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Electro-optical systems — Cavity ring-down technique for high-reflectance measurement

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National foreword

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Electro-optical systems — Cavity ring-down technique for high-reflectance measurement

Systèmes électro-optiques — Technique d'alternance de la cavité pour le mesurage du facteur de réflexion

Reference number
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Foreword

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The committee responsible for this document is ISO/TC 172, *Optics and photonics*, Subcommittee SC 9, *Electro-optical systems*.

Introduction

With the development of film-deposition technology, the performance of optical thin films, especially the highly reflective coatings which are widely used in large high-power laser systems, interferometric gravitational-wave detectors, laser gyroscopes, and cavity-enhanced and cavity ring-down spectroscopy applications, has been substantially improved in recent years. Laser-based optical systems require some optical components with extremely high reflectance characteristic. It is necessary to be able to measure this reflectance characteristic precisely. The measurement procedures in this International Standard have been optimized to allow the measurement of high reflectance (larger than 99 %, theoretically up to 100 %) of optical laser components using the cavity ring-down technique which provides reflectance data with high accuracy, high repeatability and reproducibility, and high reliability.

Electro-optical systems — Cavity ring-down technique for high-reflectance measurement

1 Scope

This International Standard specifies measurement procedures for the precise determination of the high reflectance of optical laser components. Up to now, the ISO standardized testing methods for reflectance of optical laser components have the accuracy limit of approximately 0,01 % (for measurement of absolute reflectance) which are not appropriate for measuring the reflectance higher than 99,99 % or, in some cases, measurement accuracy better than 0,01 % is required. The range of application of this standardized test method is reflectance 99 % and higher (theoretically up to 100 %).

The methods given in this International Standard are intended to be used for the testing and characterization of high reflectance of both concave and plane mirrors used in laser systems and laser-based instruments. The reflectance of convex mirrors can also be tested by taking into consideration the radius of curvature of the mirror surface.

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 11145, *Optics and photonics — Lasers and laser-related equipment — Vocabulary and symbols*

ISO 14644-1, *Cleanrooms and associated controlled environments — Part 1: Classification of air cleanliness by particle concentration*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 11145 and the following apply.

3.1
reflectance
<for incident radiation of given wavelength, polarization, and angle of incidence> ratio of the reflected radiant or luminous flux to the incident flux in the given conditions

4 Symbols used and units of measure

Table 1 — Symbols used and units of measure

Symbol	Unit	Term
c	m/s	speed of light in measurement environment
c_0	m/s	speed of light in vacuum
$h(t)$		impulse response of the ring-down cavity
$h_0(t)$		instrumental response function
L_0, L	m	lengths of the initial and test cavities
ΔL_0, ΔL	m	measurement errors of the initial and test cavity lengths
n		refractive index of air in measurement environment

Table 1 *(continued)*

Symbol	Unit	Term
R		average reflectance of the concave cavity mirrors, equals square root of R_1*R_2
R_s		reflectance of the test sample
R_1, R_2		reflectance of two concave cavity mirrors
R_3		reflectance of the planar cavity mirror
T_0	s	instrumental response time
t	s	time
$u(t)$		negative-step function
α	cm^{-1}	the overall absorption coefficient of the gases inside the cavity at the laser wavelength
$\delta(t)$		delta function
θ	rad	angle of incidence of the test sample
ρ	m	radius of curvature of concave surface of the cavity mirror
τ_0, τ	s	decay time of the initial and test cavities
$\Delta\tau_0$, $\Delta\tau$	s	measurement errors of the decay time of the initial and test cavities

5 Test principles

5.1 General

The conventional reflectance measurement techniques (spectrophotometry and laser ratiometry) are based on measuring the relative changes of light power reflected by the test sample. The measurement accuracy is limited by the power fluctuations of the light sources. The cavity ring-down (CRD) technique, on the other hand, is based on the measurement of the decay rate of laser power trapped in a ring-down cavity consisting of at least two highly reflective mirrors. It is therefore totally immune to the power fluctuations of the light sources. The CRD technique can achieve a measurement accuracy that far exceeds the limit set by the power fluctuations of the light sources.

5.2 Decay time of initial cavity and reflectance of cavity mirrors

When a laser beam is coupled into the ring-down cavity, it will gradually leak out of the cavity as a small fraction of the light is transmitted through the cavity mirrors at each reflection. The temporal behaviour of the cavity output signal immediately after the laser pulse (in the pulsed case, as shown in Figure 1) or immediately after the laser power is switched off [in the continuous wave (cw) case, as shown in Figure 2, or at the falling edge of a square-wave modulated power] can be expressed as an exponentially decay function of time according to the following decay route given in Formula (1):

$$I(t) \propto I_0 \exp\left(\frac{-t}{\tau_0}\right) \quad (1)$$

Where I_0 is the initial light intensity of the cavity output signal, τ_0 can be expressed as given in Formula (2):

$$\tau_0 = \frac{L_0}{c\left(\alpha L_0 - \ln\sqrt{R_1 R_2}\right)} \quad (2)$$

with Formula (3):

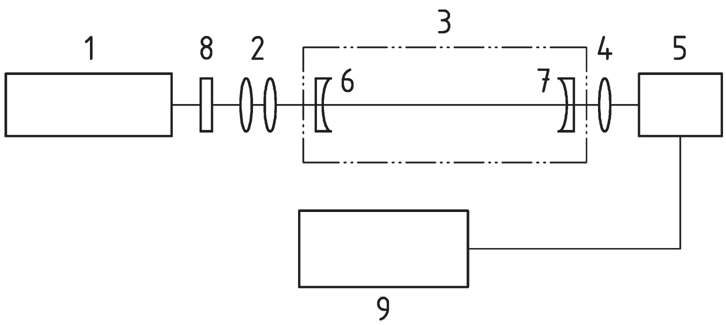
$$c = \frac{c_0}{n} \quad (3)$$

When at test laser wavelength the absorptance of gases inside the ring-down cavity is negligible, the empty cavity ring-down time, τ_0, is only dependent upon the cavity length and the reflectance of the cavity mirrors. Formula (2) reduces to Formula (4):

$$\tau_0 = \frac{-L_0}{c \ln\sqrt{R_1 R_2}} \quad (4)$$

By experimentally measuring the decay time, τ_0, the average reflectance of the cavity mirrors can be calculated as Formula (5):

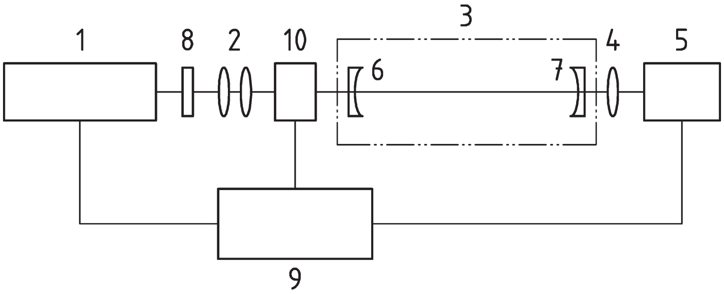
$$R = \sqrt{R_1 R_2} = \exp\left(\frac{-L_0}{c\tau_0}\right) \quad (5)$$



Key

1	laser	6	input cavity mirror, concave high reflectance mirror
2	mode matching optics	7	output cavity mirror, concave high reflectance mirror
3	initial cavity	8	polarizer
4	focusing lens	9	control and data-processing unit
5	photo-detector		

Figure 1 — Schematic of optical arrangement for pulsed-CRD technique for high reflectance measurement



Key

1 laser

2 mode matching optics

3 initial cavity

4 focusing lens

5 photo-detector

6 input cavity mirror, concave high reflectance mirror

7 output cavity mirror, concave high reflectance mirror

8 polarizer

9 control and data-processing unit

10 optical switch

Figure 2 — Schematic of optical arrangement for cw-CRD technique for high reflectance measurement

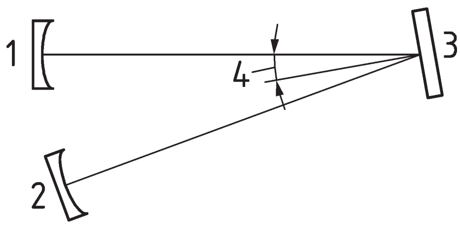
5.3 Decay time of test cavity and reflectance of test sample

If a planar test sample is to be measured, a test ring-down cavity is formed by inserting this test sample into the initial cavity as shown in Figure 3. The incident angle of the laser beam on the test sample follows the required incident angle of the test sample. In this case, the decay time of the folded test cavity can be expressed as Formula (6):

$$\tau = \frac{-L}{c \ln\left(R_S \cdot \sqrt{R_1 R_2}\right)} \quad (6)$$

Therefore, combining Formula (4) and Formula (6), the reflectance R_S of the test sample can be calculated as Formula (7):

$$R_s = \exp\left(\frac{L_0}{c\tau_0} - \frac{L}{c\tau}\right) \quad (7)$$



Key

1 input cavity mirror, concave high reflectance mirror

2 output cavity mirror, concave high reflectance mirror

3 test sample

4 angle of incidence of test sample

Figure 3 — Schematic of optical arrangement for test cavity

5.4 High reflectance measurement with an optical feedback CRD technique

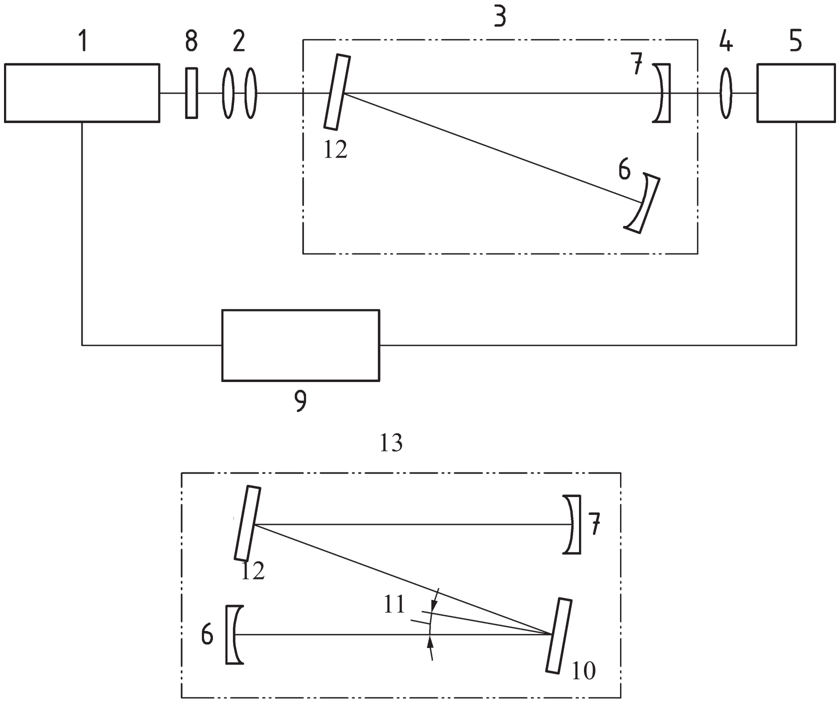
In the cw-CRD case, an optical feedback CRD (OF-CRD) scheme employing a semiconductor laser as the light source (shown in Figure 4) can be used for the reflectance measurement with an improved signal-to-noise ratio in the CRD signals. In OF-CRD scheme, the initial cavity consists of three cavity mirrors:

two concave mirrors and one planar mirror. The beam from the semiconductor laser is coaxially coupled into the ring-down cavity from the high-reflectance planar cavity mirror. The optical feedback (back-reflection of the laser beam) from the ring-down cavity is retro-reflected into the oscillator cavity of the semiconductor laser. Due to the self-mixing effect of the semiconductor laser, the spectral linewidth of the laser is significantly reduced by the frequency selected optical feedback resulting in significant enhancement of the coupling efficiency of the laser power into the ring-down cavity and therefore, a large increase of the CRD amplitude. When the laser power is modulated by a square wave signal, the cavity decay signal can be obtained at the falling edge of the square wave signal. The test principle is the same as that presented in 5.2 and 5.3. The item $\sqrt{R_1 R_2}$ in Formula (2) to Formula (6) should be substituted by $\sqrt{R_1 R_2} \cdot R_3$ in OF-CRD scheme.

The following two measurements are necessary to determine the reflectance of the test sample:

a) τ_0 and L_0 are measured with the initial cavity;

b) τ and L are measured with the test cavity.



Key

1 semiconductor laser
2 mode matching optics
3 initial cavity, with three mirrors
4 focusing lens
5 photo-detector
6 cavity mirror, concave high reflectance mirror
7 output cavity mirror, concave high reflectance mirror
8 polarizer
9 control and data-processing unit
10 test sample
11 angle of incidence of the test sample
12 input cavity mirror, plane high reflectance mirror
13 test cavity, with four mirrors

Figure 4 — Schematic of optical arrangement for OF-CRD technique for high reflectance measurement

6 Preparation of test sample and measurement arrangement

6.1 Test sample

Storage, cleaning, and preparation of the test samples shall be carried out in accordance with the instructions of the manufacturer on the test samples for normal use.

6.2 Laser source

Wavelength of the laser source, angle of incidence, and state of polarization shall correspond to those specified by the manufacturer for the use of the test sample. The state of polarization (*p* or *s*) of the laser beam shall be selected by the polarizer. If the value ranges are accepted for these three quantities, any combination of the wavelength, angle of incidence, and state of polarization may be chosen within these ranges.

Transverse mode matching between the laser beam mode and the mode of the ring-down cavity is important and absolutely required in CRD techniques, especially in the pulsed-CRD systems. Mode matching optics (i.e. beam shaping lenses) is helpful in improving the beam quality of the laser and, further, to reduce the impact of mismatching on the CRD measurements. The impact of mode beating effect on the CRD measurements can be avoided by applying a single-mode (TEM_{00} mode) excitation in the cavity. In this case, a single exponentially decay signal could be obtained.

In the pulsed-CRD system, the interval between two adjacent pulses shall be much larger than the cavity decay time. It is recommended that the duration of the laser pulse be shorter than the cavity round trip time ($2L/c$).

In the cw-CRD system, the laser power can be switched off by an optical switch. If a semiconductor laser which is modulated by square wave is employed, the laser is switched off at the falling edge of the square wave so that the optical switch can be eliminated. The modulation frequency has to be experimentally optimized to maximize the CRD amplitude at the falling edge of the square wave.

6.3 Ring-down cavity

Both initial and test cavities are optically-stable cavities, which are defined by $0 < \rho < 2L_0$, $0 < \rho < 2L$. The reflectance of convex mirror can also be measured if the test cavity consisting of cavity mirrors and the convex test mirror is optically stable.

It is recommended to use cavity mirrors with reflectance higher than 99,9 %. Cavity mirrors with higher reflectance is preferable as the reflectance measurement accuracy improves with the increasing reflectance of the cavity mirrors. Reflectance (R_1, R_2, and R_3) of each cavity mirror shall not be lower than 99,5 %.

6.4 Detection unit

The detection unit consists of a focusing lens, a photo-detector (both appropriate for the laser wavelength at which the measurement to be performed), and an oscilloscope or a fast data-acquisition card.

To ensure that the laser power exiting the output cavity mirror be fully collected, the numerical aperture (NA) of the focusing lens and the active area of the photo-detector shall be optimized carefully. The focusing lens shall be coated with anti-reflective coating at the laser wavelength.

A fast-speed photo-detector with rise time much shorter than the decay time of the cavity should be used so that the impact of the instrumental response time on the reflectance measurement can be neglected. In case a photo-detector with rise time shorter than, but somewhat comparable to, the decay time of the cavity, the influence of the rise time on the reflectance measurement has to be eliminated through data processing, see 8.1.

6.5 Data acquisition and processing

A certain number of ring-down signals are acquired by an oscilloscope or a data-acquisition card and averaged to determine the decay time of the initial cavity and of the test cavity. The number of ring-down signals shall be documented. As a general rule, the number of acquired ring-down signals should be at least larger than a number that the signal-to-noise ratio of the ring-down signal averaged over that number becomes acceptable.

6.6 Environment

The environment of the testing place shall consist of dust-free filtered air with less than 60 % relative humidity. The residual dust shall be reduced in accordance with the clean-room Class 7 as specified in ISO 14644-1. To minimize the impact of the environmental fluctuations on the test results, it is recommended that the overall length of the test cavity is kept the same as that of the initial cavity.

7 Test procedure

7.1 General

Either the pulsed-CRD method, the cw-CRD method, or the cw OF-CRD method shall be chosen to measure the reflectance. The decay time of both the initial cavity and the test cavity shall be measured to determine the reflectance of the test sample.

The incident angle of the test sample shall be set according to the manufacturer's instruction. Reflectance of normal incidence usually cannot be measured directly and instead for normal incidence, the incident angle is set in between 3° to 8°, which shall be documented.

7.2 Measurement of decay time of initial cavity

Set up the initial ring-down cavity experiment. Record the initial cavity output signal immediately after the laser pulse (in the pulsed-CRD), or immediately after the laser power is switched off, or at the falling edge of the square-wave modulation (in the cw-CRD). Subtract the dc offset using the output signal when the laser light is blocked or shut off. As shown in Figure 5, this dc offset-subtracted signal is then fitted to a single exponentially decay function, $a\exp(-t/\tau_0)$, in the linear scale, with a being the amplitude factor, or fitted to a linear function in the logarithmic scale, $\log(a)-t/\tau_0$, to determine the initial cavity decay time, τ_0. When it is fitted, eliminate the first part of the data corresponding to the time period twice the instrumental response or eliminate a certain number of data points at the beginning of the recorded signal until the fit becomes insensitive to the number of data points eliminated.

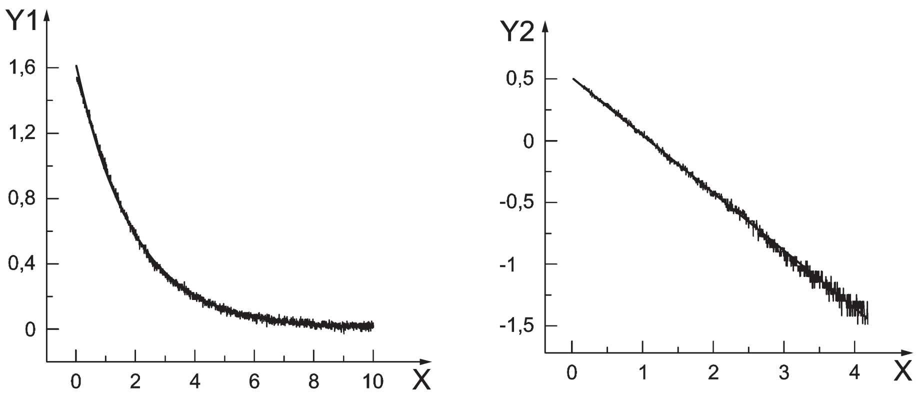


Figure 5 — Typical decay signal of the initial cavity and corresponding exponential fit in linear scale or linear fit in logarithmic scale

7.3 Calculation of reflectance of cavity mirrors

Calculate R using Formula (5), as described in 5.2.

7.4 Measurement of decay time of test cavity

Set up the test ring-down cavity experiment. Test cavity decay time, τ, is measured in the same way as described in 7.2. The decay signal of the test cavity and corresponding exponential fit in linear scale or linear fit in the logarithmic scale is shown in Figure 6.

7.5 Calculation of reflectance of test sample

Calculate R_S using Formula (7), as described in 5.3.

7.6 Assessments of the measurement

The measurement error is accessed by evaluating the goodness of the fits to the measurement data, as presented in Figure 5 and Figure 6. The deviation of the measurement data from the exponential fit in the linear scale, or from the linear fit in the logarithmic scale, shows the error of the measurement. Typically, the measurement error of the reflectance is about a few percent of (1-R) or (1- R_S).

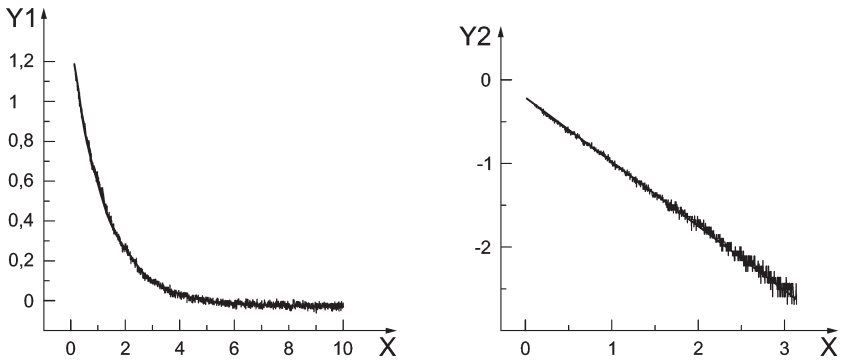


Figure 6 — Typical decay signal of the test cavity and corresponding exponential fit in linear scale or linear fit in logarithmic scale

8 Main error factors

8.1 Influence of the instrumental response time on reflectance measurement

8.1.1 General

The instrumental response time, T_0, consists mainly of the response time of the laser source, the photo-detector, and the oscilloscope or data-acquisition card. The effect of the finite response time of the experimental apparatus on the CRD signal has to be accounted for in order to achieve precise reflectance measurements. In case of $T_0 \ll \tau_0$ (and τ), the influence of the instrumental response time on the reflectance measurement is small and can be neglected. However, in case the instrumental response time becomes comparable to the decay time, the CRD signal deviates significantly from the single exponential decay function, leads to significant error in the determination of the decay time, as well as the calculation of the reflectance. Two methods, that is, multi-parameter fitting and data truncation method, can be employed to eliminate or minimize the influence of the instrumental response time on the reflectance measurement. In any case, the instrumental response time, T_0, shall always be smaller than the decay time, τ_0, (and τ) in the testing.

8.1.2 Multi-parameter fitting method

In CRD measurements, the CRD signal is proportional to the convolution of the input signal, which is the input pulse (here, a delta function is assumed) $\delta(t)$ in the pulsed case or the negative-step function, $u(t)$, in the cw case, the impulse response of the ring-down cavity, $h(t)$, and the instrumental response function, $h_0(t)$. The negative-step function, $u(t)$, the impulse response of the ring-down cavity, $h(t)$, and the instrumental response function, $h_0(t)$, can be expressed as Formula (8), Formula (9), and Formula (10), respectively:

$$u(t)=\int_{-\infty}^{t} f(x)dx=\int_{0}^{t} f(x)dx \quad (8)$$

$$h(t)=\exp\left(-\frac{t}{\tau}\right) \quad (9)$$

and

$$h_0(t)\propto\exp\left(-\frac{t}{T_0}\right) \quad (10)$$

The CRD signals are given in both pulsed-CRD and cw-CRD schemes expressed as Formula (11) and Formula (12), respectively:

$$I_{\text{pulse}}(t)=\delta(t)*\exp\left(-\frac{t}{\tau}\right)*\exp\left(-\frac{t}{T_0}\right)=a\left[\exp\left(\frac{-t}{\tau}\right)-\exp\left(\frac{-t}{T_0}\right)\right] \quad (11)$$

$$I_{\text{cw}}(t)=u(t)*\exp\left(-\frac{t}{\tau}\right)*\exp\left(-\frac{t}{T_0}\right)=a\left[\exp\left(\frac{-t}{\tau}\right)-\frac{T_0}{\tau}\exp\left(\frac{-t}{T_0}\right)\right] \quad (12)$$

where

a is the amplitude factor.

The instrumental response time, T_0, should be smaller than the cavity decay time, τ, in order to make the CRD signal applicable to determine the cavity decay time. By applying a multi-parameter estimation technique to determine simultaneously the cavity decay time and the overall response time of the experimental apparatus through fitting the experimental CRD signal to the corresponding theoretical model [Formula (11) or Formula (12)], the influence of the instrumental response time on the reflectance measurement can be eliminated.

8.1.3 Data truncation method

Due to the finite instrumental response time, the deviation between the experimental CRD signal and the corresponding best-fit is most significant at the beginning part of the decay signals. The CRD signal gradually approaches the exponential decay in the linear scale or the linear decay in the logarithmic scale with the increasing time. Therefore, the impact of the instrumental response time on the reflectance measurement can be diminished by intentionally removing the data points at the beginning part of the CRD signal from being fitted. However, care has to be taken when deleting the data points at the beginning duration to reduce the influence of the instrumental response time, as the CRD amplitude, as well as the signal-to-noise ratio of the CRD signal, also decreases as the time increases. In general, the removed data points should be within the fitted decay time τ_0 (and τ) from the beginning.

8.2 Measurement error of the reflectance of cavity mirrors

From Formula (5), the measurement error of the reflectance of the cavity mirrors can be expressed as Formula (13):

$$\left|\frac{\Delta R}{R}\right| = (1-R)\left(\left|\frac{\Delta L_0}{L_0}\right| + \left|\frac{\Delta \tau_0}{\tau_0}\right|\right) \tag{13}$$

where

$\Delta L_0/L_0$ is the measurement errors of the initial cavity length;

$\Delta \tau_0/\tau_0$ is the decay time.

The reflectance measurement error decreases as the reflectance increases. It is recommended to use cavity mirrors with reflectance higher than 99,9 % or even above 99,99 %. For example, assume that the overall measurement error for the cavity length and decay time is 1 % (for a CRD instrument, the measurement error of the cavity length can easily reach 0,1 % or less, as the cavity length is normally in the range of 0,5 m to 1,0 m), the measurement error for the reflectance of the cavity mirrors is 0,001 % when the reflectance is 99,9 %, and reduces to 0,000 1 %and 0,000 01 % when the reflectance is 99,99 % and 99,999 %, respectively. On the other hand, the reflectance of the cavity mirrors has to be optimized as the coupling efficiency of the laser power to the ring-down cavity decreases as the reflectance of the cavity mirrors increases

8.3 Measurement error of the reflectance of test sample

Similarly, the measurement error of the reflectance of the test sample can be expressed as Formula (14):

$$\left|\frac{\Delta R_s}{R_s}\right| = \left|\frac{\Delta R}{R}\right| + (1-RR_s)\left(\left|\frac{\Delta L}{L}\right| + \left|\frac{\Delta \tau}{\tau}\right|\right) \tag{14}$$

The use of cavity mirrors with a higher reflectance improves the measurement accuracy of the reflectance of the test sample. Assume that the average reflectance of the cavity mirrors is 99,99 %, according to Formula (13) and Formula (14), the typical values of measurement reproducibility of high-reflectance test sample are shown in Table 2.

Table 2 — Typical reproducibility of reflectance measurement of test sample

Reflectance	Reproducibility
99,0 % < R_s < 99,5 %	<±0,02 %
99,5 % < R_s < 99,9 %	<±0,01 %
99,9 % < R_s < 99,99 %	±0,002 %
R_s > 99,99 %	±0,000 2 %

The measurement accuracy for the reflectance can be further improved by reducing the measurement error of the decay time, which can be done by a better mode-matching between the laser modes and the ring-down cavity modes, a longer cavity length, and a more sensitive and lower-noise detection method.

9 Test report

The following information shall be documented in the test report:

a) information on the test organization

1) testing organization;

2) date of test, time;

3) examiner;

b) information concerning the test sample

1) manufacturer of test sample;

2) type of test sample;

3) part ID, date of production;

4) specifications of manufacturer for storage and cleaning;

5) specifications of manufacturer for normal use (wavelength, polarization, angle of incident, purpose of use, etc.);

c) information concerning the test facility

1) laser source (wavelength, operating mode cw/pulsed, pulse duration and repetition rate, modulation frequency for cw source, state of polarization, spectral linewidth);

2) parameters of the detection system and data acquisition (instrumental response time, sampling time, number of signals recorded for averaging);

3) description of other relevant test equipment;

4) environmental conditions (temperature, degree of cleanliness when clean room is used, humidity, vibration control, etc.);

d) information concerning testing and evaluation

1) initial and test cavity lengths;

2) reflectance of cavity mirrors;

3) location size of beam on the sample;

4) ring-down time of the initial and test cavities;

e) error budget

1) errors of decay time and cavity lengths;

2) reflectance uncertainty of cavity mirrors;

f) test results

1) graphs of cavity decay signals for both initial and test cavities and corresponding best-fit curves;

2) reflectance of test sample;

3) reflectance uncertainty of test sample;

g) reference to this International Standard, i.e. ISO 13142:2015.

Annex A
(informative)

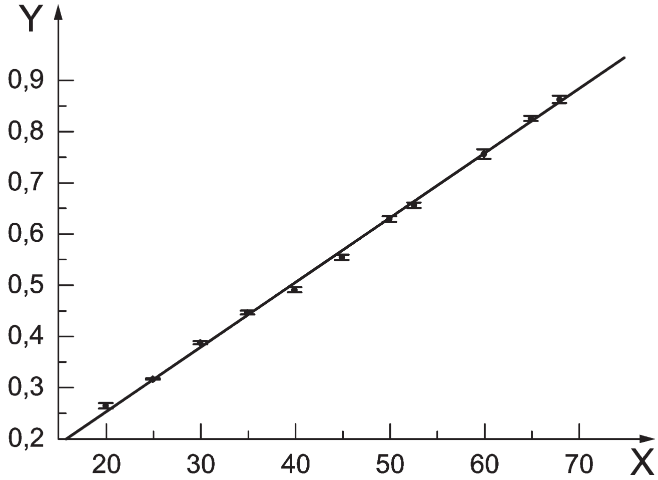
Reflectance reliability check experiment

A.1 General

This Annex describes the experimental verification of the reliability of the reflectance measurement results.

A.2 Method

In principle, the reflectance is independent of the cavity length, while other factors such as diffraction loss, effect of finite instrumental response time, etc. which can affect the reflectance measurement, might be dependent of the cavity length. Therefore, to check the reliability of the measured reflectance results, the reflectance measurement can be repeated versus changing cavity length (as long as the stable cavity condition is kept). The measured reflectance value is reliable if it is independent of the cavity length (within measurement error budget). Meanwhile, from Formula (4) and Formula (6), the cavity decay time is linearly proportional to the cavity length through $\tau = k \cdot L$, with k the slope of the linear dependence. The reflectance can also be calculated from the slope of the linear dependence of the decay time on the cavity length. The reflectance calculated through $R = \exp(-1/ck)$ shall agree with that calculated through Formula (4) at different cavity lengths. As an example, Figure A.1 shows the measured cavity decay time versus the cavity length and the corresponding linear fit. A good linear dependence, together with the good agreement among reflectance values determined with different cavity lengths and through slope of the linear dependence, is an indication of the reliability of the reflectance measurement. In this example, the average and the standard deviation of the reflectance measured at different cavity length are 99,736 % and 0,006 %, respectively, and the reflectance determined through the slope of the linear dependence is 99,733 %.

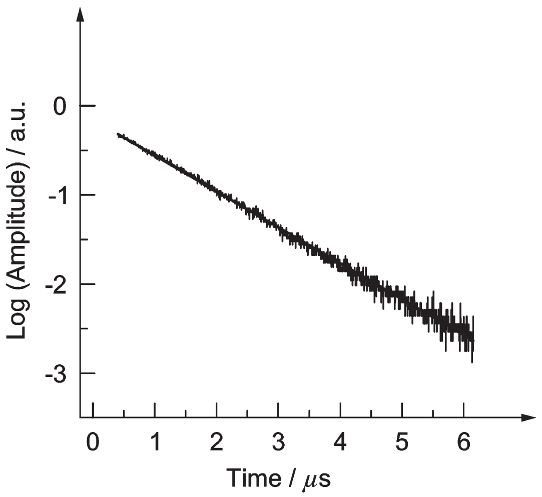
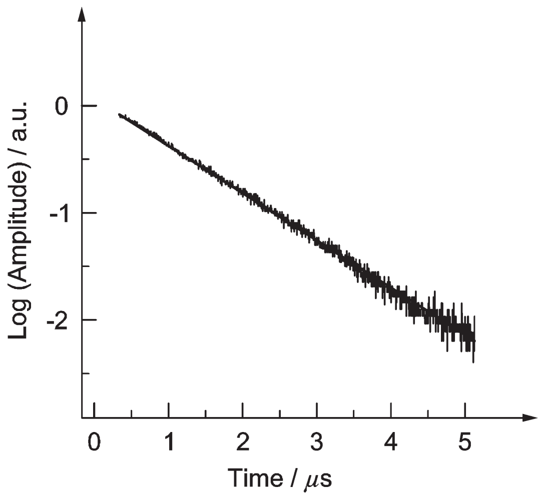


NOTE The diameter and radius of curvature of the cavity mirrors are 25,4 mm and 1 m, respectively. The laser operates at TEM_{00} mode.

Figure A.1 — Cavity decay times at different cavity lengths and the linear best-fit

Annex B
(informative)

Test report

Testing organization	Institute of Optics and Electronics, Chinese Academy of Sciences, China		
Date of test	30 May 2012	**Examiner**	BL
Manufacturer of test sample	Institute of Optics and Electronics Chinese Academy of Sciences, China		
Type of test sample	HR mirror	**Part ID**	HR-1064-0-U-05
Wavelength	1 064 nm	**Polarization**	UNP
Angle of incidence	0°		
Laser type	■cw □ Pulsed	**Wavelength**	1 064 nm
Polarization	Linear	**Average power**	6 mW
Initial cavity length	75 cm	**Decay time of initial cavity**	2,525 μs ± 0,035 μs
Test cavity length	75 cm	**Decay time of test cavity**	2,452 μs ± 0,032 μs
Location and size of laser beam on the sample		**Central area**	
Graph of cavity decay signal for <u>initial</u> cavity and corresponding best-fit in logarithmic scale (or in linear scale) 		Graph of cavity decay signal for <u>test</u> cavity and corresponding best-fit in logarithmic scale (or in linear scale) 	
Reflectance of test sample	99,911 %	**Reflectance uncertainty**	±0,003 %

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1) Replaces ISO 31–6, which has been withdrawn.

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