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AMERICAN SOCIETY FOR TESTING AND MATERIALS
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Test Method for Quantifying Tungsten Silicide Semiconductor Process Films for Composition and Thickness[1]

This standard is issued under the fixed designation F 1894; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the quantitative determination of tungsten and silicon concentrations in tungsten/silicon (WSi_x) semiconductor process films using Rutherford Backscattering Spectrometry (RBS).[2] (**1**) This test method also covers the detection and quantification of impurities in the mass range from phosphorus Å (31 atomic mass units (amu) to antimony (122 amu).

1.2 This test method can be used for tungsten silicide films prepared by any deposition or annealing processes, or both. The film must be a uniform film with an areal coverage greater than the incident ion beam (~2.5 mm).

1.3 This test method accurately measures the following film properties: silicon/tungsten ratio and variations with depth, tungsten depth profile throughout film, WSi_x film thickness, argon concentrations (if present), presence of oxide on surface of WSi_x films, and transition metal impurities to detection limits of 1×10^{14} atoms/cm^2.

1.4 This test method can detect absolute differences in silicon and tungsten concentrations of ±3 and ±1 atomic percent, respectively, measured from different samples in separate analyses. Relative variations in the tungsten concentration in depth can be detected to ±0.2 atomic percent with a depth resolution of ±70Å.

1.5 This test method supports and assists in qualifying WSi_x films by electrical resistivity techniques.

1.6 This test method can be performed for WSi_x films deposited on conducting or insulating substrates.

1.7 This test method is useful for WSi_x films between 20 and 400 nm with an areal coverage of greater than 1 by 1 mm^2.

1.8 This test method is non-destructive to the film to the extent of sputtering.

1.9 A statistical process control (SPC) of WSi_x films has been monitored since 1993 with reproducibility to ±4 %.

1.10 This test method produces accurate film thicknesses by modeling the film density of the WSi_x film as WSi_2 (hexagonal) plus excess elemental Si[2]. The measured film thickness is a lower limit to the actual film thickness with an accuracy less than 10 % compared to SEM cross-section measurements (see 13.4).

1.11 This test method can be used to analyze films on whole wafers up to 300 mm without breaking the wafers. The sites that can be analyzed may be restricted to concentric rings near the wafer edges for 200-mm and 300-mm wafers, depending on system capabilities.

1.12 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* The reader is referenced to Section 8 of this test method for references to some of the regulatory, radiation, and safety considerations involved with accelerator operation.

2. Referenced Documents

2.1 Terminology used in this document is consistent with terms and definitions as used in the *Compilation of ASTM Standard Definitions*, 8th ed ASTM, 1994, Philadelphia PA, USA, specifically for terms taken from the following ASTM standards:

2.2 *ASTM Standards:*

E 135 Terminology of Analytical Chemistry for Metals, Ores, and Related Materials[3]

E 673 Terminology Relating to Surface Analysis[4]

E 1241 Terminology of Semiconductor Technology[5]

3. Terminology

3.1 Numerous terms specific to RBS and ion stopping in solids can be found in the following references (**1, 2**)[2].

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 WSi_x—a tungsten silicide film characterized by a silicon/tungsten atomic ratio >2.00.

3.2.2 incident ions—He^+ or He^{++} ions with energy in the range of 2.25 to 2.30 MeV delivered to a sample surface from an appropriate ion source and accelerator system.

3.2.3 backscattered ions—Helium particles (charged or neutral) recoiling from atoms in a sample structure irradiated with a collimated beam of incident ions.

[1] This test method is under the jurisdiction of Committee F-1 on Electronics, and is the direct responsibility of Subcommittee F01.06 on Silicon Materials and Process Control.

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[2] The boldface numbers in parentheses refer to a list of references at the end of the text.

[3] *Annual Book of ASTM Standards*, Vol 03.05.

[4] *Annual Book of ASTM Standards*, Vol 03.06.

[5] *Annual Book of ASTM Standards*, Vol 10.05.

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3.2.4 RBS—Rutherford backscattering spectromerty, the energy analysis of backscattered ions for sample composition and depth profile.

3.2.5 normal angle detector—a detector situated at an angle between 160 and 180° from the forward trajectory of the incident ion.

3.2.6 grazing angle detector—a detector situated at an angle between 90 to 130° from the forward trajectory of the incident ion beam.

4. Summary of Test Method

4.1 Fig. 1 shows a schematic of the measurement technique. A collimated beam of alpha particles (He^{++}) is incident on the sample surface. A fraction of the incident ions are scattered out of the specimen with backscattered energies corresponding to the atomic presence of elements in the sample at corresponding depths.

4.2 Spectra of the energy of backscattered ions are acquired at normal and grazing angle detectors for a measured quantity of integrated ion charge on the sample. The grazing angle detector is movable in order to maintain appropriate depth resolution for films of various thicknesses. The grazing angle detector position is chosen to provide a wide tungsten signal (increasing depth resolution) without causing an overlap of the tungsten and silicon signals. The normal angle detector is held fixed to provide accuracy and reproducibility over many months.

4.3 The spectra are analyzed for film composition and thickness using standard software packages. Requirements on the parameters used in software are enumerated in Section 13.

5. Significance and Use

5.1 This test method can be used to ensure absolute reproducibility of WSi_x film deposition systems over the course of many months. The time span of measurements is essentially the life of many process deposition systems.

5.2 This test method can be used to qualify new WSi_x deposition systems to ensure duplicability of existing systems. This test method is essential for the coordination of global semiconductor fabrication operations using different analytical services. This test method allows samples from various deposition systems to be analyzed at different sites and times.

5.3 This test method is the chosen calibration technique for a variety of analytical techniques, including, but not limited to:

5.3.1 Electron spectroscopy for chemical analysis (ESCA or XPS),

5.3.2 Auger electron spectroscopy (AES),

5.3.3 Fourier transform infrared red spectroscopy (FTIR),

5.3.4 Secondary ion mass spectrometry (SIMS), and

5.3.5 Electron dispersive spectrometry (EDS) and particle induced x-ray emission (PIXE).

6. Interferences

6.1 Since RBS is a measurement of the energy loss suffered by energetic helium atoms from atomic masses, the interference of signals results if two or more atoms in the same layer have roughly the same atomic number (Z). The separation of atomic numbers necessary for detectable, independent signals varies depending on the mass range of the element in question (**1**). Masses in the range of $120<Z<200$ interfere with the signal from tungsten in a 1500Å WSi_x film.

6.2 The detection limits of atmospheric elements (fluorine, nitrogen, oxygen, and carbon) in WSi_x films are 5 to 15 atomic % due to interference between the signals from these elements and signals from substrate silicon, silicon oxide, silicon nitride, or polysilicon layers that may be present in the sample structure.

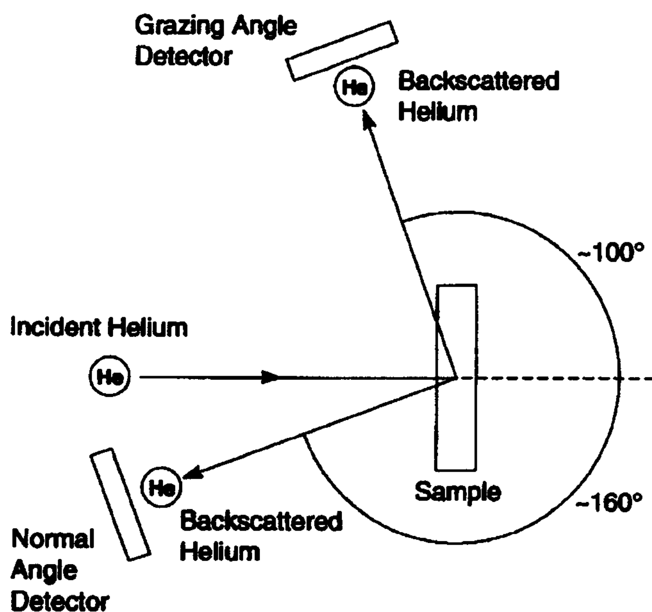
6.3 The accuracy of this test method may be degraded by nonuniformity or interface roughness of the WSi_x film. Roughness of the surface or interfaces of the sample degrades the low energy edge of the tungsten and silicon and reduces the accuracy of the theoretical modeling used to describe the interfaces.

6.4 Energy of the incident ion beam and detector resolution directly impact the quality of the acquired experimental spectra. A lack of resolution due to the poor control of either of these parameters degrades the accuracy of the depth profiling of the tungsten in the WSi_x film.

6.5 It is necessary to restrict the beam current on samples to <80 nA. Currents in excess of this for most detection apparati may result in signal pile-up in the detector electronics and degrade the accuracy of the measurement.

7. Apparatus

7.1 *RBS Instrument*, consists of a source for a monoenergetic, well-collimated beam of helium ions (He^+ or alpha particles). This source typically is comprised of an ion source, accelerator, and energy-momentum selector magnetic sector. The analysis of general RBS data is optimally performed for an incident ion beam energy of 2.0 to 2.4 MeV. The data acquisition is performed in an evacuated (pressure $<1\times10^{-5}$ Torr) end chamber that is equipped with necessary data acquisition electronics. Data acquisition and analysis should



NOTE 1—The grazing angle detector is movable to improve depth resolution of the WSi_x films.

FIG. 1 Schematic Diagram of RBS Experimental Arrangement

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proceed with the use of applicable software.

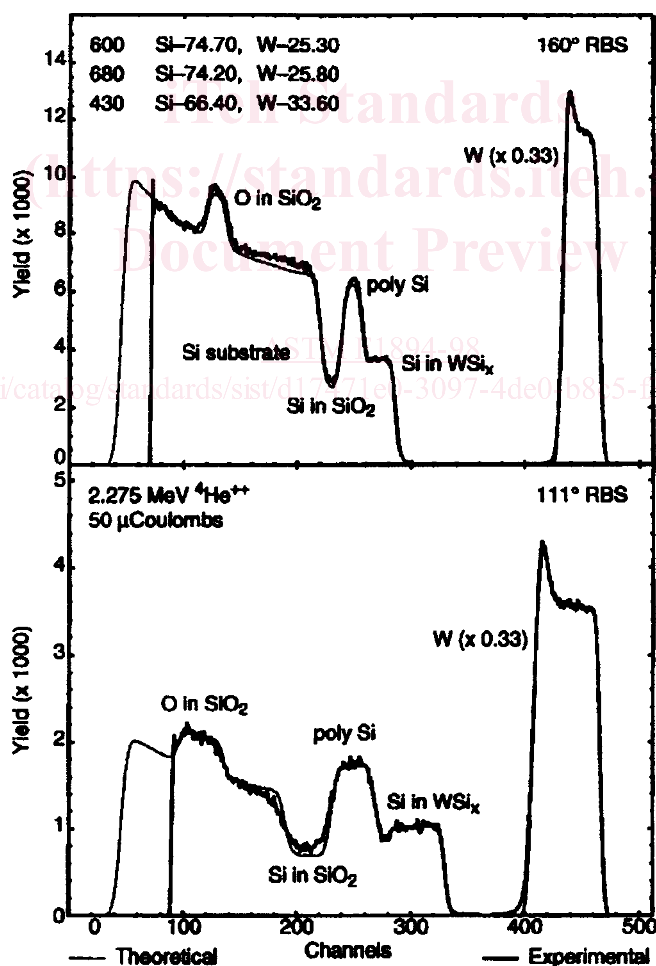
7.2 The energy of the collimated alpha particle (He^{++}) ion beam is restricted to the range of 2.25 to 2.30 MeV. The helium ions have a range of ~3-5 μm in the sample although only collisions occurring in the top ~1.5 μm result in a backscattered event detectable at the normal angle detector. This depth is limited to <1 μm for helium atoms backscattered toward the grazing angle detector. The detectors are silicon surface barrier detectors.

7.3 The majority of the incident alpha particles are implanted in the specimen. A fraction of the incident ions are scattered out of the specimen with backscattered energies corresponding to the presence of elements in the sample at corresponding depths. Fig. 2 shows sample spectra acquired from a sputter deposited WSi_x film on a polycrystalline Si/SiO_2/single crystal silicon structure at a 160° (normal angle) detector and a 110° (grazing angle) detector.

7.4 Spectra at the normal angle and grazing angle detectors are acquired for a measured quantity of charge. The grazing angle detector is movable in order to maintain appropriate depth resolution for films of various thicknesses. The grazing angle detector position is chosen to provide a wide tungsten signal (increasing depth resolution) without causing an overlap of the tungsten and silcon signals. The normal angle detector is held fixed to provide accuracy and reproducibility over many months.

7.5 The grazing angle detector spectrum must be acquired with the sample surface fixed with respect to the incident ion beam. The fixed orientation is performed with the sample normal aligned parallel with respect to the incident ion beam. The spectra from the grazing angle detector are used to measure an accurate depth profile of the tungsten in the film. Since the grazing angle detector is sensitive to surface layers, accurate information for layers deeper than ~3000Å is not obtainable from the grazing angle detector spectrum.

7.6 The normal angle detector spectrum is acquired with the sample orientation manipulated in a way that prevents ion channeling in any single crystal layers or substrates. This is referred to as a "random" orientation. The signal from the random orientation is thus normalizable from sample to sample and allows quantitative comparison of the WSi_x films on multiple samples.



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NOTE 1—The detector angle setting can be found in the upper, right legend of the figures. The contributions from each element and layer is highlighted on the figures. This sample exhibits significant tungsten enrichment at the WSi_x/poly silicon interface, The theoretical model (upper, left legend of top spectrum) is read as layer thickness (Å), element, and atomic concentration. The model shown is for the WSi_x film only. The substrate structure is Si/SiO_2/poly silicon.

FIG. 2 Spectra From the Normal and Grazing Angle Detectors