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AN ABSOLUTE CALORIMETER FOR HIGH POWER CO_2 LASER

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Abstract

An easy to operate absolute calorimeter has been successfully built and calibrated in order to measure the energy output of a high power TEA CO_2 laser. The laser beam is completely absorbed in a plastic foil glued on a copper plate. A thermocouple measures the difference of temperature between two separate sandwiches of plexiglas and copper plates, one of them taken as reference.

Tested between 1 and 12 Joules at 10.6 μ, the device showed an accuracy of 5 %. In the best case, the maximum absorbed power could reach 80 MW/cm^2 without any visible damage to the calorimeter.

Such calorimeters are particularly convenient for the energy measurement at a high power laser with large beam cross-section.

Introduction

The conventional calorimeters are inaccurate for the measurement of energy in high powered infrared lasers . The graphite or black anodized cone calorimeters (Li and Sims 1962, Scott 1966, Edwards 1967) which may be used at low power level do not work at high power for various reasons: first, the concentration of the light near the top of the cone creates a breakdown in air. When the air is ionized, the electron density of the plasma created, reaches the cut-off frequency of 10^{19} e cm^{-3} at this wavelength and the light is reflected outside the calorimeter. Furthermore part of the energy is transformed in shock wave escaping from the calorimeter, and finally for wavelength around 10 μ, the scattered light from the entrance of the cone is more important than in the visible. All those reasons make the measurements with cone calorimeters non linear and irreproducible.

The spherical cavity calorimeter (Kellock 1971) where the light is concentrated by a converging lens on a small opening on the surface of the sphere, can only be used for power density levels which do not produce breakdown at the focal point of the lens, limiting their use to low power lasers. Photon-drag detectors (Kimmit et al 1972) are easily used only for relative calibration. The crystal defects which scatter the light make absolute calibration difficult. Their use is limited by the cost of high quality large size crystals; as high power CO_2 lasers have beam cross-sections from 10 to 100 cm^2 an ideal photon-drag detector would require such an entrance area. Focussing the beam on a small surface creates surface and volume destruction in the crystal, as well as a large uncertainty on the amount of light reflected because of the large index of refraction of germanium (specially for high focussing, i.e., large varying angle of incidence).

Gas calorimeters, where the absorbing gas (Freon, SF_6) is heated by the laser pulse are of difficult use: the shock wave created by the impact of the laser beam makes the measurement of the pressure variation inaccurate. The usual calibration which consists of heating a resistive wire by a capacitor discharge lasts much longer than the laser pulse; as the fast heat exchange between the container and the heated gas makes calibration very sensitive to the time duration of the heating process, the capacitor discharge calibration is inaccurate.

This paper describes an absolute calorimeter which is specially useful for high power CO_2 lasers (Boulanger et al 1973) although it can be used at reduced power and for other wavelength too. The device allows absolute measurements of laser energy when the specific heat of its components are known.

Description of the calorimeter and calibration

The calorimeter, shown in Fig. 1, consists of two square copper plates typically 1 mm thick glued on two plates of plexiglas (Perpex ICI) or makrolon of thickness 0.5 or 1 mm. The copper plates are 5 x 5 cm adapted to the size of the laser beam. The two plates are fixed to the calorimeter housing by four small plexiglas strips. One of the plate is centered and aligned by autocolimation normally to the laser beam. This insures that the reflection factor is independent of the polarization of light. The device has been calibrated in two ways: first by weighing the plexiglas and copper (Perpex ICI: 1,47 Joule $g^{-1}\ {}^{o}C^{-1}$) , secondly using a thin resistor (Budd Nickel plate sensor) glued between plexiglas and copper, and heated for a given time by a constant voltage source. The two measurements agreed within a few percent.

Fresnel reflection and diffusion losses at the input surface of the detector are awkward to account for. However, for well-polished and clean surface the diffused light was negligible. Low level calibrations are pointless as they cannot be extrapolated into non linear regions associated with high peak power. The amount of reflected light was measured differentially by tilting the calorimeter at an angle of 5^{o} with respect to the normal incidence and sending back the reflected light toward the calorimeter with an autocolimated copper mirror. It amounted to 5 % which is a systematic correction that must be taken into account in every measurement. The measure of reflected light is difficult and the 3 % uncertainty attached to it is the biggest source of error in the results. The thickness of plexiglas is such that all the beam is entirely absorbed in the plexiglas. The difference of temperature between the heated and the reference copper plate was measured by a calibrated stell-constantan thermocouple; the emf was measured by a Keithley micro-voltmeter and recorded versus time on a x-y recorder. The typical sensitivity of the apparatus was 5 μ V J^{-1}. At small energy the output of this calorimeter agreed to a cone calorimeter measurement. Around 5 Joules, the measurement with the cone calorimeter already indicated 10 % lower results than with the plexiglas-copper calorimeter.

Measurement technique

The measurement of temperature versus time gave a rise time for the temperature around 10 seconds corresponding to the duration of the thermal transfer of heat from plexiglas to copper. The exponential decrease of temperature corresponding to the cooling of the system was 20 times smaller. By masking part of the beam the linearity of the calorimeter was satisfactorily tested, insuring that the original distribution of energy in the beam did not influence the measurement. As heated and reference copper plates were packaged in the same calorimeter housing, environmental influences producing thermal drift were minimized. The output energy was measured by plotting the output thermocouple reading versus time on a logarithmic scale and taking back the extrapolation of the curve at the origin.

Limits of operation and conclusions

The plexiglas (or makrolon)-copper absolute calorimeter appears to fill a gap for the measurement of high power long wavelength lasers. The calorimeter described in this paper was designed and successfully operated for energies in the range 0.1 to 12 Joules; smaller size and weight are possible giving better sensitivity. As the heat losses are small it could be used for pulses lasting several seconds, allowing its use for power measurements of CW CO_2 lasers. The upper limit to the pulse power depends on the cleanliness and the nature of the surface of the absorbing window. For some plexiglas samples small cracks appeared after a few shots while others, for which the surface was free of dust and very carefully repolished, could stand hundreds shots at 20 MW/cm^2 without any observable change. Makrolon can stand higher power (80 MW/cm^2). This limitation could be overcome if a more suitable material was found. The combined uncertainty due to thermal fluctuations, thermocouple calibration and reflection losses amounted to 5 %.

The advantage of such a calorimeter is its adaptability to the laser beam cross-section. They are most useful for the measurement of high power laser with large beam cross-sections. The system may be used in the visible by inserting in the volume of plexiglas or makrolon a suitable, not destroyable absorbant. For ruby laser light glass filter OB10 (Chance Pilkington glass) is usable.

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References

A double discharge TEA CO_2 laser

P. Boulanger, A. Heym, J.-M. Mayor, Z.A. Pietrzyk,
to be published

Edwards J.G., J.S.I. 44, 835 (1967)

Kellock H.A., J.S.I. 2, 377 (1971)

Kimmit, Tyte,
Wright, J.S.I. 5, 239 (1972)

Li and Sims, Appl. Pptics, 1, 325 (1962)

Scott B., J.S.I. 43, 685 (1966)

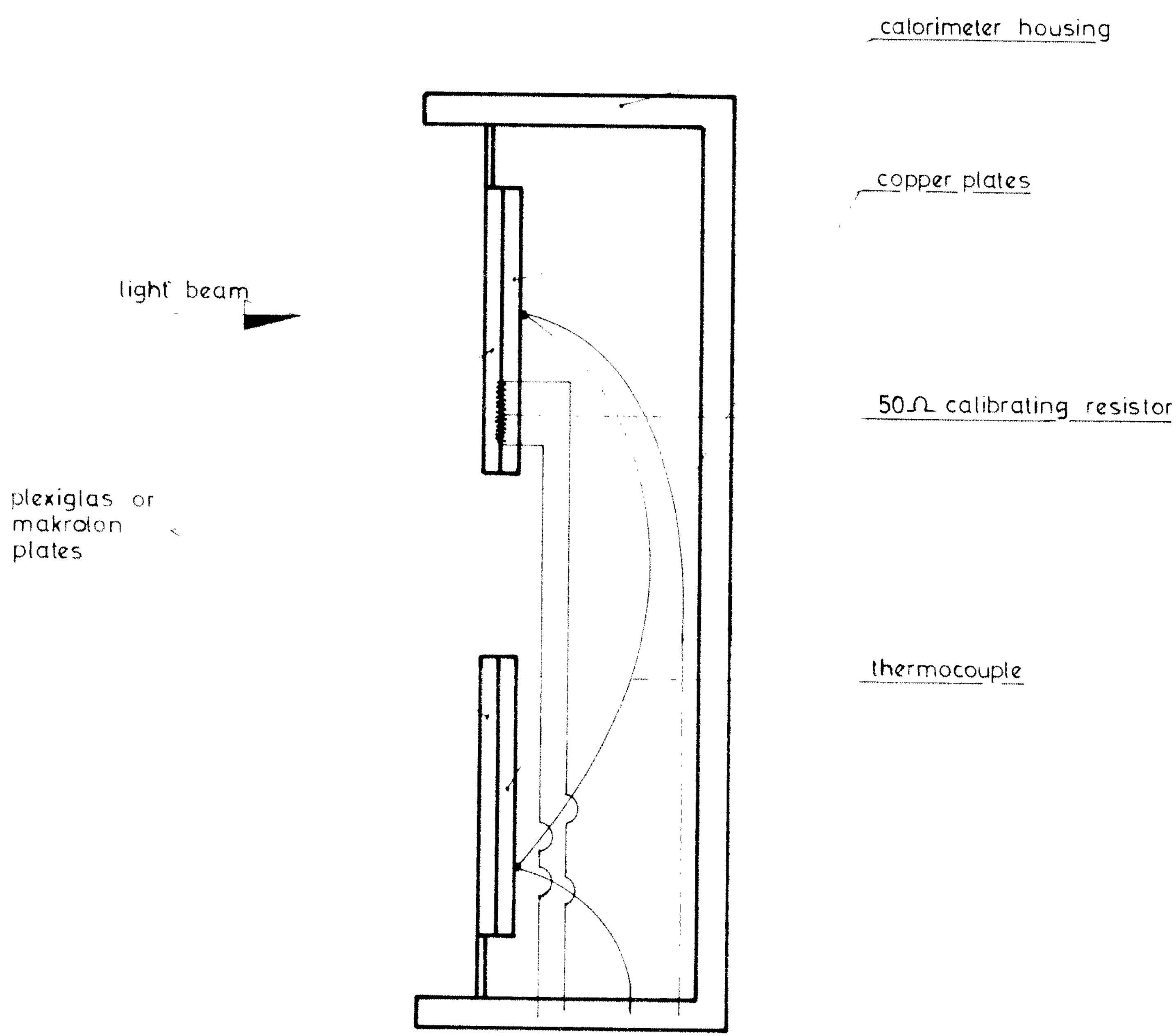

Fig.1 calorimeter design