Designation: F 1763 – 96

Standard Test Methods for Measuring Contrast of a Linear Polarizer [1]

This standard is issued under the fixed designation F 1763; 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 These test methods describe measurement of polarizer contrast. A distinction is made between contrast, which is an intrinsic polarizer property, and extinction, which is a comparison between two polarizers.

1.2 These test methods are applicable to polarizers that operate in a transmissive mode at near-normal incidence. Angular or translative offset of the transmitted beam is acceptable if the entire transmitted beam power can be measured.

1.3 The polarizer size or aperture is not limited by the test methods, but the operator must appreciate that the contrast will be an average over the beam spot on the polarizer. Contrast measured at one location on the aperture does not necessarily apply to the entire aperture.

1.4 These test methods are limited to wavelengths for which the tester can provide a collimated beam, and correctly measure changes in the transmitted beam power. The contrast obtained at one wavelength does not necessarily apply at any other wavelength.

1.5 The maximum contrast obtained by these test methods is limited by the dynamic range of the source-detector combination.

1.6 *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.* For hazard statement, see Section 7.

2. Referenced Documents

2.1 *ANSI Standard:*

Z136.1 Safe Use of Lasers [2]

3. Terminology

3.1 *Definitions:*

3.1.1 *contrast:* $C = t_1/t_2$—the ratio of maximum transmission through a polarizer (t_1) to minimum transmission (t_2) when the polarizer is rotated in a light beam of infinite contrast. Contrast is an intrinsic property of a polarizer.

3.1.1.1 *Discussion*— Contrast can also be used to describe the degree of linear polarization of a light beam. In that case it is the ratio of linearly polarized light power in the maximum direction (P_1) to the minimum (P_2). $C_L = P_1/P_2$ and $P_{tot} = P_1 + P_2$. An unpolarized or circularly polarized light beam has $C_L = 1$. A completely linearly polarized light beam has $C = \infty$.

3.1.2 *extinction, X*—the ratio of maximum to minimum transmission of light through a pair of polarizers that are rotated with respect to each other.[3] X is an average between the two measured polarizers and is not necessarily applicable to either polarizer taken alone.

3.1.2.1 *Discussion*— If the two polarizers have the same contrast, then $X = t_1/2t_2 = (1/2)C$. Extinction can be measured with unpolarized or polarized light. The inverse of X is sometimes referred to as extinction ratio. The distinction is self-evident since X varies from 1 to ∞ and $1/X$ varies from 1 to zero.

3.1.3 *leakage transmission, t_2*—the ratio of minimum transmitted light power for a polarizer rotated in a light beam of infinite contrast, to the total light beam power without the polarizer.

$$t_2 = P_{min} / P_{tot} \tag{1}$$

3.1.4 transmission, t_1—the ratio of maximum transmitted light power for a polarizer rotated in a light beam of infinite contrast, to the total light beam power without the polarizer.

$$t_1 = P_{max}/P_{tot} \tag{2}$$

4. Summary of Test Methods

4.1 Three test methods are described in this standard. The first method is a direct contrast measurement that requires a linearly polarized light source with high C_L. The second method is a comparison with a linearly polarized light source with known C_L. The third method is an indirect contrast measurement that can use an unpolarized or polarized light source of unknown C_L.

4.1.1 *Direct Contrast Measurement*—This is the preferred method for measuring C of a single polarizer. This method can be used if $C_L >> C$ for the polarizer to be tested. It is a simple, expedient, and accurate test method if a highly linear polarized light beam is available at the required wavelength. The source will normally be a polarized laser beam in combination with a

[1] These test methods are under the jurisdiction of ASTM Committee F01 on Electronics and is the direct responsibility of Subcommittee F01.06 on Silicon Materials and Process Control.

Current edition approved Dec. 10, 1996. Published February 1997.

[2] Available from American National Standards Institute, 11 W. 42nd St., 13th Floor, New York, NY 10036.

[3] Bennett, J. M., and Bennett, H. E., "Polarization," Section 10 of the *Handbook of Optics*, W. G. Driscoll and W. Vaughan, Eds., McGraw-Hill, 1978.

high-contrast prism polarizer. A tunable broad-band source can also be used if a high-contrast polarizer is available for the wavelength of interest. In this test method the polarizer being tested is rotated in the light beam and the maximum and minimum transmissions are used to calculate *C*.

4.1.2 *Contrast Measurement With Comparison*—This method is used if C_L is approximately equal to *C* for the polarizer to be tested. The value of C_L must be known to obtain the correct *C* for the polarizer. In this test method the polarizer being tested is rotated in the light beam and the maximum and minimum transmissions are used with the value of C_L to calculate *C*.

4.1.3 *Indirect Contrast Measurement*—This method requires three polarizers that have similar *C*. The polarizers are measured in pairs to obtain an *X* for each pair. The three *X*'s can then be used to approximate *C* for each individual polarizer. In this test method one polarizer is aligned in the light beam in such a way as to cancel effects of the polarization state of the light beam on the measurement. The second polarizer is rotated in the beam and the maximum and minimum transmissions are used to calculate *X* for the pair. This test method can be used with any light beam regardless of the contrast of the light beam. It is the only method that can be used when the available $C_L << C$ for the polarizer to be tested.

4.2 The parties to the test shall agree upon the following test parameters:

4.2.1 Test method to be used,

4.2.2 Light source properties including wavelength, power level, and degree of collimation, and

4.2.3 Measurement parameters at the polarizer including beam size, location in the aperture, and angle-of-incidence.

5. Significance and Use

5.1 Use of *C* to characterize polarizers is encouraged because it is an intrinsic property of the polarizer. Use of *X* to characterize polarizers is discouraged because it is an average between two polarizers and not specific to either one. [4]

5.2 Polarizer contrast is important in polarimetry systems, ellipsometers, optical modulators, shutters, and target signature discrimination based on polarized radiation.

5.3 These test methods are suitable for use in service evaluation, manufacturing control, or for research and development purposes. They are not recommended for use in acceptance testing until their precision has been evaluated by interlaboratory comparison unless the parties to the test conduct suitable correlation studies.

6. Apparatus

6.1 Contrast measurements will utilize some form of the three assemblies described in this section. These assemblies are described in a general manner so as to not exclude any particular type of measurement apparatus.

6.2 *Source Assembly*— The source assembly contains the light source and associated optics to produce a collimated light beam of power P_{tot}, with specified size at the sample polarizer, and a high contrast (for direct contrast measurement). If a broad band light source is used, the wavelength selection technique and bandwidth should be specified. If a laser source is used, it is usually sufficient to specify the center wavelength; however, it is sometimes necessary to be more specific such as the particular line in a CO_2 laser. Slightly converging or diverging source light can be used; however, it must be appreciated that the angle-of-incidence (AOI) will be compromised. Polarizer *C* may be very sensitive to AOI (for example a Brewster angle polarizer) or insensitive to AOI (for example a metal grid polarizer). It is the user's responsibility to ensure that any spread in AOI does not compromise the measurement.

6.3 *Polarizer Holder(s)*—The polarizer holder(s) must have provision for smoothly rotating the polarizer(s) in azimuth. One polarizer holder is needed for the direct and comparison test methods and two are needed for the indirect test method. It may also be necessary to have a means of adjusting the AOI on the polarizer and positioning the polarizer aperture in the beam.

6.4 *Receiver Assembly*—The receiver assembly collects the light transmitted through the polarizer(s) an provides a quantitative readout proportional to the light power. It is sufficient to measure the relative power. Absolute power levels are not needed, but are sometimes useful for calculating power density (intensity) at the polarizer aperture. Considerable care is needed to ensure that the power reading is not sensitive to (*a*) wobble of the transmitted beam as the polarizer is rotated and (*b*) polarization state of the transmitted light beam.

6.5 Transmitted power levels may vary from the noise level of the detector-preamplifier combination up to several watts for a laser source. It is essential to ensure that the power readout responds in a linear way to the actual power level. This usually requires calibration of the detector-preamplifier with optical filters of known transmission to confirm linear response.

6.6 It may be necessary to use an optical bandpass filter on the detector to minimize acceptance of stray light. This can also be accomplished by amplitude modulating (with a mechanical chopper) the source light, and using a synchronized, phase sensitive (lock-in) amplifier with the detector. Stray light reaching the detector will decrease the accuracy of the test. In particular, *C* obtained with stray light reaching the detector will be less than *C* obtainable without stray light.

7. Hazards

7.1 **Precaution**—*Avoid looking into a direct beam or into a specularly beam*. Lasers with beam powers on the order of 1 mW and greater can cause injury to personnel. The provisions of ANSI Z136.1 should be followed if a laser is used. In particular, do not let the laser beam impinge on the skin. In general, approved laser safety glasses are worn in the presence of any active laser. However, when performing this test method with low-power visible lasers, it may be necessary to remove the goggles in order to facilitate the beam alignment.

8. Procedure and Calculation

8.1 *Direct Contrast Measurement*:

8.1.1 Use this procedure and calculation only if $C_L >> C$ for the polarizer to be tested. It is not necessary to know the value C_L.

8.1.1.1 Record the transmitted power level, P_{tot}, without the polarizer in place.

[4] Leonard, T. A., "Infrared Polarizer Selection," *SPIE*, Vol 288, 1981, p. 129.

8.1.1.2 Position the polarizer in the holder, rotate the polarizer for a maximum reading, and record the transmitted power level, P_{max}.

8.1.1.3 Rotate the polarizer for a minimum reading and record the transmitted power level, P_{min}.

8.1.1.4 Block the light beam at the source assembly and record the noise level, P_n. If $P_n \approx P_{min}$ increase the dynamic range of the measurement apparatus by increasing P_{tot} or decreasing P_n so that a successful measurement can be made.

8.1.2 *Calculation*:

8.1.2.1 The calculation is as follows:

$$P_{max} = P_{tot} t_1 \tag{3}$$

and

$$P_{min} = P_{tot} t_2 + P_n \tag{4}$$

so

$$C = t_1/t_2 = (P_{max})/(P_{min} - P_n),\ t_1 = P_{max}/P_{tot} \tag{5}$$

Normally $P_n \ll P_{tot}$ and P_{max}, so it is only necessary to consider the noise level with the P_{min} measurement.

8.2 *Contrast Measurement With Comparison*:

8.2.1 Use this procedure and calculation only if C_L is on the order of C for the polarizer to be tested. It is necessary to know the value of C_L for the calculation. Note that this procedure is similar to measuring X for a pair of polarizers when the contrast of one of the polarizers is known.

8.2.1.1 Record the transmitted power level, P_{tot}, without the polarizer in place.

8.2.1.2 Position the polarizer in the holder, rotate the polarizer for a maximum reading, and record the transmitted power level, P_{max}.

8.2.1.3 Rotate the polarizer for a minimum reading and record the transmitted power level, P_{min}.

8.2.1.4 Block the light beam at the source assembly and record the noise level, P_n. If $P_n \approx P_{min}$ increase the dynamic range of the measurement apparatus by increasing P_{tot} or decreasing P_n so that a successful measurement can be made.

8.2.2 *Calculation*:

8.2.2.1 The calculation is as follows:

$$P_{tot} = P_1 + P_2, \tag{6}$$
$$C_L = P_1/P_2$$

$$P_{max} = P_1 t_1 + P_2 t_2,$$
$$P_{min} = P_1 t_2 + P_2 t_1 + P_n \tag{7}$$

so

use P_{tot} and C_L to solve for P_1 and P_2 then solve for t_1 and t_2 to obtain

$$C = t_1/t_2 \tag{8}$$

Normally $P_n \ll P_{tot}$ and P_{max} so it is only necessary to consider the noise level with the P_{min} measurement.

8.3 *Indirect Contrast Measurement*:

8.3.1 This procedure and calculation can be used with an unpolarized or polarized light beam of unknown C_L. It must be used if $C_L \ll C$ for the polarizer to be tested. You must have three polarizers (denoted by A, B, C). All three polarizers can have unknown C and t_1, but the accuracy of the calculated values are best if they are similar.

8.3.2 This test method ignores the $t_2 t_2$ terms in the approximations for t_1 and C. If $C > 10$ for all three polarizers, the resulting error in C will be <1 %.

8.3.3 Position A in the first holder and rotate it midway between the maximum and minimum readings. The maximum and minimum readings will be 90° apart, so the polarizer will be 45° from each. This divides P_{tot} equally between the t_1 and t_2 axes of A.

8.3.4 Record the transmitted power level, P_{tot}, without a polarizer in the second holder.

8.3.5 Position B in the second holder, rotate B for a maximum reading and record the transmitted power level, P_{max}.

8.3.6 Rotate B for a minimum reading and record the transmitted power level, P_{min}.

8.3.7 Block the light beam at the source assembly and record the noise level, P_n. If $P_n \approx P_{min}$ increase the dynamic range of the measurement apparatus by increasing P_{tot} or decreasing P_n so that a successful measurement can be made.

8.3.8 Calculate as follows:

$$X^{AB} = (P_{max})/(P_{min} - P_n),\ t^B_1 \approx P_{max}/P_{tot} \tag{9}$$

8.3.9 Repeat 8.3.3 through 8.3.7 with B in the first holder and C in the second holder.

8.3.10 Calculate as follows:

$$X^{BC} = (P_{max})/(P_{min} - P_n),\ t^C_1 \approx P_{max}/P_{tot} \tag{10}$$

8.3.11 Repeat 8.3.3. through 8.3.7 with C in the first holder and A in the second holder.

8.3.12 Calculate as follows:

$$X^{CA} = (P_{max})/(P_{min} - P_n),\ t^A_1 \approx P_{max}/P_{tot} \tag{11}$$

8.3.13 Use the following three approximations for extinction along with the measured parameters to solve for t^A_2, t^B_2, and t^C_2:

$$X^{AB} \approx (t^A_1 t^B_1)/[(t^A_1 t^B_2) + (t^A_2 t^B_1)] \tag{12}$$

$$X^{BC} \approx (t^B_1 t^C_1)/[(t^B_1 t^C_2) + (t^B_2 t^C_1)] \tag{13}$$

$$X^{CA} \approx (t^C_1 t^A_1)/[(t^C_1 t^A_2) + (t^C_2 t^A_1)] \tag{14}$$

8.3.14 Calculate contrast as follows:

$$C^A = t^A_1/t^A_2, \tag{15}$$

$$C^B = t^B_1/t^B_2, \tag{16}$$

$$C^C = t^C_1/t^C_2, \tag{17}$$

9. Report

9.1 Report the following information:

9.1.1 Laboratory name, operator's name, and date,

9.1.2 Polarizer identification,

9.1.3 Test method used—direct, comparison or indirect,

9.1.4 Light source properties including wavelength, power level, beam divergence,

9.1.5 Measurement parameters at the polarizer including beam size, location in the aperture, and angle-of-incidence,

9.1.6 Contrast and t_1,

9.1.7 Optional information that can be reported if desired:

9.1.7.1 For direct measurement of C:

$$P_{tot}, P_{max}, P_{min}, P_n \quad (18)$$

9.1.7.2 For comparison measurement of C:

$$P_{tot}, P_{max}, P_{min}, P_n, C_L \quad (19)$$

9.1.7.3 For indirect measurement of C:

$$P_{tot}, P_{max}, P_{min}, P_n$$

,

and X for each pairing and all three calculated C and t_1.

10. Precision

10.1 The precision of these test methods has not been evaluated by interlaboratory round-robin measurements.

11. Keywords

11.1 contrast; extinction ratio; polarization; polarization ratio; polarizer