this assumption and mathematical model, the study combined experimental data from two different incidence angles (10° and 15°) to calculate eight thickness values for interference orders 7, 8, 9, and 10, ultimately determining the epitaxial layer thickness to be 8.0089 μm. The calculated average thicknesses at 10° and 15°

incidence angles (8.0381 μm and 7.9797 μm) differ by less than 0.06 μm, indicating the algorithm's high consistency and insensitivity to incident angle variations. Most importantly, reliability analysis of relative errors demonstrates that all calculated thickness values maintain relative errors below 0.40%, confirming the results' high reliability.

The primary limitation of the model solution in this research lies in its core conclusions being highly dependent on simplified assumptions regarding refractive index. To simplify calculations, the model assumes the epitaxial layer refractive index is constant within a specific wavenumber range. This ignores the potential correlation between the actual epitaxial layer refractive index and parameters such as wavelength and dopant carrier concentration, potentially introducing systematic errors into the computational results. Furthermore, this study utilized experimental data from only two specific incident angles and selected only certain interference orders for calculation. The model's sensitivity and robustness require broader consideration. Future research should focus on relaxing the assumption of a constant refractive index. This includes precisely modeling the refractive index function over a broader wavenumber range using methods such as the Cauchy dispersion formula, and exploring calculations and validation across a wider range of incident angles and interference orders to enhance the model's universality.

References

[1] Li Mingda, Li Pusheng. Study on the Preparation of Multilayer Thick-Film High-Resistance Silicon Epitaxial Materials Using Thin Silicon Substrates for 1200 V IGBT Power Devices [J]. Electronic Components and Information Technology, 2025, 9 (05): 26-29.

[2] Feng Rui. Study on Single-Particle Radiation Hardening of 200V Power Field-Effect Transistors [D]. China Electronics Technology Group Corporation, Electronics Science Research Institute, 2025.

[3] Lü Bingchen. Van der Waals Epitaxy of AlGaN-Based Materials and Research on Ultraviolet Photodetectors [D]. University of Chinese Academy of Sciences (Changchun Institute of Optics, Mechanics and Physics, Chinese Academy of Sciences), 2025.

[4] Wang, Yuhang. Design and Simulation of a 1200 V/110 A Electrostatic Induction Thyristor [D]. Lanzhou University, 2025.

[5] Peng Zhimeng. Study on Pulse Laser Single-Particle Burnout of Silicon-Based Power MOSFET Devices [D]. Harbin Institute of Technology, 2025.