

SEMI E143-0306

TEST METHOD FOR MEASURING POWER VARIATION INTO A 50-Ω LOAD AND POWER VARIATION AND SPECTRUM INTO A LOAD WITH A VSWR OF 2.0 AT ANY PHASE ANGLE

This standard was technically approved by the global Metrics Committee. This edition was approved for publication by the global Audits and Reviews Subcommittee on November 29, 2005. It was available at www.semi.org in February 2006 and on CD-ROM in March 2006.

1 Purpose

1.1 The purpose of this test method is to provide an accurate method for measuring the output power and spectral content of RF generators being driven into both matched and mismatched loads to simulate their actual performance in RF power delivery systems for semiconductor processing equipment to support SEMI E113.

2 Scope

2.1 This test method specifies the testing procedures and test equipment required for precisely determining the output power and spectral variations of RF generators. This test method uses a spectrum analyzer, power meter, and signal sampling device, all of which have been previously calibrated by a suitable method recommended by the manufacturer. This test method is used to validate three main performance characteristics of RF generators in order to support the following SEMI E113 specifications:

2.1.1 This test method is used to validate that RF generators shall provide consistent power delivery with a variation of less than $\pm 1\%$ of the requested power level (over time and during steady state wafer processing conditions) when operated into a matched (50-Ω) load.

2.1.2 This test method is used to validate that RF generators shall provide consistent power delivery with a variation of less than $\pm 1.5\%$ of the requested power level (over time and during steady state wafer processing conditions) when operated into a load impedance with a reflection coefficient of ≥ 0.33 at any phase angle (VSWR of ≥ 2.0) from 10% to 100% of the maximum rated output power.

2.1.3 This test method is used to validate that RF generators providing a single or fixed frequency output shall provide an output power harmonic or spurious spectral content of -40 dB or less when operated into a load impedance with a reflection coefficient of ≥ 0.33 at any phase angle (VSWR of ≥ 2.0) from 10% to 100% of the maximum rated output power.

2.1.4 This test method can also be used to validate output power harmonic or spurious spectral content for variable- or multiple-frequency output RF generators provided that the following two conditions are met and understood:

2.1.4.1 The variable frequency RF generator must be placed in a single fixed frequency mode for purposes of this test in order to obtain valid results.

2.1.4.2 The output power harmonic or spurious spectral content of the variable frequency RF generator will typically be higher than the -40 dB requirement for a fixed frequency RF generator.

2.2 The primary focus for this test method is semiconductor processing equipment including, but not limited to, the following equipment types:

- Dry etch equipment
- Film deposition equipment (CVD and PVD)

NOTICE: This standard does not purport to address safety issues, if any, associated with its use. It is the responsibility of the users of this standard to establish appropriate safety and health practices and determine the applicability of regulatory or other limitations prior to use.

3 Limitations

3.1 This test method is meant to provide a general means of measuring the true output power and spectral variations of RF generators operating over a wide range of frequency and power. Limitations in the frequency and power coverage of this method are determined by the individual system components chosen.

3.2 This test method assumes that the transmission system characteristic impedance is 50 Ω.

4 Referenced Standards and Documents

4.1 SEMI Standards

SEMI E113 — Specification for Semiconductor Processing Equipment RF Power Delivery Systems

SEMI E114 — Test Method for RF Cable Assemblies Used in Semiconductor Processing Equipment RF Power Delivery Systems

4.2 U.S.A Department of Defense Military Standards¹

MIL-PRF-39012 — General Specification for Connectors, Coaxial, Radio Frequency

MIL-STD-348 — Military Interface Standard, Radio Frequency Connector Interfaces

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

5 Terminology

5.1 Abbreviations and Acronyms

5.1.1 CVD — Chemical Vapor Deposition

5.1.2 PVD — Physical Vapor Deposition

5.1.3 RF — Radio Frequency

5.1.4 VNA — Vector Network Analyzer

5.1.5 VSWR — Voltage Standing Wave Ratio

5.2 Definitions

5.2.1 *cable assembly* — the section of cable (transmission line), including the connectors, used to connect various parts of the RF power delivery system.

5.2.2 *electrical length* — the length of the cable assembly at the operating frequency expressed in terms of degrees, where one wavelength at the nominal operating frequency is equal to 360 degrees.

5.2.3 *harmonic frequency* — the harmonic frequencies are defined as integer multiples of the fundamental frequency. For example, the second harmonic of 13.56 MHz is 27.12 MHz.

5.2.4 *load impedance* — the load impedance is the impedance to which an RF generator is driven into.

5.2.5 *matched load* — a matched load impedance is defined as typically having a magnitude of $50 \pm 3.3 \Omega$ at a phase angle of up to ± 3.8 degrees. In other words, the load is considered matched if the reflection coefficient is < 0.032 at any phase angle.

5.2.6 *mismatched load* — a load impedance which is purposely made to be different (either larger or smaller) in magnitude, phase, or both than 50Ω in order to produce a determined VSWR value. As an example, a 3:1 mismatched load could be produced by using either a $150 + j0$ or $16.7 + j0 \Omega$ load and varying the electrical length up to a half wavelength to outline a contour of 3:1 VSWR magnitude through all phase angles.

5.2.7 *RF generator* — a component in the RF power delivery system used to develop RF energy.

5.2.8 *RF load* — another term used to describe an RF termination.

5.2.9 *RF system* — the RF system is defined as the combination of the RF generator, matching network, chamber interface, and the associated connecting cable assemblies that are specific to a particular tool/chamber.

5.2.10 *RF termination* — a device for terminating RF transmission systems, and converting RF electrical energy into heat. RF terminations normally have values that are the same as the characteristic impedance of the transmission system.

6 Test Apparatus

6.1 *Spectrum Analyzer* — This instrument is designed to be used in conjunction with a high power RF signal sampler, or coupling device, that will reduce the coupled signal to an acceptable level (typically < 1 watt or $+30$ dBm) that will not damage the sensitive input circuitry of the spectrum analyzer. Choose instruments capable of providing a spectral display across the intended frequency range (including the highest order harmonic desired).

6.2 *RF Termination* — This device provides a low VSWR (i.e., high return loss) termination for the testing of the RF generator. Use an RF termination sized appropriately for the RF generator under test. The return loss of the RF

¹ Available from Defense Supply Center Columbus, 3990 East Broad Street, Columbus OH 43218-3990, U.S.A. 1-877-352-2255, website: www.dscc.dla.mil.

termination shall be no less than 30 dB. This return loss ensures maximum power transfer between the RF generator and the termination.

NOTE 1: It is very important that the return loss remain stable at all times under RF power as this could affect the contour of the VSWR magnitude path through all phase angles.

6.3 Signal Sampler — These nondirectional devices are capable of sampling a portion (usually very small) of the output RF power available on the transmission line and sending it to an external device for display or further processing purposes.

6.4 RF Generator Supply — This power supply is used as a source of clean RF energy for the purposes of producing RF power for the system. Use an RF generator sized for the test to be performed and that provides a very stable output at all levels.

6.5 Cables and Connectors — Various interconnecting cables are required to perform the tests outlined in this test method. These include low-loss cables to connect the DC power source to the measuring instrument and to the RF load, in addition to low-loss RF cables and connectors to connect the RF generator output to the load. All cable assemblies shall adhere to industry standards for cables and connectors (e.g., MIL-PRF-39012, MIL-STD-348).

6.6 RF Power Meter — These devices are capable of being inserted in the transmission line at the point at which RF power is intended to be measured. Choose power meters that are capable of measuring RF to an accuracy of $\pm 1\%$ in a 50- Ω system and $\pm 1.5\%$ into a VSWR of 2:1.

NOTE 2: It may be necessary to adjust the reading obtained by the power meter to compensate for the cable loss due to the length of cable used between the RF generator and the meter. For example, suppose that an RF generator, operating at 13.56 MHz and developing 3 kW is connected to the RF termination through a 6-m (20-foot) length of RG-217/U coaxial cable. RG-217/U coaxial cable has a loss specification of 0.41 dB per 30 m (100 feet) of cable at 13.56 MHz. Therefore, for 6 m (20 feet) of cable, the loss would be approximately 0.41/5, or 0.082 dB. If the RF generator is developing 3 kW, this means that approximately 2.944 kW would appear at the power meter due to the cable loss.

6.7 Vector Network Analyzer (VNA) — A vector network analyzer is used to measure the electrical length of RF cables and can also be used to determine the coupling response (relative to the fundamental frequency) of the signal sampler as a function of the harmonic frequencies of interest. The network analyzer requires vector capability so that both the magnitude and phase of the reflection coefficient and transmission coefficient can be measured as a function of frequency for the combination of cable and mismatch load under test. The frequency range shall include the fundamental operating frequency of the test source RF generator.

7 Safety Precautions

7.1 International, national, and local codes, regulations and laws should be consulted to ensure that the equipment and procedures meet regulatory requirements in each location.

7.2 Certain safety issues associated with the test procedures themselves are mentioned as a reminder that safety procedures are necessary for safe conduct of the test.

7.3 The tests described in this test method involve using high-output power RF generators and test instrumentation. Extreme caution should be used at all times and procedures as dictated by the manufacturer must be strictly followed.

7.4 Work should be conducted in accordance with local safety requirements and test device manufacturer's recommended safety procedures.

7.5 The area immediately surrounding the test setup should be kept free and clear of unnecessary equipment and materials.

7.6 Testing personnel should ensure they have adequate lifting devices for large weights such as RF terminations and generators.

7.7 Adequate cooling ventilation or cooling-water flow rates should be appropriate to the RF terminations used in the test. Consult the manufacturer's operating load manual for this information.

7.8 It is important to periodically check the resistor used in the RF termination for damage due to time and use. This can be done easily by measuring the resistance of the load resistor using a simple digital multimeter or VNA. With the RF termination disconnected from the RF cable, place one probe on the center conductor of the termination and the other probe on the termination's outer conductor. Measure the DC resistance of this path. If the DC resistance is more than 53 Ω , replace the resistor in the termination.

7.9 This standard does not address any safety or performance issues related to RF emissions or electrical codes (e.g., Underwriter's Laboratory, Inc. (UL), the National Electrical Code (NEC), Federal Communications Commission