

SEMI M82-0712

TEST METHOD FOR THE CARBON ACCEPTOR CONCENTRATION IN SEMI-INSULATING GALLIUM ARSENIDE SINGLE CRYSTALS BY INFRARED ABSORPTION SPECTROSCOPY

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1 Purpose

1.1 The purpose of this Document is to specify a method for the measurement of the carbon acceptor concentration in semi-insulating (SI) gallium arsenide (GaAs) by infrared absorption.

2 Scope

2.1 This Standard test method covers the determination of the carbon content in GaAs using infrared (IR) absorption. The test method utilizes the linear relationship between the carbon content and the integrated absorption of the localized vibration of substitutionally bonded carbon (C_{As}). At a measurement temperature of 300 K (room temperature) this absorption band is observed at 580 cm^{-1} , at 77 K between 582 and 583 cm^{-1} .

2.2 This Test Method covers the determination of substitutional carbon mainly in SI single crystal GaAs. It may also be used for polycrystalline GaAs and conducting GaAs up to a free carrier concentration of about $1 \times 10^{16}\text{ cm}^{-3}$.

2.3 This Test Method is applicable for carbon content between $1 \times 10^{13}\text{ cm}^{-3}$ and the solubility limit ($>1 \times 10^{16}\text{ cm}^{-3}$). The lower limit depends on the measurement temperature, the sample geometry and the quality of the spectrometer.

2.4 Measurement temperatures of both 300 K and 77 K may be used.

2.4.1 Advantages of the 300 K measurement are:

- the necessary spectral resolution is 1 cm^{-1} as compared to 0.1 cm^{-1} required at 77 K;
- cryostat is not necessary.

2.4.2 Advantages of the 77 K measurement are:

- sensitivity is higher (and therefore the detection limit lower);
- no reference sample with a low carbon content is necessary;
- commercial thin wafers can be measured.

2.5 The chemical carbon content in GaAs may be higher than the substitutional carbon content C_{As} as measured by this Standard. According to the present knowledge, however, state-of-the-art single crystal GaAs contains C_{As} only.

2.6 The document follows the roadmap laid out by SEMI M54, Guide for Semi-Insulating (SI) GaAs Material Parameters, defining the carbon concentration as an essential material parameter.

NOTICE: SEMI Standards and Safety Guidelines do not purport to address all safety issues associated with their use. It is the responsibility of the users of the Documents to establish appropriate safety and health practices, and determine the applicability of regulatory or other limitations prior to use.

3 Referenced Standards and Documents

3.1 *SEMI Standards and Safety Guidelines*

SEMI M54 — Guide for Semi-Insulating (SI) GaAs Material Parameters

SEMI M64 — Test Method for the EL2 Deep Donor Concentration in Semi-Insulating (SI) Gallium Arsenide Single Crystals by Infrared Absorption Spectroscopy

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

4 Terminology

NOTE 1: Refer to SEMI's Compilation of Terms (COT) for a list of the most current terms and their definitions.

4.1 Terms, acronyms, and symbols relating to compound semiconductor material technology are defined in SEMI M64.

4.2 Other Terms Used in this Standard

4.2.1 *single beam spectrum I* — intensity of IR radiation impinging on the detector as a function of the wavenumber.

4.2.2 *wavenumber ν* — reciprocal wavelength of IR radiation, measured in units of cm^{-1} .

5 Physical Background and Methodology

5.1 *Case 300 K/Room Temperature (Sample Temperature Between 290 and 310 K)* — The localized mode of carbon in gallium arsenide leads to an absorption band with the main line at 579.8 cm^{-1} (full width at half maximum [FWHM] 1.3 cm^{-1}) and a weak side line at 576.6 cm^{-1} (see Figure 1 [a]). The carbon band is superimposed on a three-phonon band of the GaAs matrix that has to be subtracted using a carbon-lean reference sample.

5.2 *Case 77 K (Sample Temperature Between 75 and 85 K)* — At temperatures $<100 \text{ K}$ the carbon band shows a fine structure due to the different masses of the isotopes ^{69}Ga and ^{71}Ga ¹. The center of the band is situated at 582.4 cm^{-1} . FWHM of the whole band amounts to 0.65 cm^{-1} . FWHM of the single lines of the fine structure is about 0.1 cm^{-1} (see Figure 1 [b]). Due to the nearly constant absorption of the matrix in the range of the carbon band no reference sample is needed in this case.

5.3 *Baseline Method* — A straight baseline is used to separate the carbon band from the remaining contributions to the absorption spectrum. It connects two regions of the absorption spectrum to the left and right of the carbon band. These regions should be chosen as close to the carbon band as possible; however outside the interval from 581.9 cm^{-1} to 582.9 cm^{-1} at 77 K and outside the interval from 573 cm^{-1} to 583 cm^{-1} at 300 K , respectively (see Figure 1).

5.4 The baseline method can only be used if the absorption spectrum without the carbon band is a reasonably linear function of the wavenumber. Careful control of proper baseline settings is recommended.

5.5 *Integrated Absorption Method* — Quantitative determination of the area of the carbon band (integrated absorption) requires that the line shape of the band is not distorted by the convolution with the resolution function of the spectrometer². At 300 K , therefore, the resolution must be at least 1 cm^{-1} . At 77 K , the resolution must be at least 0.1 cm^{-1} . If $\alpha_{\text{max}}d < 0.1$, where α_{max} is the maximum absorption coefficient of the band and d is the sample thickness, a reduced spectral resolution of about 0.5 cm^{-1} is sufficient.

5.6 Measurement temperature lower than 77 K is discouraged, as the FWHM of the lines of the fine structure becomes smaller³ and, therefore, the spectral resolution must be further increased.

¹ W. M. Theis, K. K. Bajaj, C. W. Litton and W. G. Spitzer, Appl. Phys. Lett. 41, 70 (1982).

² H. Ch. Alt: Semicond. Sci. Technol. 3, 154 (1988).

³ B. V. Shanabrook, W. J. Moore, T. A. Kennedy and P. P. Ruden: Phys. Rev. B 30, 3563 (1984).

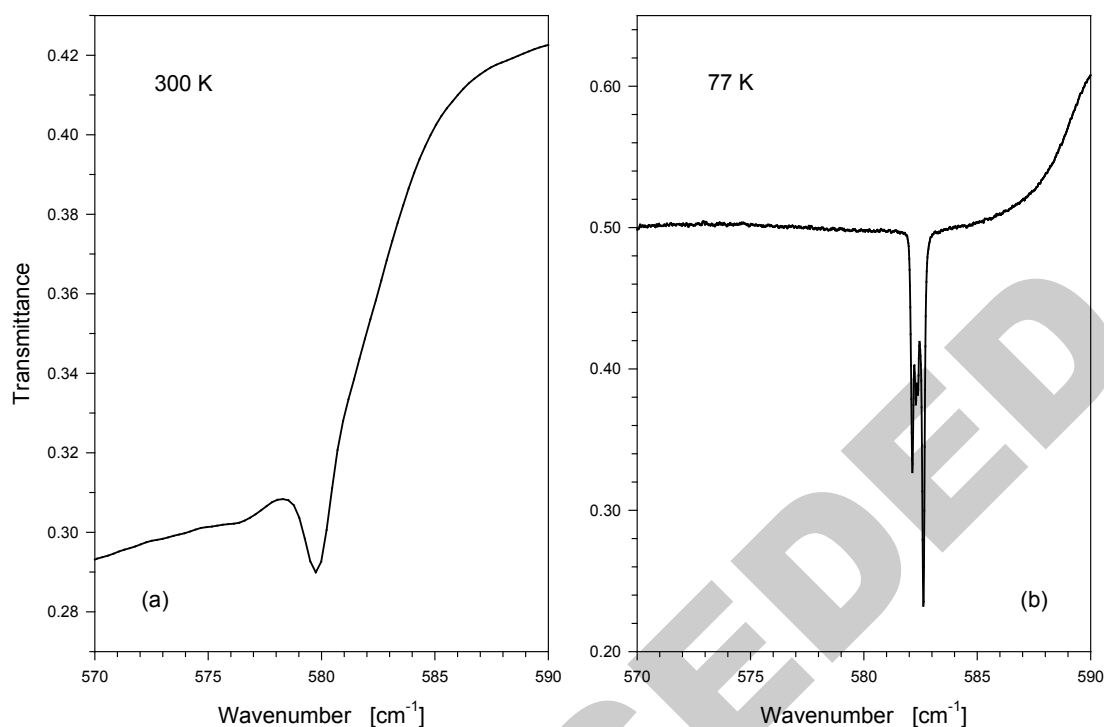


Figure 1
Transmittance spectra of a single-crystalline, SI GaAs sample ($d = 0.50$ cm) at 300 K (a) and at 77 K (b), recorded with a spectral resolution of 1 cm^{-1} (a) and 0.06 cm^{-1} (b), respectively. Carbon content is $3.2 \times 10^{15}\text{ cm}^{-3}$.

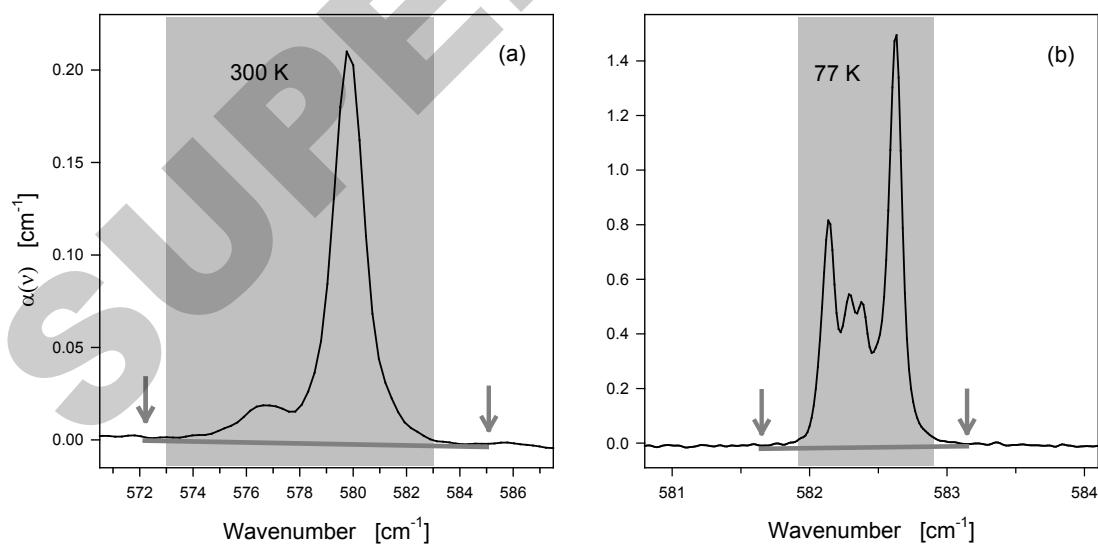


Figure 2
Absorption bands of carbon resulting from the spectra plotted in Figure 1. (300 K: after subtraction of the absorption spectrum of the reference sample). Light grey area: Spectral range of the carbon band. Dark grey line: Baseline (fitting regions are indicated by arrows).