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Optics and photonics — Optical materials and components — Test method for refractive index of infrared optical materials

Optique et photonique — Matériaux et composants optiques — Méthode d'essai de l'indice de réfraction des matériaux optiques infrarouges

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Foreword

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The committee responsible for this document is ISO/TC 172, *Optics and photonics*, Subcommittee SC 3, *Optical materials and components*.

Introduction

This International Standard applies to the measurement of relative refractive index to the air for infrared optical materials.

Two major methods for measuring the refractive index of infrared materials exist. These are interferometric methods and minimum deviation methods. In this International Standard, a test method using minimum deviation for infrared materials is described, which is also used in the visible spectral range. It has the advantages of being applicable to more kinds of materials compared with interferometric methods and of ease of data processing because of the simple measurement principle.

Optics and photonics — Optical materials and components — Test method for refractive index of infrared optical materials

1 Scope

This International Standard provides a standard method for measuring the relative refractive index to the air of infrared materials used in the infrared spectral range from 0,78 µm to 25 µm.

The scope of this International Standard excludes methods for measuring the refractive index of birefringent materials and methods for measuring the complex refractive index.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 11382:2010, *Optics and photonics — Optical materials and components — Characterization of optical materials used in the infrared spectral range from 0,78 µm to 25 µm*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
refractive index
absolute refractive index
ratio of the velocity of the electromagnetic waves at a specific wavelength in a vacuum to the velocity of the waves in the material

[SOURCE: ISO 12123:2010, 3.1]

3.2
relative refractive index
ratio of the (absolute) refractive index of the material of the specimen to the (absolute) refractive index of the material in contact with the specimen at a specific wavelength

3.3
angle of minimum deviation
angle between the ray incident upon the specimen prism and the ray exiting the specimen prism at its minimum value, which occurs when the ray inside the specimen prism makes equal angles with the entrance and exit faces of the specimen prism

4 Method for measuring

4.1 General

In this International Standard, the technique of the minimum deviation method for measuring refractive index is described.

The minimum deviation method shall be applied for measuring refractive index.

4.2 Principle

As shown in Figure 1, when the monochromatic light beam is refracted by the specimen prism with minimum deviation, the relative refractive index of the specimen prism to the air at the wavelength of the monochromatic light beam is described by Formula (1):

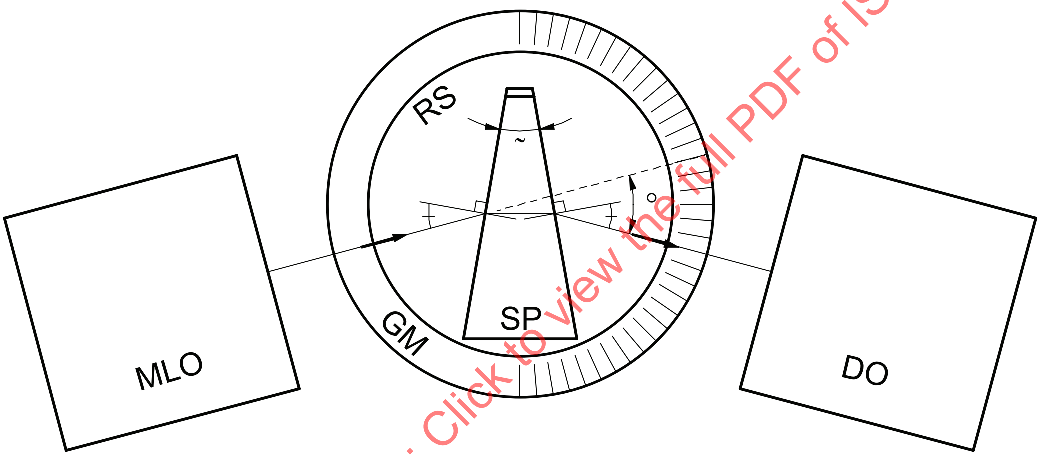
$$n_{\text{rel}} = \frac{\sin\left[(\alpha + \delta)/2\right]}{\sin(\alpha/2)} \tag{1}$$

where

n_{rel} is the relative refractive index of the specimen prism to the air;

α is the apex angle of the specimen prism;

δ is the angle of minimum deviation of the monochromatic light beam refracted by the specimen prism.



Key

MLO monochromatic light source optics

SP specimen prism

RS rotating stage

GM goniometer

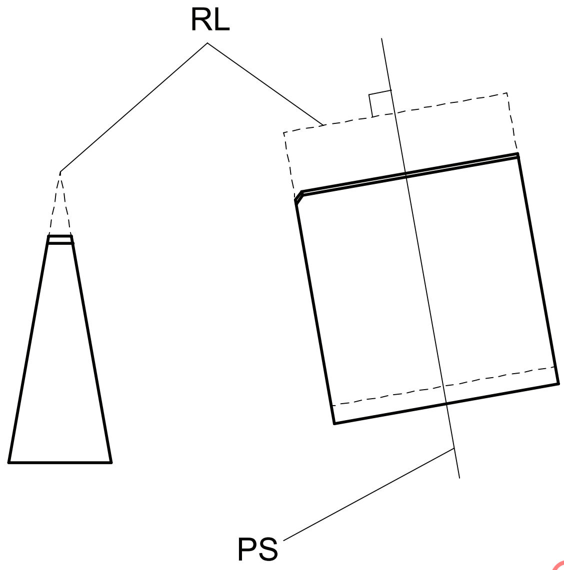
DO detector optics

δ angle of minimum deviation

α apex angle of the specimen prism

Figure 1 — Schematic of the minimum deviation method

The monochromatic light beam shall be parallel to the plane of section, PS, of the specimen prism. (See Figure 2.)



Key

RL ridge line

PS plane of section

Figure 2 — Ridge line and the plane of section of the specimen prism

4.3 Apparatus and procedure for measurement

The apparatus for measurement shall be equipped with the following:

a) a method to emit a collimated monochromatic light beam of specified wavelength to the specimen prism;

b) a method to vary the angle of the collimated monochromatic light beam to the entrance face of the specimen prism;

c) a method to determine the direction of the monochromatic light beam refracted by the specimen prism;

d) a method to indicate the angle of minimum deviation δ;

e) a method to measure the temperature of the specimen prism.

Examples of apparatus for measurement of the angle of minimum deviation are shown in Annex A. A procedure for measurement is also described in Annex A. In addition, the absolute value of the angle of deviation error is described in Annex B.

NOTE See Figure 1.

4.4 Wavelength of light beam for measurement

The wavelengths of measurement shall adequately sample the spectral range of interest to enable curve fitting of the data to a dispersion formula, allowing calculation of the relative refractive index at any arbitrary wavelength within the spectral range.

5 Specimens

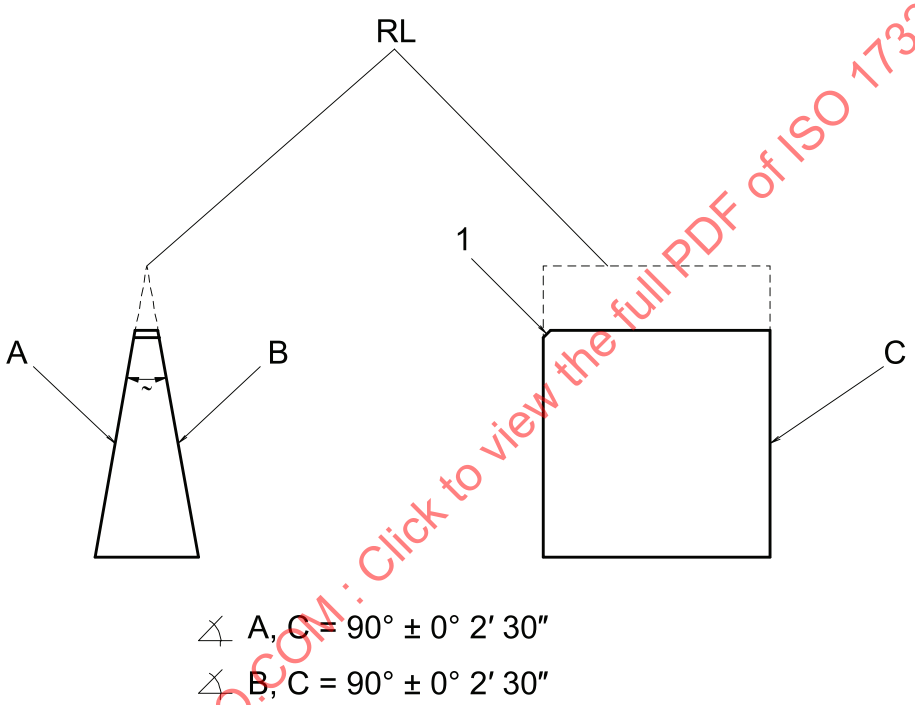
5.1 The shape and dimensions of the specimen prism

The specimen shall be a wedged prism made of the material to be measured. The entrance face and the exit face shall be polished.

An example of the shape of the specimen prism is shown in Figure 3. The optimum apex angle (such that error in measurement of the apex angle is least severe) for a material of the relative refractive index n_{rel} is

$$\alpha = 2\arctan(1/n_{rel}) \tag{2}$$

For low index materials, this relation can result in undesirably large apex angles; this relation shall be used as guidance.



Key

1 chamfer

RL ridge line

α apex angle of the specimen prism

Figure 3 — Shape of the specimen prism

5.2 Surface accuracy

The surface accuracy of the entrance face and the exit face of the specimen prism shall be measured with an interferometer. Any measured power term shall not be subtracted from measurement data. A surface flatness error should be 150 nm P-V or less over the entire clear aperture of the specimen prism faces.

6 Test report

The test report shall specify the following:

a) specimen name in accordance with ISO 11382:2010, 5.6;

b) date, place, measurer's name;

c) temperature, humidity, air pressure of ambient air;

d) apex angle of the specimen prism;

e) temperature of the specimen prism;

f) surface accuracy of the entrance face and the exit face;

g) wavelengths and bandwidth (full width at half maximum) of wavelengths for measurement;

h) angles of minimum deviation;

i) relative refractive indices to the air.

Values of c), d), e), g), h), and i) shall be specified with values of uncertainty.

Annex A
(informative)

Apparatus for measurement

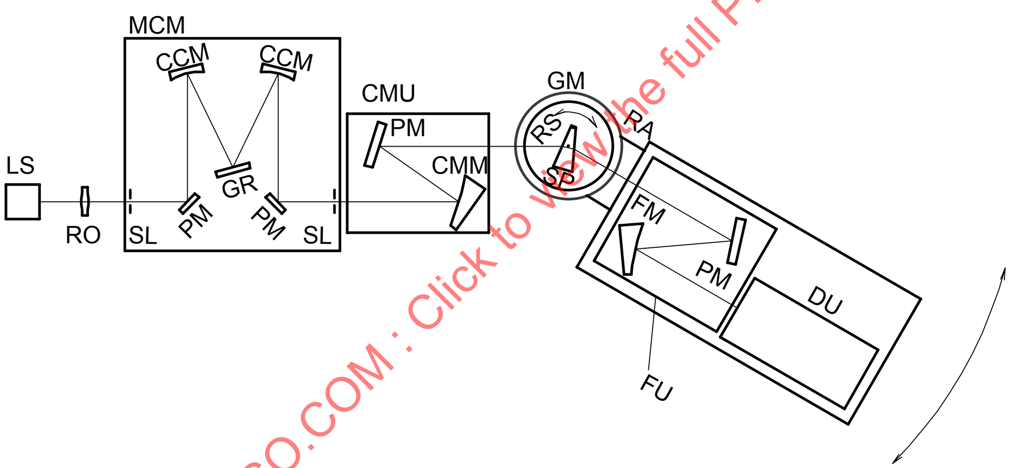
A.1 General

Examples of apparatus for measurement of the relative refractive index and the measurement procedure are described.

In the measurement room, air temperature, pressure and humidity, and the temperature of the specimen prism are kept at specified values during the measurement time.

A.2 Apparatus for measurement

The apparatus is composed of those parts in Figure A.1. It is shown in a configuration that uses a monochromator. However, the monochromator can be replaced with another wavelength selecting unit.



Key

LS	light source
RO	relay optics
SL	slit
PM	plane mirror
CCM	concave mirror
GR	grating
MCM	monochromator
CMU	collimating unit
CMM	collimating mirror
SP	specimen prism
RS	rotating stage
GM	goniometer
RA	rotating arm
FU	focusing unit

FM focusing mirror
DU detector unit

NOTE Arrows indicate rotation of rotating stage and rotating arm.

Figure A.1 — Outline of configuration

A.2.1 Light source

The light source emits the light which includes the spectrum of measurement wavelengths.

A.2.2 Wavelength selecting unit

The wavelength selecting unit selects a desired light from a slit or from a pinhole that is located at the focus of the collimating unit.

The grating monochromator is a part for selecting the monochromatic light beam of desired wavelength from the light source.

The light beam from the light source enters the grating monochromator through the entrance slit or the entrance pinhole, and the monochromatic light beam of selected wavelength is passed through the exit slit or the exit pinhole.

The optical systems of the grating monochromator are composed of the reflecting optical components to make the grating monochromator operational in the wide spectral range. The calibration light beams are the monochromatic emission lines which wavelengths are known accurately. The calibration light beams are applied to the calibration of the wavelength-counter of the grating monochromator.

The light beam from the light source and the calibration light beam are transmitted at the same position on the entrance slit and the exit slit of the grating monochromator.

Band-pass filter can also be used as wavelength selecting units.

NOTE 1 Some bandpass filters shift their centre wavelengths with temperature.

NOTE 2 The wavelength of the light beam exiting from the grating monochromator changes along with the longitudinal direction of the slit.

A.2.3 Collimating unit

The collimating unit is a unit for collimating the monochromatic light beam from the entrance slit or from the entrance pinhole of the wavelength selecting unit. It consists of reflecting optics to avoid errors caused by chromatic aberration of the optics.

A.2.4 Goniometer

The goniometer consists of a rotating stage and a rotating arm. It has a function for reading a rotation angle of the rotating arm. The rotating stage holds the specimen prism at the position where the entrance face of the specimen prism is illuminated by the monochromatic light beam from the collimating unit and rotates the specimen prism. The rotating arm rotates a focusing unit and a detector unit.

The rotating axis of the rotating stage and the rotating axis of the rotating arm are parallel to the ridge line defined by the entrance face and the exit face of the specimen prism. The holder of the specimen prism has an adjusting mechanism for tilting.

The plane of section, PS, of the specimen prism is maintained parallel to the monochromatic light beam. The plane, PS, is defined as a plane normal to the ridge line of the specimen prism.

NOTE 1 The measured angle of minimum deviation alters due to the angle between the monochromatic light beam and the plane of section, PS.

NOTE 2 The relationship between change in the specimen prism rotation angle and change in rotating arm angle to maintain the condition of minimum deviation once established is a fixed ratio of 1:2 respectively.

A.2.5 Focusing unit

The focusing unit focuses the monochromatic light beam refracted by the specimen prism and forms the image of the exit slit or the exit pinhole of the wavelength selecting unit. The focusing unit is placed on the rotating arm of the goniometer.

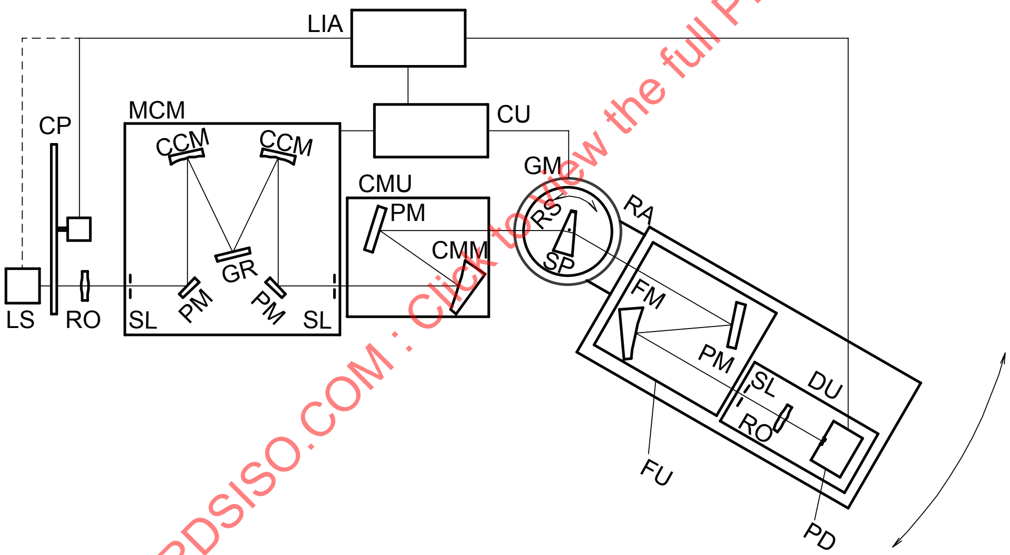
A.2.6 Detector unit

A.2.6.1 General

The detector unit is unified with the focusing unit on the rotating arm.

A.2.6.2 Photodetector

As shown in Figure A.2, the slit or the pinhole is placed on the focal plane of the focusing unit, and then the monochromatic light beam through the slit or the pinhole is detected by the detector unit. If necessary, relay optics can be put between the slit or the pinhole and the photodetector to focus the monochromatic light beam on the photodetector. Many other valid or even preferred configurations are also available.



Key

LS light source
CP chopper
RO relay optics
SL slit
PM plane mirror
CCM concave mirror
GR grating
MCM monochromator
CMU collimating unit
CMM collimating mirror
SP specimen prism
RS rotating stage
GM goniometer

RA rotating arm
FU focusing unit
FM focusing mirror
DU detector unit
PD photodetector
LIA lock-in amplifier
CU control unit

NOTE 1 Arrows indicate rotation of rotating stage and rotating arm.

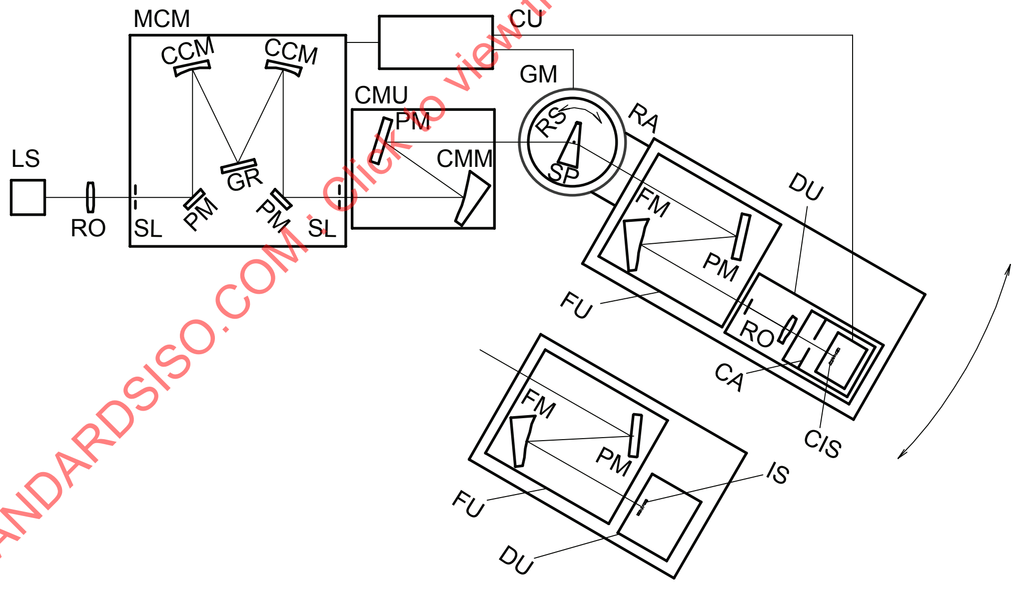
NOTE 2 A chopper and a lock-in amplifier are used for obtaining a high signal to noise ratio. The blinking light source is also used.

Figure A.2 — Configuration employing point sensor

A.2.6.3 Image sensor

As shown in Figure A.3, the image of the exit slit or the exit pinhole of the wavelength selecting unit is formed on the image sensor surface. Many other valid or even preferred configurations are also available. The area array image sensor is generally used. The line sensor is also used.

NOTE If the image sensor is a cooled type, a cold aperture, or a cold stop, is set up in the sensor dewar. In that case, a relay optics may be necessary between the focusing unit and the detector unit to project the image of the exit slit of the wavelength selecting unit on the image sensor surface.



Key

LS light source
RO relay optics
SL slit
PM plane mirror
CCM concave mirror
GR grating
MCM monochromator
CMU collimating unit
CMM collimating mirror

SP specimen prism
RS rotating stage
GM goniometer
RA rotating arm
FU focusing unit
FM focusing mirror
DU detector unit
CA cold aperture
IS image sensor
CIS cooled image sensor
CU control unit

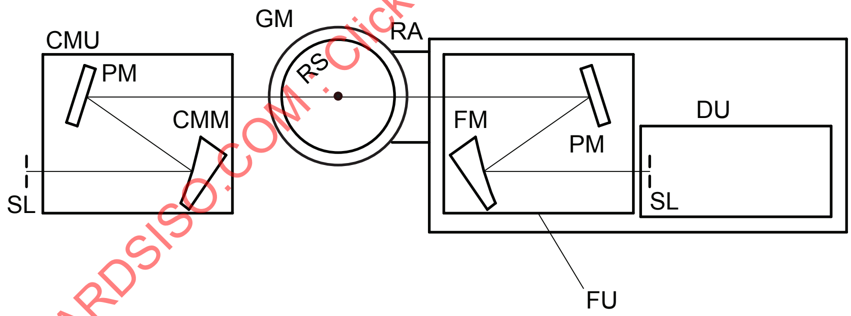
NOTE Arrows indicate rotation of rotating stage and rotating arm.

Figure A.3 — Configuration employing image sensor

A.3 Procedure for measurement

A.3.1 Initial position

As shown in Figure A.4, the exit slit or the exit pinhole image of the wavelength selecting unit is set on the slit of the photodetector or the standard pixel of the image sensor by adjusting the angle of the rotating arm without the specimen prism. This angle is defined as the initial position of the optical system. Measurements should be implemented to ensure either that the initial position is stable over the course of measurements over wavelength and temperature, or that any variations in initial position are detected and compensated.



Key

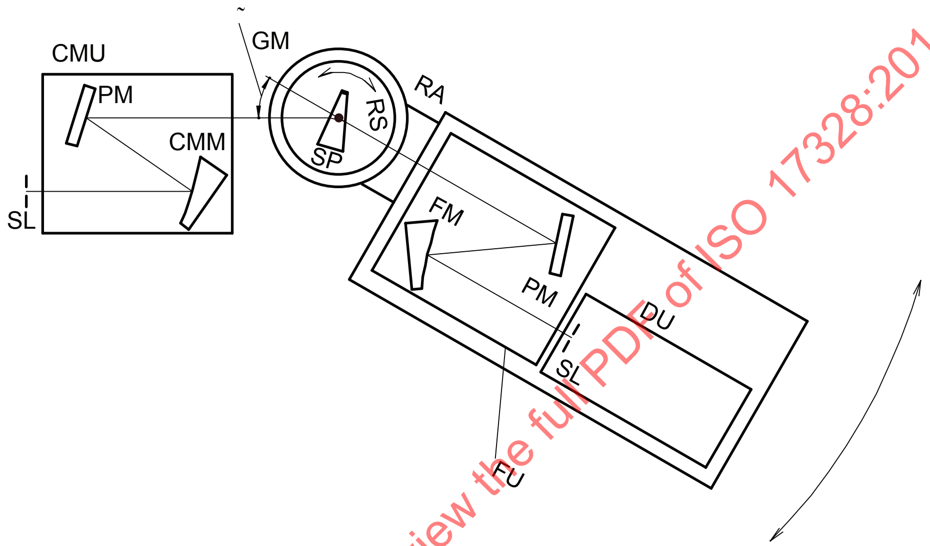
SL slit
CMU collimating unit
CMM collimating mirror
PM plane mirror
RS rotating stage
GM goniometer
RA rotating arm
FU focusing unit
FM focusing mirror
DU detector unit

Figure A.4 — Initial position of optical system

A.3.2 Angle of minimum deviation

After setting the initial position of the rotating arm, the specimen prism is set on the rotating stage. It is then rotated to establish the condition of minimum deviation. The angle of minimum deviation, δ, which depends on wavelength, specimen prism temperature, and air temperature, is the difference between the angle of the rotating arm read out with the rotating arm positioned to detect the monochromatic light beam refracted by the specimen prism and the rotating arm angle at the initial position and soak time prior to measurement to ensure it has reached thermal equilibrium. See Figure A.5.

In the case of photodetector, the angles of deviation measured at each step of the rotating stage are fitted a parabolic curve to determine the angle of minimum deviation.



Key

SL slit
CMU collimating unit
CMM collimating mirror
PM plane mirror
SP specimen prism
RS rotating stage
GM goniometer
RA rotating arm
FU focusing unit
FM focusing mirror
DU detector unit
δ angle of minimum deviation

NOTE Arrows indicate rotation of rotating stage and rotating arm.

Figure A.5 — Position of optical system at measurement of angle of minimum deviation

Figure A.6 illustrates an alternate method of establishing the angle of minimum deviation. In this method, the minimum deviation condition is established for two positions of the specimen prism — with the collimated beam entering the specimen prism first through one of its polished faces and then through the other. The angle of minimum deviation, δ, is half of the total angular excursion of the rotating arm between the two minimum deviation positions.

