SLL 78-170

cp. 1

UCRL-51873 Suppl I

CALORIMETRIC MEASUREMENTS OF LASER ENERGY AND POWER—1977 SUPPLEMENT

Stuart R. Gunn

October 10, 1977

Prepared for U.S. Energy Research & Development Administration under contract No. W-7405-Eng-48

LAWRENCE LIVERMORE LABORATORY

University of California/Livermore

U3942

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Available from
National Technical Information Service
U.S. Department of Commerce
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Springfield, VA 22161
Price: Printed Copy $; Microfiche **$3.00**

Page Range	Domestic Price	Page Range	Domestic Price
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Accession Number: 3942

Publication Date: Oct 10, 1977

Title: Calorimetric Measurements of Laser Energy and Power - 1977 Supplement

Personal Author: Gunn, S.R.

Corporate Author Or Publisher: Lawrence Livermore Laboratory, University of California, Livermore, CA Report Number: UCRL-51873, Suppl. I

Report Prepared for: U.S. Department of Energy Report Number Assigned by Contract Monitor: SLL 78-170

Comments on Document: Archive, RRI, DEW.

Descriptors, Keywords: Calorimeter Measurement Laser Energy Power Disk Cone Hollow Sphere Volume Absorption Pyroelectric Black Surface Chemical Actinometry

Pages: 00011

Cataloged Date: Nov 30, 1990

Contract Number: W-7405-ENG-48

Document Type: HC

Number of Copies In Library: 000001

Record ID: 25322

Source of Document: DEW

Distribution Category
UC-21

LAWRENCE LIVERMORE LABORATORY
University of California/Livermore, California/94550

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ABSTRACT

The use of calorimeters for measuring laser output energies and powers is reviewed, primarily for the period 1975-1977 since preparation of earlier reviews.

INTRODUCTION

References 1-113 and 116-186 of this report were discussed in earlier reviews.[114, 115, 187] The present review primarily covers papers that have been published since; it also includes some earlier papers that were previously unavailable or overlooked.

CALORIMETER DESIGNS

DISK CALORIMETERS

Nakatsuka and Kubo[188] described a twin calorimeter for pulsed CO_2 lasers, somewhat similar to that of Jacob et al.[126] The 50 × 50 × 0.6 mm plates are of alumina ceramic rather than anodized aluminum; 20 thermocouple junctions are attached to the rear surface of each. The reflectivity was measured as <2% at 10.6 μm, and the response was found to be linear within 2% for 100-ns pulses up to 14 J/cm^2.

Kubarev et al.[189] described a twin calorimeter rather similar to the shallow inverted-cone-and-tube calorimeters of Geist, Schmidt, and Case[127] and of West and Case.[129] The laser beam strikes a shallow inverted cone at the end of a short tube; both are blackened. The calibrating heater is located on the rear surface of the shallow cone. A photoelectric radiometer with a spherical integrating sphere surrounding the beam at the entry to the tube is used to correct for reflected radiation. Govor, Kubarev, and Obukhov[190] described another similar system in which the blackened shallow inverted cone is at the rear of the interior of a copper sphere. These designs are of course somewhat equivalent to hollow-sphere calorimeters, differing primarily in that most of the radiation is absorbed upon initially striking the inverted shallow cone.

Rubtsov[191] calculated the temporal response of thin metal-plate calorimeters with thermocouples on the rear surface to laser pulses of specified shape.

Day, Gaddy, and Iversen[192] studied thin-film thermopiles for the temporal resolution of infrared laser pulses. Film thicknesses of 0.1 to 0.2 μm were used, and response times down to 0.1 μs were obtained. Bar-Isaac and Korn[193] described a line array of thin-film thermocouples with junctions 5 μm apart for spatial resolution of focused laser beams. The technology of these devices is similar to that of other thin-film thermopiles applied to measurements of neutral beams[194,195] and x rays.[196]

Schimmel and Donaldson[197] calculated the performance of a system that absorbs short laser pulses in a thin metal film; the infrared radiation from the heated metal surface would be suppressed by placing over it a barrier, transparent at the laser wavelength but opaque in the infrared.

Stevens[198] has given a general review of radiation thermopiles.

Chodzko et al.[199,200] described a calorimeter for measuring the output power of an edge-coupled cw unstable resonator. Four water-cooled copper plates are mounted within the cavity between the mirrors; their position adjusts to define a variable rectangular aperture. The plates are coated with black Ebanol C oxide coating and grooved (thus being partially equivalent to a cone calorimeter) to absorb >98% of the DF chemical-laser radiation; the temperature rise of the flowing water is measured with thermocouples.

Durran[201] described a system for measurements of intracavity laser power by observing the power dissipation in the mirrors defining the laser cavity. The mirrors are water-cooled; the temperature rise at a known flow rate is measured with a pair of thermistors.

CONE CALORIMETERS

Edwards[202] described a high-accuracy cone calorimeter for pulsed lasers. The cone is of nickel-coated copper: the average temperature is sensed with a coil of nickel-alloy resistance wire wound over the whole outer surface. Less than 1% of the incident laser radiation escapes from the cone; and this loss is monitored by a photodiode near the cone opening which looks at a diffusing reflector, in the form of a spherical segment surrounding the beam entry hole in the outer jacket, some distance in front of the cone. The instrument was compared with a National Bureau of Standards "C" series calorimeter[13]; agreement was within 1%.

Kuz'michev, Zinchenko, and Valitov[203] analyzed the heat transport in a cone.

HOLLOW-SPHERE CALORIMETERS

Drong and Moeny[204] described a system consisting of a hollow sphere of a subliming solid such as carbon dioxide; energy (or power) is to be derived from the change (or rate of change) in the weight of the sphere, as measured by a transducer and recorder.

Pierce[205] described the use of a water-cooled hollow sphere to serve simultaneously as a calorimeter and as an integrating-sphere attenuator for another detector. The interior of the sphere is coated with a diffusely reflecting material of high reflectivity. A second hole is provided in the sphere to deliver a fraction of the energy to the second detector, which may be a fast-response type for pulse-shape measurement. The attenuation factor between the input and output ports is readily measured.

Daehler[206] described a liquid-helium-cooled hollow-sphere calorimeter used for infrared radiation and capable of measuring powers down to about 1 μW.

VOLUME-ABSORPTION CALORIMETERS

Franzen and Schmidt[207] gave a detailed description of a high-accuracy calorimeter for high-power pulses using solid volume absorbers. Neutral-density glasses are used as the absorbers at 1.06 μm; several of these, and several crystalline dielectrics which could be used at 9 to 11 μm, were checked for damage thresholds and bleaching effects. The calorimetric body is in the form of a shallow, slant-bottomed electroformed copper cup of square cross section. The first absorber is cemented to the bottom of the cup; the laser beam strikes it at an angle of 30° to the normal. The first-surface Fresnel reflection from this is directed to the second absorber, which is cemented to one wall of the cup; the angle of incidence on this is again 30° to the normal. The residual reflection from this is directed to black paint on the opposite wall. The temperature rise is measured with a 40-junction thermopile whose junctions are distributed approximately uniformly on the outer surface of the cup; a calibration heater is wound on a spool on the outside of the slanted bottom, which bears the first absorber on the inside. A detailed error analysis is given.

Fisk and Gusinow[208] described a liquid-absorption calorimeter utilizing a similar principle to reduce reflection losses. The liquid is circulated behind two fused-silica windows forming a 40° wedged cavity with an entry aperture of 18 × 20 cm. The beam strikes the first at 40° to the normal, and the first-surface reflection strikes the second at 10°. Operation is by the isoperibol, not flow, method; the absorbing liquid is recirculated by a small pump, and the temperature rise produced in the system by a laser pulse or immersed electrical calibrating heater is measured with a thermistor. Aqueous copper sulfate solution was used for 248-nm radiation and heavy water (normal water being too absorptive) at 3 μm.

Emmony and Bunn[209] described a simple water-flow calorimeter for cw CO_2 lasers. The water flowed as a vertical film over an alumina plate perpendicular to the beam, and the temperature rise was measured with a pair of thermocouples. The reflectance is 0.8%. The absorption coefficient is very high, so the surface of the water film is heated above the average water temperature; however, the calculated power was found to be independent of the flow rate within the precision of the measurements of flow rate and temperature rise, so heat loss by evaporation was evidently not a serious problem. Other heat losses, by conduction to the alumina plate, convection to the air, and evaporation from the average water temperature, would be largely proportional to the temperature rise at the small rises (2 to 5°C) used and hence would not be detected by varying the flow rate; the authors proposed that these could be largely eliminated by making the mean temperature of the water equal to ambient temperature.

Rice and Macomber[210] studied the properties of three types of commercially available filters for use as laser pulse attenuators. Two types of neutral density filter showed reversible bleaching (decrease in attenuation with increase of power level); a third type, consisting of colloidal carbon dispersed in gelatin, did not. The results are pertinent to volume-absorption calorimetry, which depends on the absorbing medium not showing an excessive change of absorptivity at the power densities being measured. However, other studies have shown no such saturation effects for various absorbers at 1.06 μm[146,207] and 10.6 μm.[98]

Various gases have been studied as attenuators and isolators for CO_2 laser wavelength[211-215]; these would be applicable to gas-absorption calorimeters.

PARTIAL-ABSORPTION CALORIMETERS

Kuz'michev et al.[216,217] described partial-absorption bolometers consisting of grids of fine nickel or platinum wire covering the whole beam area and connected into a bridge circuit for measurement of the temperature rise. Use of two mutually perpendicular arrays of wire eliminates dependence of the response on the orientation of polarization of the beam. The response does depend on the reflectivity of the wire surface, so the system must be calibrated against an absolute calorimeter at the wavelength to be measured.

MISCELLANY

REVIEWS

Boyne[218] has briefly reviewed laser power and energy measurements, including calorimetry. Cunningham[219] has summarized commercially available calorimeters and other power meters. In some respects, the calorimetry of laser beams is related to the calorimetry of beams of x rays, gamma rays, and accelerated ions; a supplement to earlier reviews in this field has recently been published.[220]

PYROELECTRIC METERS

A number of papers[180,221-233] have described the development and application of high-accuracy chopper-stabilized electrically-calibrated pyroelectric meters applicable to low-level cw and pulsed laser measurements as well as general radiometry. The absorbing surface of gold black on the face of the pyroelectric materials also serves as the heater for electrical calibration in some versions; in others the heater is a separate metal film behind the absorbing layer.

Morozov, Nikolaev and Russov[234] described a cylindrical pyroelectric detector surrounding a laser beam and intercepting the outer edge as the beam diverged. Baker[235] described a peak-hold circuit permitting use of a moving-coil meter rather than an oscilloscope to record the peak reading of pyroelectric detectors used with pulsed lasers. Putley[236] and Kremenchugskii and Roitsina[237] gave general reviews of pyroelectric detectors.

TEST AND COMPARISON PROCEDURES

Thacher[238] gave a detailed discussion of a procedure for calibrating pulse calorimeters with reference to cw power meters, using a timed interval of a cw beam. Falconer, Niland, and Turk[239] and Neufeld *et al*.[240] discussed the advisability of using splitters at low angles of incidence where the polarization of the beam being analyzed is unknown or variable.

ABSORPTANCE MEASUREMENTS

In this related field, calorimetric methods have been applied in a number of investigations of absorption coefficients of optical materials.[241-251]

BLACK SURFACES

Low-reflectivity coatings are useful for cw disc calorimeters and some other types. Blevin and Geist[226] and Peterson *et al*.[227] evaluated gold-black and black paint coatings on pyroelectric detectors. Cuomo, Ziegler and Woodall[252] described preparation of dendritic tungsten surfaces of low reflectivity.

CHEMICAL ACTINOMETRY

Demas and coworkers have published several papers[253-255] on this technique which, while in no sense calorimetric, may have certain advantages for measurements of laser energy in some situations.

CLASSIFICATION

In Table 1 the newly described calorimeters are classified according to the same scheme used earlier.[187]

Table 1. Characteristics of laser calorimeters.

Reference	1	2	3	4	5	6	7	8
188	sur	blk	dis	tot	en	iso	tc	noh
189	sur	blk	cup	tot	pow	sst	tc	htr
190	sur	blk	cup	tot	pow	sst	tc	htr
192	sur	met	dis	tot	en	iso	tc	noh
193	sur	met	dis	tot	en	iso	tc	noh
199	sur	blk	dis	tot	pow	flo	tc	noh
201	sur	met	dis	par	pow	flo	tst	noh
202	sur	met	con	tot	en	iso	res	htr
204	sur	—	hol	tot	both	pha	—	noh
205	sur	—	hol	tot	pow	flo	—	noh
207	vol	sol	cup	tot	en	iso	tc	htr
208	vol	liq	cup	tot	en	flo	tst	htr
209	vol	liq	dis	tot	pow	flo	tc	noh
216	sur	met	—	par	pow	iso	bol	noh

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