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# Dual-Beam Interferometric Study of Epitaxial Layer Thickness Based on Infrared Interferometry

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## ABSTRACT

To address the precise measurement of epitaxial layer thickness in silicon carbide materials, this paper constructs a dual-beam epitaxial layer thickness calculation model based on infrared interferometry. Derived from the fundamental optical principle of optical path difference, this model considers only the scenario where interference occurs due to a single reflection and transmission at the epitaxial layer-substrate interface. First, the optical path difference Δ is determined through geometric optical path analysis and Snell's law. Considering that the refractive index of the epitaxial layer is not a constant and exhibits dispersion effects, the refractive index function of the epitaxial layer is established using the Cauchy dispersion formula. Subsequently, under the condition of half-wave loss, the effective optical path difference formula is derived by calculating the optical path differences of reflected light 1 and reflected light 2. By combining the constructive interference condition with the effective optical path difference formula, a quantitative relationship was ultimately derived between the epitaxial layer thickness and the interference order, wave number, incident angle, and refractive index. This model provides a rigorous mathematical framework for establishing fundamental geometric relationships and incorporating dispersion characteristics in epitaxial layer thickness measurements.

## KEYWORDS

Dual-Beam Interference; Optical Path Difference; Refractive Index.

## 1. INTRODUCTION

As an emerging third-generation semiconductor material, silicon carbide (SiC) holds significant frontier significance in physical property research. Given that epitaxial layer thickness serves as a key parameter for evaluating SiC material performance, establishing an accurate mathematical model for its measurement becomes the core issue of this study. This research focuses on addressing the fundamental construction of the epitaxial layer thickness calculation model, aiming to establish mathematical relationships for thickness calculation based on infrared interferometry. Previous studies have predominantly focused on fundamental optical physics theories, yet they lack rigorous derivation processes that integrate geometric optical path analysis, half-wave loss conditions, dispersion effects, and interference constructive/destructive conditions to directly derive quantitative relationships between thickness and physical quantities such as interference fringe order and wavelength [1-2]. The innovations of this research are as follows: First, starting from the fundamental optical physics of optical path difference derivation, and considering only single reflection and transmission scenarios, we analyzed geometric optical path diagrams to construct an epitaxial layer thickness calculation model under dual-beam conditions. Second, the model incorporates dispersion effects by introducing the Cauchy dispersion formula to establish an epitaxial layer refractive index function, making the refractive index dependent on infrared spectral wavelength. Third, it rigorously accounts for the λ/2 condition representing the half-wavelength loss when light propagates from a less dense medium into a more dense one, thereby deriving the effective optical path difference formula. The overall research approach in this research follows a rigorous physical modeling process: First, geometric optical path analysis is performed to define optical parameters; second, the refractive index function of the epitaxial layer is established, accounting for dispersion effects; third, the effective optical path difference is calculated, incorporating half-wave loss; finally, by combining constructive or destructive interference conditions, the final mathematical formula for calculating the epitaxial layer thickness is derived.

# 2. PROBLEM ANALYSIS

## 2.1. Analysis of Problem

Problem requires establishing a mathematical model to determine the thickness of the epitaxial layer. We believe the key to this problem lies in establishing the mathematical relationship for calculating the epitaxial layer thickness under the infrared interferometry method. Starting with geometric optical path analysis, we calculate the optical paths of reflected ray 1 and reflected ray 2 respectively, and establish the effective optical path difference formula considering the condition of half-wave loss; given that the refractive index of the epitaxial layer is related to the wavelength of the infrared spectrum, we focus on the dispersion effect and establish the epitaxial layer refractive index function using the Cauchy dispersion formula; then, using the basic idea of thin-film interference and combining the conditions for constructive and destructive interference, we deduce the calculation formula for the epitaxial layer thickness, thereby establishing the mathematical model. Flow chart of Problem thinking is shown in figure 1.

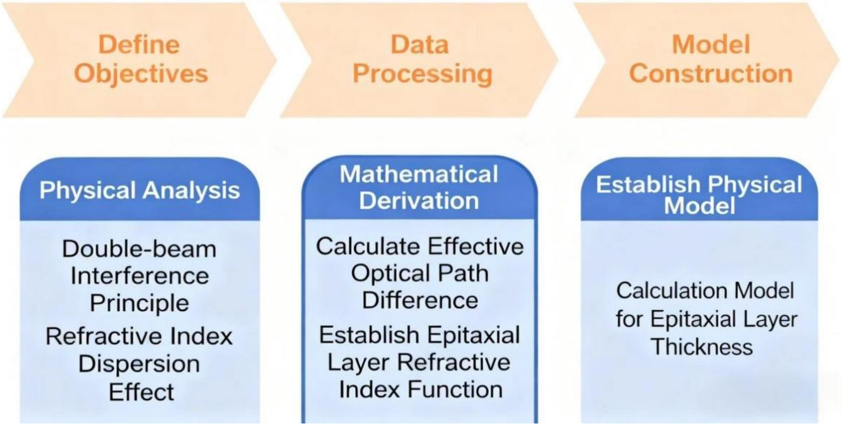

**Figure 1.** Flow chart of Problem thinking

# 3. NOMENCLATURE

Nomenclature is shown in table 1.

**Table 1.** Nomenclature of key parameters and variables

| Symbol | Meaning | Notes |
|---|---|---|
| $e_i$ | Thickness of the epitaxial layer at different incident angles | |
| $\lambda$ | Wavelength of infrared light | |
| $\nu$ | Wavenumber | Reciprocal of wavelength |
| $i$ | Incident angle | 10°, 15° |
| $\gamma$ | Refraction angle | |
| $n_i$ | Refractive index of different media | $i = 1,2,3$ |
| $\delta$ | Optical path difference | |
| $S_i$ | Optical path | |
| $k$ | Order of interference fringes | $k$ is an integer |
| $\Delta\varphi, \varepsilon$ | Phase difference | Used in different sections |
| $S$ | Finesse | |
| $\rho$ | Reflectance ratio | |
| $\tau$ | Transmittance ratio | |
| $r$ | Amplitude reflection coefficient | |
| $t$ | Amplitude transmission coefficient | |
| $R$ | Total reflectivity | |

# 4. MODEL ESTABLISHMENT AND SOLUTION

## 4.1. Model Establishment of Problem

Problem requires establishing a model for calculating the epitaxial layer thickness considering only the interference caused by one reflection and transmission. We believe this is a problem of establishing the relationship between the epitaxial layer thickness and physical quantities such as infrared wavelength and reflectivity based on the phenomenon of light interference combined with the laws of light reflection and refraction.

### 4.1.1. Geometric Optical Path Analysis

Schematic diagram of optical path analysis is shown in figure 2.

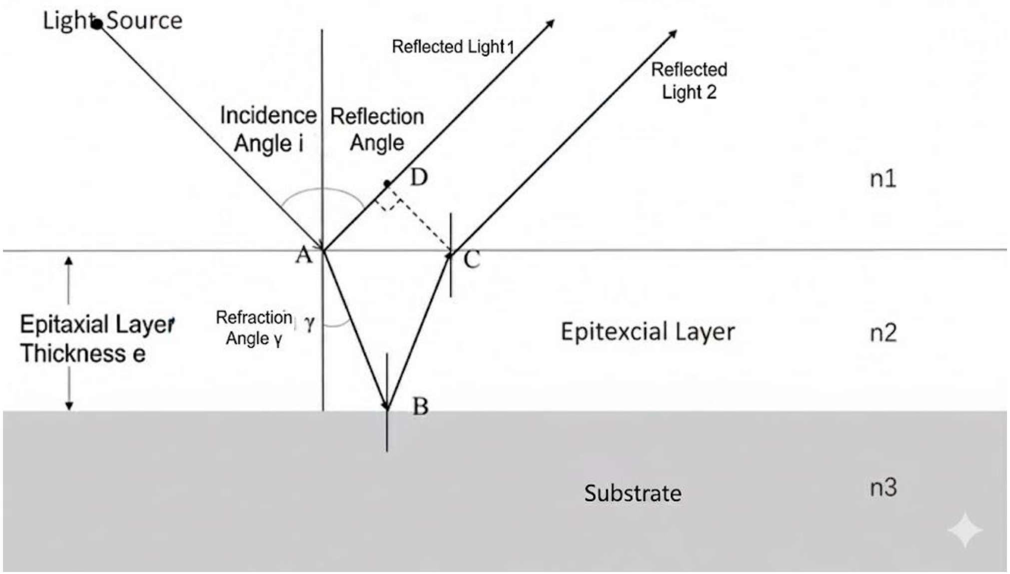

**Figure 2.** Schematic diagram of optical path analysis

Step 1: Set the refractive index of air as $n_1 = 1$, the incident angle of infrared light as $i$, the refractive index of the epitaxial layer as $n_2$, and the refraction angle as $\gamma$;

Step 2: According to Snell's law [3], $n_1 \sin i = n_2 \sin \gamma$;

Step 3: Optical path of reflected ray 1: $S_1 = \overline{AD}$; Optical path of reflected ray 2: $S_2 = \overline{AB} + \overline{BC}$;

Step 4: When light travels from an optically thinner medium (air) to an optically denser medium (epitaxial layer), a half-wave loss $\frac{\lambda}{2}$ occurs.

### 4.1.2. Establishment of Epitaxial Layer Refractive Index Function

Since the refractive index of the epitaxial layer is not a constant and is related to multiple parameters, we consider its relationship with the wavelength of the infrared spectrum (i.e., dispersion exists) as required by the problem. We explore the Cauchy dispersion formula $n_2(\lambda) = A + \frac{B}{\lambda^2} + \frac{C}{\lambda^4}$ and establish the epitaxial layer refractive index formula $n_2(\nu)$.

### 4.1.3. Calculation of Effective Optical Path Difference

After point A, the optical path difference generated by reflected ray 2 compared to reflected ray 1 is: $\delta = n_2(\nu)S_2 - n_1S_1 + \frac{\lambda}{2}$

Step 1: Calculation of relevant length data.

$$\overline{AB} = \overline{BC} = \frac{e}{\cos \gamma} \tag{1}$$

$$\overline{AD} = \overline{AC} \cdot \sin i \tag{2}$$

$$\overline{AC} = 2e \cdot \tan \gamma \tag{3}$$

Step 2: Specific expression of optical path difference.

$$\delta = 2 \cdot n_2(\nu) \cdot \frac{e}{\cos \gamma} - 2e \cdot \tan \gamma \cdot \sin i + \frac{\lambda}{2} \tag{4}$$

Step 3: Combined with Snell's law, transform to get $n_2 = \frac{\sin i}{\sin \gamma} n_1$

### 4.1.4. Interference Conditions

(1) The condition for constructive interference is that the optical path difference is an integer multiple of the wavelength, at which point the reflectivity reaches a peak (maximum value), i.e., $\delta = k\lambda$ ($k = 1, 2, \ldots$, $k$ is an integer);

(2) The condition for destructive interference is that the optical path difference is an odd multiple of half the wavelength, at which point the reflectivity reaches a valley (minimum value), i.e., $\delta = (2k + 1)\frac{\lambda}{2}$ ($k = 0, 1, 2, \ldots$, $k$ is an integer).

### 4.1.5. Deduction of Epitaxial Layer Thickness Calculation Formula

Step 1: Organize the constructive interference conditions and combine the effective optical path difference formula

$$\begin{cases} \delta = k\lambda, k = 1, 2, \ldots \ (\text{k is an integer}) \\ \delta = 2e\sqrt{n_2(\nu)^2 - \sin^2 i} + \frac{\lambda}{2} \end{cases} \tag{5}$$

Deduce the core calculation formula [4-5]:

$$e = \frac{(k-\frac{1}{2})\lambda}{2\sqrt{n_2(\nu)^2-\sin^2 i}}, k = 1,2,\dots \text{ (k is an integer)} \tag{6}$$

Step 2: Unify variables according to the problem. Given the relationship between wavenumber and wavelength is $\nu = \frac{1}{\lambda}$;

Step 3: Establish the epitaxial layer thickness calculation formula:

$$e = \frac{k-\frac{1}{2}}{2\nu\sqrt{n_2(\nu)^2-\sin^2 i}}, k = 1, 2, \dots \text{ (k is an integer)} \tag{7}$$

## 5. CONCLUSIONS

This study successfully constructs a dual-beam epitaxial layer thickness calculation model based on infrared interferometry. It resolves the quantitative relationship between epitaxial layer thickness and physical quantities such as infrared wavelength, incident angle, and refractive index under scenarios involving a single reflection and transmission-induced interference. Optical path parameters were determined by analyzing geometric optical diagrams in conjunction with Snell's law. The model's core lies in systematically integrating the dispersion effect of the epitaxial layer (using the Cauchy dispersion formula to establish the refractive index function), half-wave loss (due to light transitioning from a less dense to a more dense medium), and effective optical path difference calculations. This ultimately derives the core calculation formula. This model provides a robust theoretical foundation for subsequent thickness calculations and reliability analysis using experimental data.

The model constructed in this research is simplified, with its primary limitations being: it considers only a single reflection and transmission at the epitaxial layer-substrate interface (i.e., two-beam interference), neglecting the multi-beam interference effects arising from the superposition of multiple reflections. Furthermore, the derivation simplifies the physical properties of the epitaxial layer and substrate, such as assuming the interface is nearly parallel and both surfaces are ideal planes, while ignoring the phase effects of surface roughness. Future research should focus on extending this fundamental model to more complex real-world interference scenarios. This includes developing a total reflectance model under multi-beam interference conditions and further investigating potential correlations between the refractive index function and parameters such as doped carrier concentration.

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