

SEMI M19-91

SPECIFICATION FOR ELECTRICAL PROPERTIES OF BULK GALLIUM ARSENIDE SINGLE CRYSTAL SUBSTRATES

This Standard was technically approved by the Silicon Wafer Global Technical Committee. Originally published 1991.

NOTICE: This Standard or Safety Guideline has an Inactive Status because the conditions to maintain Current Status have not been met. Inactive Standards or Safety Guidelines are available from SEMI and continue to be valid for use.

NOTICE: The section symbol (§) is used to reference a numbered section, paragraph, or header and all subordinate paragraphs, headers, and embedded material (i.e., EXCEPTIONs, lists) therein. The paragraph symbol (§) is used to reference a particular numbered paragraph and embedded material therein. When duplicated (i.e., §§ and §§) the symbols are used to reference more than one section or paragraph, respectively.

NOTICE: Paragraphs entitled 'NOTE:' are not an official part of this Standard or Safety Guideline and are not intended to modify or supersede the official Standard or Safety Guideline. These have been supplied by the global technical committee to enhance the usage of the Standard or Safety Guideline.

1 Introduction

1.1 For the Specification, three principal types of material were identified: semi-insulating, *n*-type, and *p*-type. This encompasses the full range of conductivity characteristics for gallium arsenide (GaAs). § 4 considers subclasses of these characteristics defining the species which may be used for producing the conductivity type. For semi-insulating material, special cases have been isolated.

1.2 Undoped, Grade A1 represents those materials which are of high resistivity and stable following growth, without necessitating any additional annealing or processing. The Grade A2 material, 'high purity', requires additional thermal processing following growth to bring the resistivity to a level $>107 \Omega \cdot \text{cm}$. At this time, most producers have indicated that the majority of the Grade A2 ingots have resistivity characteristics which rise into the acceptable range after an appropriate thermal cycle. However, this phenomenon is sensitive to the details of the time-temperature cycle, and thus, such an increase cannot be guaranteed in every application. Thus, the label 'Grade A2' is used to denote this material.

1.3 Chromium doping produces a high resistivity material. However, due to the rapid diffusion of Cr during processing and the propensity for surface accumulation, it is not as well suited to processing as grades 3.A.1 and 3.A.2, thus we assign this material 'Grade A'.

1.4 Iso-electric dopant additions do not appear to affect the resistivity significantly, but rather, permit the reduction of dislocation generation in the final product. Thus, this material is classified Grade A. While In is the most effective hardening agent, Al, P, and Sb are also viable species. They are included for completeness and to reduce the likelihood of document revision at a later date. The Grade B specification encompasses those materials where the impurity and point defect densities are not quite in the proper balance, but the resistivity is suitable for less-stringent applications.

1.5 For conducting material, the best characterized, non-transition metal species have been included as *n*-type dopants; for *p*-type, a broader range of species has been included, as transition metals are useful acceptor impurities.

1.6 § 5 defines the resistivity and stability of semi-insulating material as specified in § 4. A stringent limit was placed on the Grade A2 material to minimize the likelihood that this material converts to low resistivity upon annealing. The issue of surface conversion in Cr-doped material was dealt with by eliminating a requirement for *n*-type characteristics following annealing.

1.7 The resistivity ranges for *n*-type conducting material were determined from the carrier concentration table (refer to § 6) and mobility values, using the analysis of Walukiewicz *et al.*, J. Appl. Phys. 50 (1979) 899. This places a constraint on the permissible compensation ratio, selected to be in the range of approximately 0.0 to 0.7. The specification was designed then to exclude abnormally poor crystals. As limited data and demand exist for *p*-type material, there are no ranges specified at this writing. Should a significant body of data evolve, this Specification may be designed and balloted as appropriate.

1.8 § 6 deals with impurity concentrations, net electron yields and implicitly, with point defect concentrations. For semi-insulating material of high quality, the impurities are, at the present time, not reliably measurable (carbon is the notable exception). Thus the ‘unspecified’ nomenclature. For types A-3 and A-4, the determination of the amount of the relevant impurity species is given to the appropriate party, the user, and producer, respectively.

1.9 For *n*-type materials, the ranges were selected to define a high purity regime ($n \leq 4 \times 10^{16} \text{ cm}^{-3}$), an intermediate regime where donor density is not more than ~10 times the typical deep level density; the transition region wherein deep levels are suppressed (range B-3); a highly doped range (>10 ppm net electron concentration yield); and ‘saturation’ doping range where the crystal growth process and thermodynamics determine the limits of impurity incorporation and electron yield.

1.10 The electron mobility values and ranges are stated in § 7. For semi-insulating materials, the values that have been determined by consensus are 5000 cm²/V-s for Grade A1 and 6000 cm²/V-s. In the interest of harmony, and to prevent further debilitating discussions, the authors and participants at the SEMI meetings, and responses from producers have been used to set this value at 5000 cm²/V-s. The producers indicated that the Grade A2 material nearly always exceeds 6000 cm²/V-s, and thus this value was adopted. For chromium doped materials, the mobility is less predictable and, therefore, is negotiated between the user and producer. In-doped materials have consistently lower mobilities, resulting from strain-effects, scattering, and other related phenomena. Thus, based on producer experience, the minimum value was set at 3500 cm²/V-s.

1.11 For *n*-type materials, the mobility ranges were selected to represent compensation ratios in the range of approximately 0.0 to 0.7 for a given net electron concentration. *P*-type material is not yet characterized sufficiently to warrant a specification.

2 Scope

2.1 This Standard specifies the characteristics and ranges of electrical properties for bulk GaAs crystals and substrate wafers. For high resistivity and *n*-type conducting materials, the permissible growth conditions or impurity species are stated; the electrical properties corresponding to the appropriate range(s) are noted. Due to the limited understanding, experience and demand for *p*-type materials only guidelines are provided in this Specification at the present writing.

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 None.

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

4 Conductivity Type

- A. Semi-insulating, *n*-type
- B. Conducting, *n*-type
- C. Conducting, *p*-type

5 Dopant Species

- A. 1. Undoped; Grade A1
- 2. Undoped; Grade A2
- 3. Chromium; Grade A
- 4. Isoelectronic impurity; Grade A Dopant specified by producer: In, Al, P, Sb
- 5. Undoped; Grade B
- B. Dopant specified by user: Si, S, Se, Te, Sn
- C. Dopant specified by user: Zn, Cd, Be, Mn, Fe, Co, Mg