SAND78-1918
UNLIMITED RELEASE

THE DEVELOPMENT OF A PORTABLE SPECULAR REFLECTOMETER FOR FIELD MEASUREMENTS OF SOLAR MIRROR MATERIALS

JAMES M. FREESE

Prepared by Sandia Laboratories, Albuquerque, New Mexico 87115 and Livermore, California 94550 for the United States Department of Energy under Contract AT(29-1)-789

OCTOBER 1978

Sandia Laboratories
energy report

Issued by Sandia Laboratories, operated for the United States Department of Energy by Sandia Corporation.

Printed in the United States of America
Available from
National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
Price: Printed Copy $4.00; Microfiche $3.00

SAND78-1918

The Development of a Portable Specular Reflectometer for Field Measurements of Solar Mirror Materials

James M. Freese
Thermophysical Properties
Division 5842

Abstract

A portable reflectometer designed for in-the-field measurements of solar mirror materials has been developed. This instrument is of a convenient size for use by one operator in an outdoor environment. Instrument design, operation, and calibration are discussed. It is shown that the instrument responds linearly (± 0.006 transmission units) to variations of intensity of incident and reflected beams and that the readings are not affected by the presence of stray light. The mirror materials measured with the portable instrument include samples of polished aluminum, metallized plastic film and silvered glass. The reflectance values of these materials were within ±0.005 reflectance units of the values obtained from appropriately averaging reflectance versus wavelength data taken with a laboratory bidirectional reflectometer. This instrument should prove useful in monitoring the effects of dirt and weathering on mirror specular reflectance in the field.

Acknowledgment

The author would like to thank R. B. Pettit for his helpful discussions concerning the portable reflectometer.

Table of Contents

List of Figures

List of Tables

I. Introduction

A large number of mirror surfaces from the Midtemperature Solar Systems Test Facility (MSSTF) and the Solar Thermal Test Facility (STTF) located at Sandia Laboratories, Albuquerque, NM, have been exposed to the weather for some time. Specular reflectance measurements of these mirror surfaces are needed in order to determine the effect of accumulated dust as well as to detect any permanent degradation of the reflectance values. However, it is impractical to remove a mirror from a collector for measurements in the laboratory. Therefore, there is a requirement for a portable reflectometer which is capable of measuring the specular reflectance properties of mirror surfaces in the field.

A potential obstacle in the development of this field instrument is that scattering, resulting from either accumulated dust or the mirror material itself, is wavelength-dependent.[1] When these factors are significant, a large number of measurements at different wavelengths would have to be taken to completely characterize the specular reflectance properties of these mirrors. However, these problems have proved to be solvable. The wavelength dependence can be measured in the laboratory and a correction factor can be generated for each material at every collection aperture size. Also, it has been shown that for silvered glass with accumulated dust, a measurement at one wavelength was sufficient to predict values at all wavelengths.[1] It is probable that this is also true for other mirror materials. The data that are generated by the portable reflectometer can only be used to determine changes in the specular reflectance properties and cannot be used to distinguish between the dust scattering, scratches, or permanent degradation of the mirror surface. However, the degradation of a mirror surface can be determined by measuring the total hemispherical reflectance in the field with a Gier-Dunkle solar reflectometer.[2]

II. Instrument Description

The portable reflectometer essentially consits of two parts: collimation optics and collection optics, as shown in the photograph in Figure 1A and the schematic in Figure 1B. Many of the optical components in the system were chosen for convenience and availability. The collimation optics consist of a tungsten filament lamp, filter, focusing lens, source aperture, collimating lens, and beam aperture. The filter (Corion Corporation IRS-2) passes only a beam of radiation with wavelengths from 350 to 750 nm with the peak transmission occurring at 560 nm (Figure 2). This radiation is imaged onto a 0.25 mm diameter aperture with a 17 mm focal length lens. The circular aperture is positioned at the focal point of the collimating lens (50 mm focal length) so that the collimating optics produce a beam of radiation whose divergence is 5.0 mrad (0.25 mm/50 mm). A permanent beam aperture positioned in front of the collimating lens limits the beam diameter to 5 mm. This beam aperture insures that

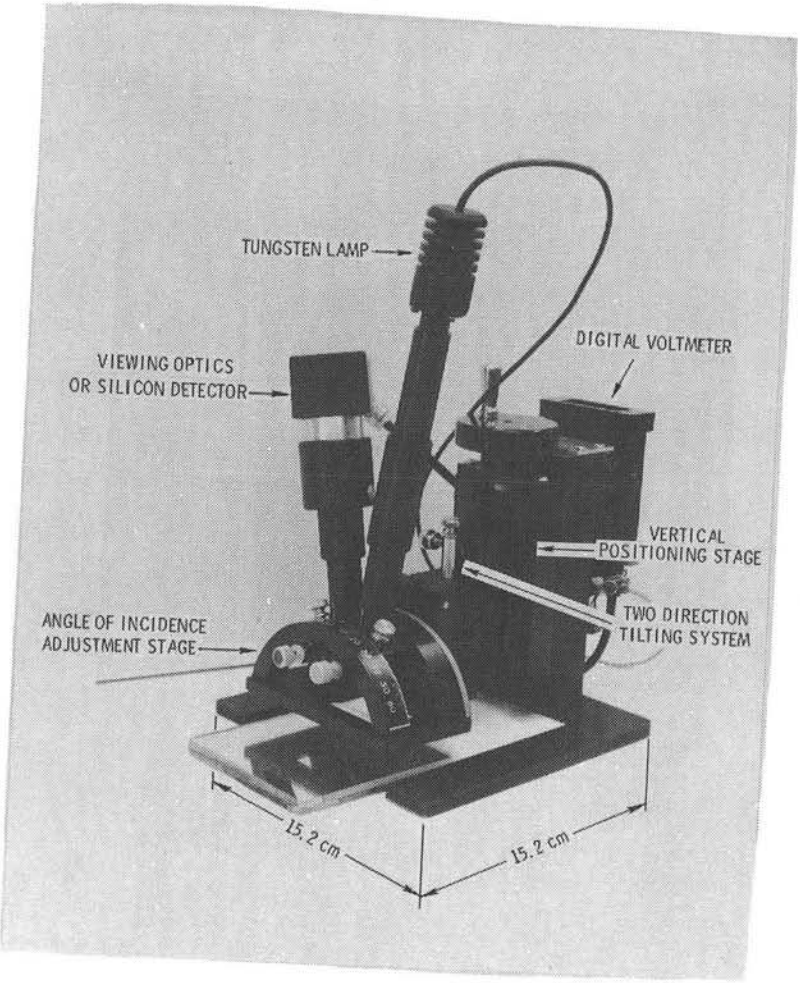


Figure 1A. Photograph of Portable Reflectometer.

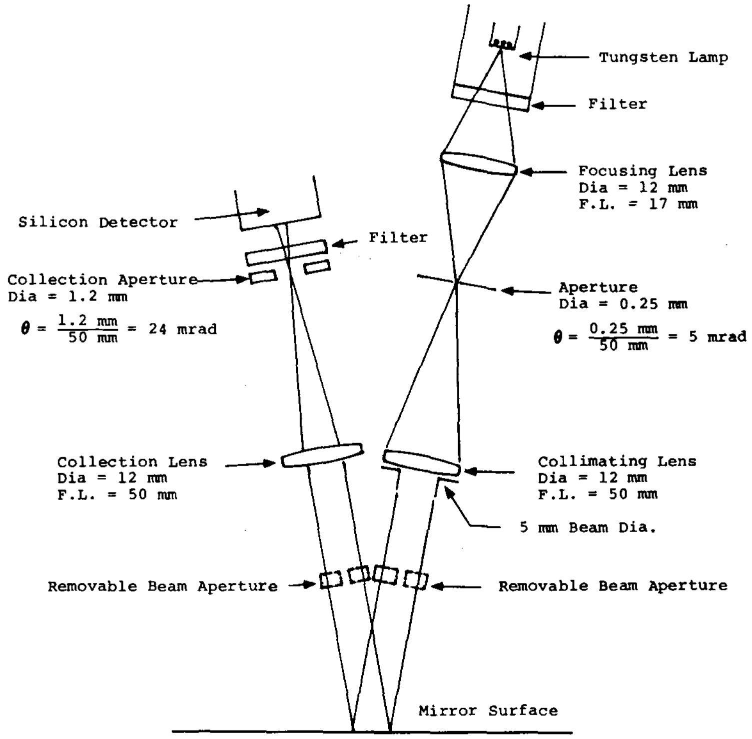


Figure 1B. Schematic Diagram of Portable Reflectometer.

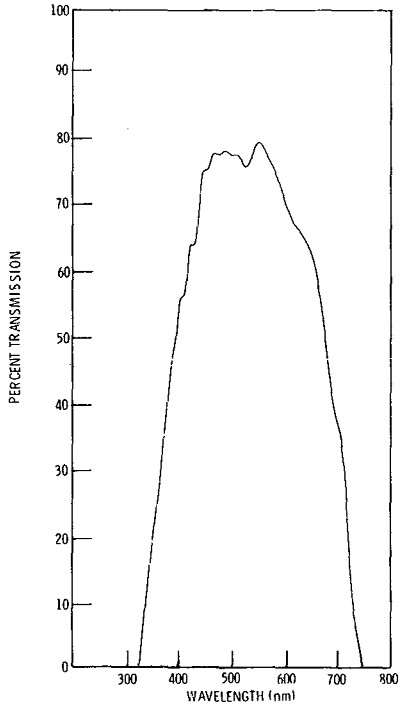


Figure 2. Transmission Curve for Corion Corporation Filter (IRS-2)

all of the reflected and scattered radiation from the mirror surface is collected by the 12 mm diameter collection lens.

The collection optics consist of a collection lens, which is identical to the collimating lens, a collection aperture, filter and viewing optics or silicon detector. The collection lens is positioned to produce an image of the collimating aperture at the plane of the collection aperture. The aperture diameter is 1.2 mm, which corresponds to a beam divergence of 24.0 mrad (1.2 mm/50 mm), and was chosen for easy collimation aperture positioning and alignment. Also, a large aperture size was needed to collect most of the specular beam for materials of interest.[3] The size of the aperture selected may be different for different mirror materials but should always be larger than the collimating aperture. The collection filter is identical to the collimating filter and is used at this location to reduce scattered radiation from the sun. The viewing optics are focused on the 1.2 mm diameter aperture and allow the viewer to observe the reflected beam. The viewing optics can be replaced with a silicon detector (United Detector Technology Inc., Model 500) which detects the radiation that is passed through the collection aperture and converts the energy to a current. The current is then passed through a built-in operational amplifier which produces a voltage output which is read directly from a digital voltmeter.

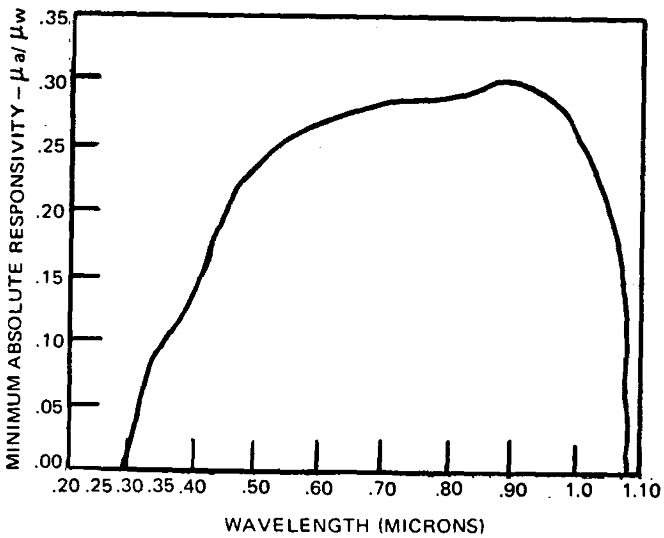


Figure 3. Spectral Response Curve of United Detector Technology Inc., Detector Model UDT-500.

Some components from a Gamma Scientific Inc. Model 191A microreflectometer were incorporated in the portable reflectometer to expedite the construction of the instrument. These components consist of the tungsten filament lamp, lamp power supply, vertical position stage, and the angle of incidence adjustment stage. A new baseplate with a soft felt backing was constructed to support the reflectometer on the surface to be measured. In addition, a two-direction (x-y) tilting system was fabricated for alignment purposes. Finally, a pair of small beam apertures was constructed to fit into the angle of incidence adjustment stage (see Figure 1A). The instrument is normally operated on 110V ac; however, nickel-cadmium batteries can be used to make the instrument completely portable.

III. Alignment Procedure

It is important that the reflected beam be centered on the collection lens and also centered on the collection aperture. This alignment is a function of the type of mirror material to be measured (e.g., first-surface versus second-surface mirror) and the orientation of the reflectometer with respect to the surface normal. To accomplish the alignment, the beam apertures are placed in the collimation and collection beam paths. With the viewing optics in position, the vertical height and x-y tilt are adjusted to provide maximum radiation from the light source through the 0.25 mm aperture and to center the beam in the collection aperture. The viewing optics are then replaced with the silicon detector and final adjustments are made to maximize the signal.

IV. Measurement Procedure

The system is turned on 5 minutes prior to any measurements to allow the lamp to reach temperature and stabilize. This portable instrument does not have the capability for the collimation optics to be pointed directly into the collection optics to obtain a direct 100% reading. Thus the sequence for measuring the specular reflectance of a surface is to first set the angle of incidence between the collimating and collecting optics. The incidence angle that is usually chosen is 10°. Next, a standard reference sample is placed in the system and the reflectometer is aligned. The reference sample we used is an aluminized quartz flat which has been calibrated by the National Bureau of Standards and has a reflectance of R_{std}. A digital voltmeter reading is taken (V_{std}) and the standard mirror is replaced with the mirror whose reflectance is unknown. The alignment procedure is repeated and a digital voltmeter reading is again taken (V_{sample}). The reflectance of the unknown surface is obtained from the relation

$$R_{sample} = R_{std} \; (V_{sample}/V_{std})$$

V. Calibration Experiments

A. Neutral Density Filter Experiment

Neutral density filters from 0.3 to 1.0 absorptance were placed in the beam path of both the bidirectional reflectometer and the portable reflectometer to compare transmission results and as a check on the linearity of the portable instrument. The laboratory bidirectional reflectometer was operated at a wavelength of 565 nm, while the portable instrument has a 400 nm bandwidth from 350 to 750 nm. Table I contains the results of this experiment. The first column is the nominal optical density for each filter. The next column represents the values of transmission measured by the laboratory bidirectional reflectometer, while the last column contains the values measured by the portable instrument. The measurements of the two instruments compare favorably with each other (± 0.006 transmission units) and indicate that the portable instrument output is linear.

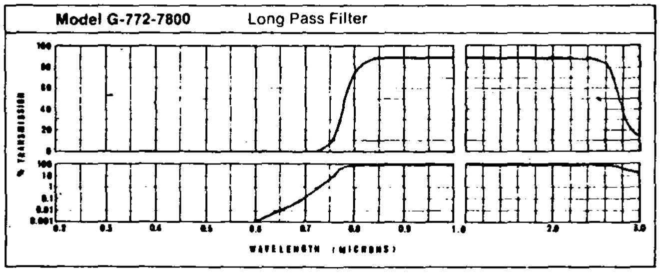
Table I. Transmission Values for Oriel Neutral Density Filters Measured on the Laboratory Bidirectional Reflectometer and the Portable Reflectometer

Nominal Optical Density	Laboratory Bidirectional Reflectometer % Transmission Measured at 565 nm	Portable Reflectometer % Transmission
0.3	50.8	51.0
0.5	31.7	31.4
0.3 + 0.5	16.8	16.2
1.0	11.6	11.3

B. Stray Light Experiment

An experiment was conducted outdoors in natural sunlight to determine if stray light had any effect on the specular reflectance measurement made by the portable instrument. Two filters with different transmission curves were used in this experiment (see Figure 4). One was an Oriel Corporation long pass filter (Model G-772-7800) which blocked radiation up to 700 nm and passed radiation from 700 to 3000 nm. The other filter was an Oriel Corporation band pass filter

(Model G-774-3550) which passed radiation between 300 and 400 nm. Each filter was individually placed in both the collimating beam path and the collecting beam path of the portable reflectometer. The readings from the digital voltmeter for each filter were zero. Because the filters blocked the band of light that was passed by the Corion filters and passed other wavelengths of light, any stray light in the filter pass bands would have given a non-zero reading on the digital voltmeter. Thus it is concluded that the instrument responds only to the specular reflected beam produced by the source and mirror.



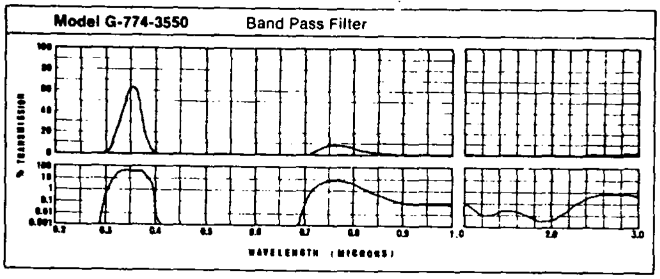


Figure 4. Spectral Trnamission Curves for Oriel Color Glass Filters (Model G-772-7800 and G-774-3550).

C. Mirror Reflectance Determination

The specular reflectance properties of a variety of mirror samples was measured using both the laboratory bidirectional reflectometer[3] and the portable reflectometer. The mirror samples selected for these measurements were as follows: (1) second-surface aluminized quartz flat (this was the reference sample calibrated by NBS), (2) Alcoa Type I specular reflector sheet without Alzak® anodized coating, (3) polished aluminum sheet manufactured in France (without any protective coating), (4) aluminized acrylic manufactured by 3M (special Scotchal 5400), and (5) second-surface silvered float glass.[4]

In order to compare the specular reflectance values of these materials as determined by two instruments, one must first look at the differences in the optical configuration in the instruments. There are four principal differences in these instruments which could affect the measured specular reflectance values: incident beam divergence, the aperture configuration, aperture size, and the spectral range of the measurement. First, the portable instrument has a larger incident beam divergence than the laboratory bidirectional instrument (5 mrad versus 1 mrad). It has been shown that at a constant angular acceptance aperture, as the incident beam divergence increases, the measured specular reflectance value decreases.[3] Thus, one would predict that the specular reflectance values of the portable instrument would be lower than the values determined with the laboratory bidirectional instrument. Second, the portable instrument utilizes a circular aperture configuration, while the laboratory instrument utilizes slit apertures. Thus, if both instruments had the same incident beam divergence, the specular reflectance values measured with the circular aperture (portable instrument) would always be less than or equal to the values measured with a slit aperture (laboratory instrument).[3] In addition, the acceptance aperture size of the portable instrument is larger than the bidirectional instrument (24 to 15 mrad) which would have the effect of producing higher specular reflectance values from the portable instrument. Finally, the spectral bandwidth of the laboratory instrument is approximately 4 nm and is set at discrete wavelengths between 400 to 900 nm, while the spectral bandwidth of the portable instrument, as defined by the filters and detector (see Figures 2 and 3) peaks at approximately 560 nm and has a full width at half-maximum of 250 nm. The procedure used to adjust for the different spectral bandwidth is discussed below.

Since the specular reflectance properties for the aluminized quartz flat, polished aluminum sheet from France, 3M metallized plastic, and the silvered glass samples reach their asymptotic values (constant) within the acceptance apertures of both instruments, the specular reflectance values measured by the two instruments should not be affected by the different aperture configurations, incident beam divergences, and aperture sizes. However, the Alcoa Type I specular reflector does not reach an asymptotic value because of the very fine rolling marks on the reflective surface of the material. In addition, the specular reflectance properties are asymmetrical.[3] A detailed mathematical analysis would have to be performed for this sample in order to determine the effect that these variables have on the specular reflectance values measured by the two instruments.

The experimental specular reflectance values of the mirror materials are shown in Table II. For the laboratory bidirectional reflectometer, the specular reflectance was measured at three wavelengths (500, 600, and 700 nm). In order to compare the results, the values determined with the laboratory instrument were "averaged" over the measurement spectrum of the portable instrument. This "average" value was calculated using the following procedure: The measurement spectrum of the portable instrument was obtained by first taking data points from 350 to 750 nm (at 25 nm intervals) from the transmission curve $T(\lambda)$ for the Corion Corporation (IRS-2) filter used on the portable instrument (see Figure 2). Because two filters are used in the optical system (see Figure 1B), the square of the transmittance values was obtained. Next, data points from 350 to 750 nm (also at 25 nm intervals) were taken from the response curve $X(\lambda)$ of the dtector (UDT-500) used on the portable instrument (Figure 3). The spectral bandwidth was then generated from the product of these data points (T^2X) and is shown in Figure 5. This curve was then divided into three regions: (I) 350 to 550 nm, (II) 550 to 650 nm, and (III) 650 to 750 nm. The fractional area of each region was then determined. The re-

Table II. Specular Reflectance Values of Mirror Materials Measured on the Laboratory Bidirectional Reflectometer and the Portable Reflectometer

Mirror Description	Percent Reflectance Measured on Laboratory Bidirectional Reflectometer			Calculated Percent Reflectance from Laboratory Bidirectional Reflectometer	Percent Reflectance of Portable Reflectometer
	500 nm	600 nm	700 nm		
Aluminized Quartz Flat	88.2	86.9	84.8	87.2	
(<u>Polished Aluminum</u>) Special Alzak (Parallel to Roller Marks)	86.3	86.2	85.3	86.1 } 83.9	83.5
Special Alzak (Perpendicular to Roller Marks)	81.0	82.2	82.2	81.7	83.5
French Reference #6	88.8	88.5	87.1	88.4	88.6
(<u>Metallized Plastic</u>) SCS 1790 (3M Scotchcal 5400)	85.1	84.4	82.6	84.5	84.8
(<u>Silvered Glass</u>) R119 Float	91.9	90.4	82.5	90.0	89.6

sults were: (I) 0.46, (II) 0.40, and (III) 0.14. Finally, the reflectance values measured by the laboratory bidirectional instrument were weighted by the respective fractional area value to produce weighted specular reflectance values, as shown in the next to last column of Table II. The specular reflectance values of all but one material measured on the portable reflectometer, as shown in the last column of Table II, are within ± 0.005 reflectance units of the values calculated from the laboratory bidirectional instrument data. The exception is the Alcoa Type I reflector where orientation affected the calculated average values. However, if an average of the two orientations is taken, the calculated average value of 0.839 is very close to the value of 0.835 determined with the portable instrument.

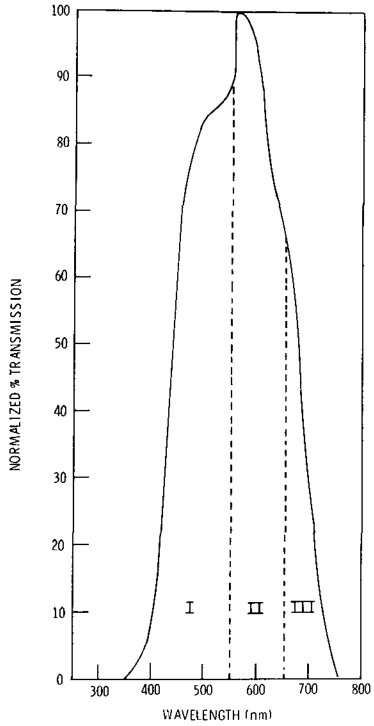


Figure 5. Instrument Spectral Bandwidth Which Includes Two Filters and Detector Response Curve.

VI. Conclusions

A portable reflectometer instrument has been developed to measure the specular reflectance of mirror materials in the field. A description of the instrument along with an alignment and measurement procedure has been provided to aid the operator in the field. The instrument has been checked for linearity by running a neutral density filter experiment. A stray light check was also made. These experiments proved that the portable instrument data compared favorably with the laboratory bidirectional instrument data and indicates that the response of the portable instrument is linear to within ± 0.006 transmission units (Table I). Also, no observable stray light passed by the filters in the portable instrument to give an erroneous reflectance reading. Finally, the specular reflectance of several different types of mirror materials was measured by the portable instrument and compared with the calculated specular reflectance values of the laboratory bidirectional instrument. With the exception of the Alcoa Type I sample, the portable instrument values were within ± 0.005 reflectance units of the values calculated from the laboratory instrument. Additional testing of this portable instrument will be performed at Sandia Laboratories' Solar Thermal Test Facility and the Midtemperature Solar Systems Test Facility.

The second phase in the development of the portable instrument will be to increase the beam diameter to ~ 2.5 cm. This will allow the instrument to average over a larger surface area of a mirror and reduce the number of measurements on a mirror required for obtaining a good averaged specular reflectance. In addition, this instrument will incorporate the capability of a straight-through beam configuration to obtain a 100% value and thus eliminate the need for a reference sample. Finally, the detector and viewing optics will be combined and an adjustable built-in collection aperture will be included to improve the convenience of instrument operation.