SEMI MF95-1107 (Reapproved 0718)
TEST METHOD FOR THICKNESS OF LIGHTLY DOPED SILICON EPITAXIAL LAYERS ON HEAVILY DOPED SILICON SUBSTRATES USING AN INFRARED DISPERSIVE SPECTROPHOTOMETER

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1 Purpose

1.1 The thickness of the epitaxial layer is an important process control and materials acceptance requirement for silicon epitaxial wafers.

1.2 This Test Method provides a technique for the measurement of the thickness of epitaxial layers of silicon deposited on silicon substrates.

1.3 This Test Method is suitable for reference measurements.

2 Scope

2.1 This Test Method is a manual technique that requires the use of a dispersive infrared spectrophotometer. For this measurement, the resistivity of the substrate must be less than 0.02 Ω·cm at 23°C and the resistivity of the layer must be greater than 0.1 Ω·cm at 23°C. A brief description of the theory of this Test Method is given in Related Information 1.

2.2 This technique is capable of measuring the thickness of both *n*- and *p*-type layers greater than 2 µm thick. With reduced precision, the technique may also be applied to both *n*- and *p*-type layers from 0.5 to 2 µm thick.

2.3 Automated test systems, utilizing Fourier-transform infrared spectrophotometry (FT-IR), are now widely used for epitaxial layer thickness measurements. Because such instruments are normally supplied with proprietary software for measurement analysis, detailed procedures for the use of such instruments are not included in this Test Method. However, for information purposes, estimates of single instrument repeatability and multi-instrument reproducibility, based on a 1986/1987 multilaboratory comparison of FT-IR instrument measurements are given in Note 6 and Related Information 2.

2.4 Procedures for preparing the specimen, for measuring its size, and for determining the temperature of the specimen during the measurements are also given.

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3 Referenced Standards and Documents

3.1 *SEMI Standards and Safety Guidelines*

SEMI M59 — Terminology for Silicon Technology

SEMI MF84 — Test Method for Measuring Resistivity of Silicon Wafers with an In-Line Four-Point Probe

3.2 *ASTM Standards*[1]

ASTM E177 — Standard Practice for Use of the Terms Precision and Bias in ASTM Test Methods

ASTM E932 — Practice for Describing and Measuring Performance of Dispersive Infrared Spectrophotometers (Withdrawn 1980)

[1] ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA; Telephone: +1.610.832.9585, Fax: +1.610.832.9555, http://www.astm.org

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NOTICE: Unless otherwise indicated, all documents cited shall be the latest published versions.

4 Terminology

4.1 Terms relating to silicon and other semiconductor technology are defined in SEMI M59.

5 Summary of Test Method

5.1 The reflectance of the specimen is measured as a function of wave number using an infrared spectrophotometer. The reflectance spectrum of a suitable specimen exhibits successive maxima and minima characteristic of optical interference phenomena. The thickness of the epitaxially deposited layer is calculated using the wave numbers of the extrema in the reflectance spectrum, the optical constants of the layer and the substrate, and the angle of incidence of the infrared beam upon the specimen.

6 Apparatus

6.1 *Double-Beam Infrared Spectrophotometer* — That utilizes monochromatic infrared light of known and variable wave numbers. This light shall be reflected from the specimen and the reflectivity shall be recorded as a function of wave number. It is essential that the wave numbers indicated by the apparatus be carefully calibrated. Calibration accuracy shall be determined in accordance with ASTM E932, using polystyrene lines at 1601.6 and 648.9 cm^{-1}. The calibration accuracy shall be 0.3 cm^{-1} or better. The useful range of wave numbers is from 1670 to 250 cm^{-1}. The precision and thickness capabilities stated in § 12 were established using data in the range 900 to 300 cm^{-1}. In general, thinner specimens require a broader wavelength range than thicker ones.

NOTE 1: Although the specifications on the spectrophotometer have been changed from wavelength values to wave number values, the illustration of the reflection spectrum (see Figure 1) and the calculations (see § 10) are still carried out in wavelengths.

6.2 *Specimen Holder* — Constructed so that no damage can be inflicted by the holder on the epitaxial layer.

6.3 *Masking Aperture* — Of such size as to restrict the illuminated area on the specimen surface to a value sufficiently small to eliminate the effect of thickness fluctuations, without impairing detection of the reflected light. The masking aperture shall be constructed from a nonreflecting material such as matte-surface graphite.

7 Test Specimen

7.1 The specimen surface shall be highly reflective, free from large-area imperfections, and free of passivating layers except native oxides. The specimen surface may be cleaned prior to measurement by any technique that does not affect the specimen polish or the layer thickness.

8 Preparation of Apparatus

8.1 Establish the maximum allowable scan speed as follows:

8.1.1 Choose a specimen with a substrate resistivity between 0.008 and 0.02 Ω·cm, and an epitaxial layer of such thickness that an observable minimum occurs at a wave number less than 400 cm^{-1}.

8.1.2 Choose a suitable masking aperture.

8.1.3 Place the specimen on the instrument and record the spectrum of a minimum wave number less than 400 cm^{-1} using the slowest scan speed available.

8.1.4 Record the position of the minimum.

8.1.5 Increase the scan speed in steps and record the position of the minimum for each scan speed.

8.1.6 Allowable scan speeds are those which show a shift of the minimum of less than ±1 cm^{-1} relative to the position of the minimum as determined at the slowest scan speed.

9 Procedure

9.1 Handle the specimen carefully to avoid surface damage to the thin epitaxial layer.

9.2 Place the specimen over the aperture mask to expose the desired location to the beam.

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9.3 Obtain a reflection spectrum similar to that shown in Figure 1 (see Note 1). Do not attempt a calculation of layer thickness if the peak amplitude to noise amplitude ratio is less than five.

NOTE 2: The interference pattern may be obscured or illegible if the thickness of the epitaxial layer varies by more than 4% over the masking aperture, or if the interface impurity concentration profile does not approximate a step function.

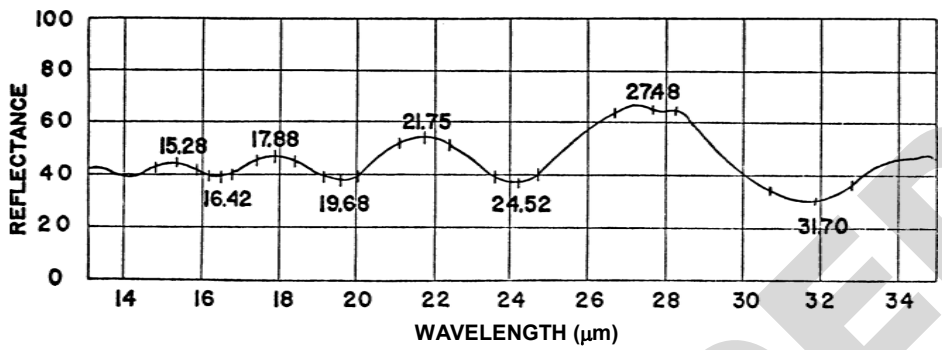

Figure 1
Typical Reflection Spectrum for *n*-Type Specimen

9.4 Determine the wave number of each extremum in the reflection spectrum by averaging the intercepts of the reflection spectrum and a horizontal line 3% of full scale below a maximum or above a minimum. This procedure reduces the ambiguity encountered when the extrema are broad.

NOTE 3: A more correct procedure for locating the position of the extrema on layers less than 2 µm thick is to draw the tangent envelope to the spectrum and determine the intersection of the envelopes with the interference spectrum.[2] However, this procedure is apparently more difficult to perform since its use in a interlaboratory test (see ¶ 12.3) resulted in reduced rather than improved precision.

9.5 Measure the resistivity of the substrate in the area of the thickness measurement on the side opposite the epitaxial layer using SEMI MF84.

10 Calculations

10.1 Convert the wavenumbers of the extrema to wave length using the following equation:

$$\lambda_i = \frac{10{,}000}{\nu_i} \tag{1}$$

where:

λ_I = wavelength, in µm, associated with the ith extremum.

ν_I = wavenumber, in cm^{-1} associated with the ith extremum.

Determine the orders for the maxima and minima observed using the following equation:

$$P_2 = \frac{m\lambda_1}{\lambda_1 - \lambda_2} + \frac{1}{2} - \frac{\phi_{21}\lambda_1 - \phi_{22}\lambda_2}{2\pi(\lambda_1 - \lambda_2)} \tag{2}$$

where:

P_2 = order of extremum associated with λ_2.

$\lambda_1 = 10{,}000/\nu_1$.

$\lambda_2 = 10{,}000/\nu_2$.

[2] Schumann, P. A. "The Infrared Interference Method of Measuring Epitaxial Layer Thickness." *J. Electrochem. Soc.* **116** (1969): p. 410.

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m = difference in the orders of the extrema considered.

ϕ_{21} and ϕ_{22} are the phase shifts suffered by the ray reflected at the interface for λ_1 and λ_2 respectively.

10.1.1 Obtain the phase shifts ϕ_{21} and ϕ_{22} from Table 1 or Table 2. Round off the calculated order, P_2, to an integer for a maximum and a half integer for a minimum. After calculating one order, assign the orders to the remaining extrema in descending order with increasing wavelength as shown in Figure 1.

10.2 Calculate the thickness using the following equation:

$$T_n = \left[P_n - \frac{1}{2} + \frac{\phi_{2n}}{2\pi} \right] \cdot \frac{\lambda_n}{2\sqrt{n_1^2 - \sin^2\theta}} \tag{3}$$

where:

T_n = epitaxial layer thickness, in µm.

n_1 = index of refraction of the epitaxial layer (n_1 = 3.42 for silicon).

θ = angle of incidence of the beam upon the epitaxial layer.

the other symbols have the same meaning they had in Equation 2. Use the same units for the thickness as for the wavelength. Calculate T_n for all of the observed maxima and minima and calculate the average value of T.

NOTE 4: When several extrema are available, somewhat better precision than that reported in § 12 results if the longer wavelength points are excluded from the calculation.

Table 1 Phase Shifts ($\phi/2\pi$) for *n*-Type Silicon

Wave-length, µm	*Test Specimen Resistivity, Ω·cm*														
	0.001	*0.002*	*0.003*	*0.004*	*0.005*	*0.006*	*0.007*	*0.008*	*0.009*	*0.010*	*0.012*	*0.014*	*0.016*	*0.018*	*0.200*
2	0.033	0.029	0.028	0.027	0.027	0.026	0.025	0.024	0.023	0.022	0.020	0.019	0.017	0.016	0.021
4	0.061	0.050	0.047	0.046	0.045	0.043	0.041	0.039	0.038	0.036	0.034	0.031	0.029	0.027	0.025
6	0.105	0.072	0.064	0.062	0.060	0.057	0.055	0.052	0.050	0.048	0.044	0.042	0.039	0.036	0.033
8	0.182	0.099	0.083	0.078	0.075	0.071	0.067	0.064	0.016	0.059	0.054	0.051	0.047	0.043	0.040
10	0.247	0.137	0.105	0.095	0.090	0.084	0.079	0.075	0.071	0.069	0.063	0.059	0.055	0.051	0.047
12	0.289	0.183	0.132	0.115	0.106	0.098	0.091	0.084	0.081	0.078	0.072	0.067	0.062	0.057	0.053
14	0.318	0.225	0.164	0.137	0.124	0.113	0.104	0.097	0.092	0.087	0.080	0.074	0.069	0.064	0.059
16	0.339	0.258	0.197	0.163	0.144	0.129	0.117	0.109	0.102	0.097	0.088	0.082	0.075	0.070	0.065
18	0.355	0.283	0.226	0.189	0.166	0.146	0.131	0.121	0.113	0.107	0.096	0.089	0.082	0.076	0.070
20	0.368	0.303	0.251	0.214	0.188	0.165	0.147	0.134	0.124	0.117	0.105	0.096	0.088	0.081	0.075
22	0.378	0.319	0.272	0.236	0.209	0.183	0.163	0.148	0.136	0.127	0.113	0.104	0.095	0.087	0.081
24	0.387	0.333	0.289	0.255	0.229	0.202	0.179	0.162	0.148	0.138	0.122	0.111	0.101	0.093	0.086
26	0.394	0.344	0.303	0.272	0.246	0.219	0.196	0.177	0.161	0.150	0.131	0.119	0.108	0.099	0.091
28	0.401	0.353	0.316	0.286	0.261	0.235	0.211	0.191	0.175	0.161	0.141	0.127	0.115	0.104	0.096
30	0.406	0.362	0.326	0.298	0.275	0.250	0.226	0.206	0.188	0.173	0.150	0.135	0.121	0.110	0.101
32	0.411	0.369	0.336	0.309	0.287	0.263	0.240	0.219	0.210	0.185	0.160	0.143	0.128	0.116	0.106
34	0.415	0.375	0.344	0.319	0.297	0.274	0.252	0.232	0.213	0.197	0.170	0.151	0.135	0.122	0.112
36	0.419	0.381	0.351	0.327	0.307	0.285	0.263	0.243	0.225	0.209	0.180	0.160	0.143	0.129	0.117
38	0.422	0.386	0.357	0.335	0.315	0.294	0.273	0.254	0.236	0.220	0.191	0.167	0.150	0.135	0.123
40	0.425	0.391	0.363	0.341	0.323	0.302	0.283	0.264	0.246	0.230	0.200	0.178	0.158	0.141	0.128

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