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Test method for thickness of silicon carbide epitaxial layers —Infrared reflectance method

碳化硅外延层厚度的测试　红外反射法

(English Translation)

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Foreword

SAC/TC 203 and SAC/TC 203/SC2 are in charge of this English translation. In case of any doubt about the contents of English translation, the Chinese original shall be considered authoritative.

This standard is drafted in accordance with the rules given in the GB/T 1.1-2009 *Directives for standardization-Part 1:Structrue and drafting of standards.*

This standard was jointly proposed and prepared by SAC/TC203 National Technical Committee for Standardization of Semiconductor Equipment and Materials and SAC/TC203/SC2 Sub-technical Committee on Materials of the National Technical Committee for Standardization of Semiconductor Equipment and Materials.

Test method for thickness of silicon carbide epitaxial layers —Infrared reflectance method

1 Scope

This standard specifies the test method of thickness of silicon carbide epitaxial layers.

This standard is applicable to the thickness test of silicon carbide homoepitaxial layers with dopant concentration of $< 1\times10^{16}\mathrm{cm}^{-3}$, which grown on the n-type silicon carbide substrate with dopant concentration of $>1\times10^{18}\mathrm{cm}^{-3}$. The test range is 3 μm-200 μm.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

GB/T 6379.2, Accuracy (trueness and precision) of measurement methods and results--Part 2: Basic method for the determination of repeatability and reproducibility of a standard measurement method.

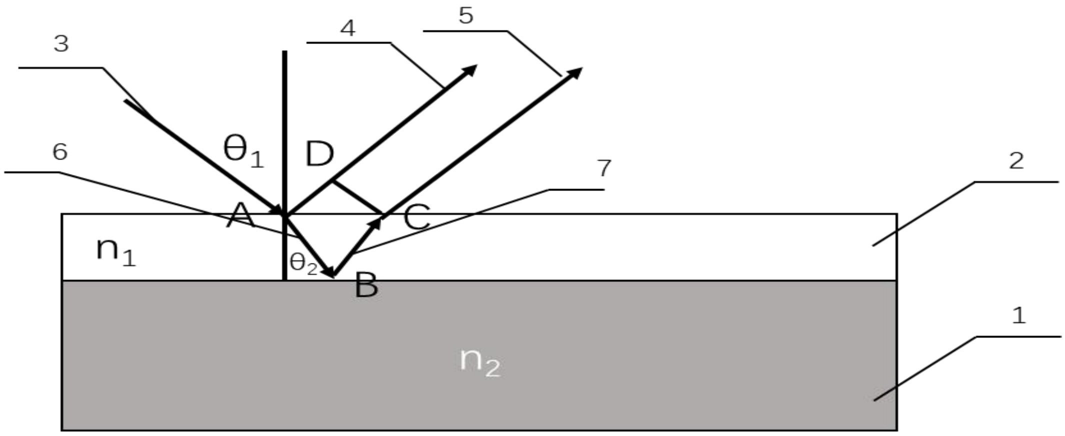
GB/T 14264, *Semiconductor materials-Terms and definitions*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in GB/T 14264 , the following terms and definitions apply.

4 Principle

The difference between the optical constant of the silicon carbide substrate and the epitaxial layer leads to the optical interference phenomenon of continuous maximum and minimal characteristic spectrum in the reflection spectrum of the sample, and the corresponding epitaxial layer thickness is calculated according to the extreme wavenumber of the interference fringes in the reflection spectrum, the optical constant of the epitaxial layer and substrate and the incidence angle of the infrared beam on the specimen. A schematic diagram of the thickness measurement principle of the silicon carbide epitaxial layer is shown in Figure 1.



where：

1——Silicon carbide substrate;

2——Silicon carbide epitaxial layer;

3——Incident light from air to the epitaxial layer;

4——Reflected light on the surface of the epitaxial layer;

5——Refracted light from the epitaxial layer to air;

6——Refracted light from air to the epitaxial layer;

7——Reflected light at the interface of the epitaxial layer and substrate;

θ_1——The angle of incidence of the incident light;

θ_2——The angle of refraction of incident light。

Figure 1 Schematic diagram of thickness measurement principle of silicon carbide epitaxial layer

5 interfering factors

5.1 Water vapor and carbon dioxide atmosphere in the environment will form absorption peaks, which will affect the interference spectrum and test results. High purity nitrogen purging can be used to eliminate the impact of water vapor and carbon dioxide.

5.2 The temperature change will cause the optical intensity of the instrument to drift, which will affect the test results.

5.3 Excessive vibration in the environment will affect the optical path difference and the test results.

5.4 The surface roughness of the sample and many defects making lattice incomplete, will lead to the reduction of reflectivity, and affect the test results.

5.5 If the doping concentration difference between the substrate and the epitaxial layer is too small, the interference fringes will be affected.

6 Apparatus

6.1 Fourier transform infrared spectrometer. Instrument wavenumber range: $360cm^{-1}$～$7800cm^{-1}$.

6.2 The reflective accessories match with the instrument, the incidence angle is less than 30°, and it is recommended that the incidence angle is 15°.

6.3 Rotatable sample table.

7 Sample

The sample shall have a good optical surface, and shall not have a large area of passivation layer and a large area of lattice imperfections. The sample surface shall be kept clean before the test, and the surface roughness (Ra) of the sample shall be less than 5nm.

8 Testing environment

8.1 Temperature: (22±2)℃.

8.2 Relative humidity: （45±10）%.

9 Testing procedure

9.1 Instrument calibration

9.1.1 With a polystyrene film with a thickness of less than 50μm as a standard, with the standard at $1601.34cm^{-1}$ peak as the test reference peak, according to the instrument wavenumber specified in GB/T 6379.2, the wavelength repeatability should not be greater than $0.5cm^{-1}$, and the wavelength accuracy should meet $\pm 0.5cm^{-1}$.

9.1.2 Move it into the optical path, Open the reflection attachment.

9.1.3 Calibrate the instrument with at least two calibration samples of known thickness and containing the thickness of the sample to be measured, adjust the slope and intercept, and the deviation between the test value and the value of the calibration sample should not be more than 3%.

9.2 Test steps

9.2.1 The sample is placed on the equipment so that it has obvious interference fringes in the wavenumber range of $360cm^{-1}$~$7800cm^{-1}$, and at least two interference cycles.

9.2.2 Spectra of extreme values recorded in the wavenumber range of $360cm^{-1}$~$7800cm^{-1}$.

9.2.3 Record the location of the maximum or minimum.

10 Test data processing

10.1 According to Figure 1, the incident light is incident at A, one part of the light is reflected by the epitaxial surface AC, and the other part of the light is reflected at the substrate and epitaxial interface B after being refracted, and is emitted from C, and the phase difference （δ）between the light from C and D is calculated according to formula (1):

$$\delta=[\frac{2\pi(L_{AB}+L_{AC})}{\lambda}]n_1-[\frac{2\pi L_{AD}}{\lambda}]+\Phi_1-\Phi_2 \cdots\cdots (1)$$

where ：

δ——Phase difference of reflected light;

L_{AB}—— Distance from point A to point B, in nm;

L_{AC}——Distance from point A to point C, in nm

λ——Vacuum wavelength, in nm;

n_1——The refractive index of the epitaxial layer, 2.55 for SiC;

Φ_1——Phase displacement at point A;

Φ_2——Phase displacement at point B。

10.2 According to Figure 1, the distance from point A to point B (L_{AB}) and the distance from point A to point C (L_{AC}) should meet the formula (2):

$$L_{AB}+L_{AC}=\frac{2T}{\cos\theta 2} \cdots\cdots (2)$$

where:

L_{AB}—— Distance from point A to point B, in nm;

L_{AC}——Distance from point A to point C, in nm;

T——Thickness of epitaxial layer, in microns (μm);

θ_2—Angle of refraction of incident light, in degrees (°)

10.3 According to Figure 1, the distance (L_{AD}) from point A to point D is calculated according to formula (3):

$$L_{AD}=2T\tan\theta_2\sin\theta_1 \cdots\cdots (3)$$

where:

L_{AD}—— Distance from point A to point D, in nm;

T——Thickness of epitaxial layer, in microns (μm);

θ_1——Angle of incidence of incident light, in degrees (°);

θ_2——Angle of refraction of incident light, in degrees (°);

10.4 According to Snell's law, the incident angle of incident light (θ_1) And the angle of refraction of the incident light (θ_2) Formula (4) shall be satisfied:

$$\mathrm{Sin}\,\theta_1=n_1\sin\theta_2 \cdots\cdots (4)$$

Where ：

n_1——The refractive index of the epitaxial layer, 2.55 for SiC;

θ_1——Angle of incidence of incident light, in degrees (°);

θ_2——Angle of refraction of incident light, in degrees (°)。

10.5 The number of stages (P) is calculated according to formula (5):

$$P=\frac{\delta}{2\pi} \cdots\cdots (5)$$

Where ：

P——series;

δ——Phase difference of reflected light.

10.6 If two extreme values of interference amplitude can be observed, the series of extreme values of interference fringes shall be calculated according to Formula (6):

$$P_i=\frac{m\lambda_1}{\lambda_1-\lambda_i}+0.5+ \quad \cdots\cdots (6)$$

Where:

P_i - series corresponding to the i th extremum;

m- difference of λ_1 and λ_i;

λ_1 -- The wavelength at the selected first extremum, set as the reference wavelength, in nanometer (nm);

λ_i- wavelength at the i th extremum, and $\lambda_1 > \lambda_i$. The unit is nanometer (nm);

0.5 - reflection of light beam from air insulated interface, constant.

10.7 The thickness of the epitaxial layer corresponding to the ith extreme value is calculated according to Formula (7):

$$T_i=(P_i-0.5)\cdot\frac{0.001\lambda_i}{\sqrt{n_1{}^2-\sin\theta1^2}}+\frac{\Phi1-\Phi2}{2\pi} \quad \cdots\cdots (7)$$

Where:

T_i——Thickness of epitaxial layer corresponding to the ith extremum, the unit is microns (μm);

P_i——Series corresponding to the ith extremum;

0.5——reflection of light beam from air insulated interface, constant;

λ_i——wavelength at the i th extremum, and $\lambda_1 > \lambda_i$. The unit is nanometer (nm);

n_1——The refractive index of the epitaxial layer, 2.55 for SiC;

θ_1——Angle of incidence of incident light, in degrees (°);

Φ_1——Phase displacement at point A;

Φ_2——Phase displacement at point B。

10.8 As the effect of phase shift is ignored, when the additional phase shift is zero, the thickness of the epitaxial layer at the ith extreme value is calculated according to Formula (8):

$$T_i=(P_i-0.5)\cdot\frac{0.001\lambda_i}{\sqrt{n_1{}^2-\sin\theta_1{}^2}} \quad \cdots\cdots (8)$$

where:

T_i——Thickness of epitaxial layer corresponding to the ith extremum, the unit is microns (μm);

P_i——Series corresponding to the ith extremum;

0.5——reflection of light beam from air insulated interface, constant;

λ_i——wavelength at the i th extremum, and $\lambda_1 > \lambda_i$. The unit is nanometer (nm);

n_1——The refractive index of the epitaxial layer, 2.55 for SiC;

θ_1——Angle of incidence of incident light, in degrees (°);

11 Precision

The 6.5μm, 10μm, 55μm, 200μm thick silicon carbide epitaxial wafer samples were tested in five laboratories, and each sample was tested 3 times respectively.

the relative standard deviation of silicon carbide epitaxial layer thickness is not more than 1% in a single laboratory. The relative standard deviation of silicon carbide epitaxial layer thickness is not more than 5% in several laboratories.

12 Test report

The test report shall at least include the following contents:

a) Test date;

b) Sample No.

c) Sample Measurement position;

d) Maximum and minimum series used（P_i）;

e) Calculated thickness (T_i);

f) Average thickness (T);

g) Tester;

h) The code of this document.