Precision Broadband Far-Infrared Attenuator

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Abstract

With the advance of far-infrared (FIR) laser applications the need arises to vary the radiation intensity over a large dynamic range. An example is laser radar where a return loss of 50 or even 100 db has to be achieved without distorting the wavefront.

First we review the more common techniques used to attenuate FIR laser beams, and then describe a new step attenuator that uses diffracting metal mesh screens to attenuate the laser radiation. Broadband performance over nearly one decade of frequency is achieved. The design can handle even higher peak and average FIR powers than are available at present, while maintaining beam quality in all respects, including arbitrary input polarization.

Introduction

Far-infrared spectroscopy has long suffered from the low intensity of thermal sources which mostly allow a small dynamic range of measurement only. The advent of far-infrared lasers brought a large increase of dynamic range and thus the potential of exploring nonlinear physical phenomena by changing the power. The most common need for precise attenuation arises from the limited dynamic range of detectors. For example, a limit may be set in cooled semiconductor bolometers by radiation heating, in the Golay cell by saturating the readout system, or in diodes by the rectified voltage disturbing the bias.

Traditional methods of attenuating FIR beams

Some simple ways of FIR attenuation are unsatisfactory. For example, cardboards are often employed and the attenuation is counted as the number of cardboards. While this may be acceptable for mere level setting, any quantitative work is hampered by unknown factors like multiple reflections between cardboards, the extent of near-forward scattering, the moisture content, etc. A well-established solution is the use of a pair of free-standing wire grid polarizers[1], for applications where the input polarization is linear. Since these polarizers are very broad banded, the attenuator is also broad band. Care should be taken to avoid standing waves between the grids. Problems arise in this device when the input polarization is changing, e.g. in research with high-power pulsed FIR lasers[2], and also when a high dynamic range of attenuation is required. For example, when an attenuation of 15 db is to be effected (i.e., a transmission of 3%), the steepness of the attenuation vs. rotation angle puts a tight tolerance on the angle setting and thus results in poor resettability.

Much higher precision at large attenuation settings can be obtained by using absorbing plates. Two types of materials were recently used in our work.

Precision glass plates

Glasses are known to be extremely homogeneous isotropic materials with sizable absorption in the far infrared. For our nonlinear optical work in the far infrared we recently had to compare and absolutely determine the energy of FIR pulses differing by more than eight orders of magnitude[3]. We decided to solve the problem by selecting a well-defined glass sort with reproducible properties “Borsilikatglas 3.3 Tempax” [4]. Precision polished plane-parallel plates were prepared with thicknesses 0.534 mm, 1.315 mm, 2.481 mm, 5.596 mm and 11.950 mm. These plates were used to measure the room temperature absorption coefficient of the glass, by using a Fourier spectrometer and c.w. laser lines.

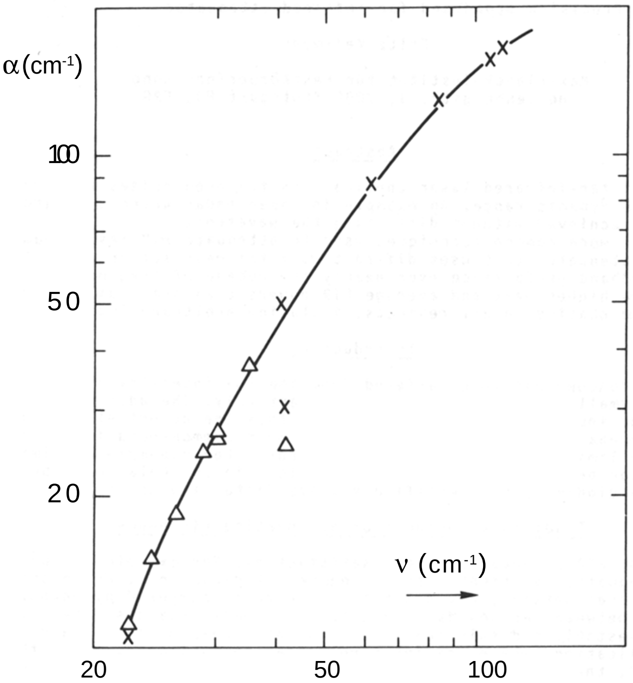

Fig. 1.
Far-infrared absorption curve of borosilicate glass 3.3 “Tempax”.

The experimental data of Fig. 1 show the expected strong increase of the absorption with increasing frequency [5,6]. The scatter in the data is sufficiently small so that quantitative power measurements become feasible[3].

For the general use of glass attenuators the advantages are that virtually no stray radiation is generated and that the polarization status of the light is not affected. While the attenuation is not at all flat over the far-infrared spectral region, the response curve is smooth enough to allow - with a series of sample thicknesses - a truely broadband setting of very high attenuation.

Metal films

It has long been known that thin metal films have very broadband characteristics when used as beam splitters and partial absorbers throughout the far-infrared. [7,8] In short, constant values of reflectivity R, absorptivity A and transmissivity T are theoretically expected for all wavelengths $\lambda_c >> d$, where d is the metal thickness. The maximum value of A=0.5 with R=T=0.25 occurs with a film thickness giving an electrical sheet resistivity of 189 Ω/square, typically d = 10 nm.

Thus metal films could be ideal “neutral density filters” covering the mid and far infrared. However, there are two obstacles, (i) the need of a supporting substrate which itself exhibits standing wave resonances and absorption bands, (ii) the difficulty of obtaining homogeneous films over large areas and protecting them from becoming corroded and scratched.

Recently we tested aluminized plastic foils[9] used in the building industry for solar shielding. The Al film is sandwiched between two plastic foils and thus perfectly protected. The film is optically clear and shows homogeneous, reproducible infrared attenuation (Fig.2).

The spectrum in Fig. 2 comes out flat enough so that these aluminized foils can well serve as approximately neutral density filters for a large portion of the far-infrared region. We have used these foils in our recent survey of high-power far-infrared gas lasers[2]. Up to 4 such foils were inserted in tandem, with some tilt to direct the reflections out of the system, to set the pulse energy in the linear response range of the Golay cell. The wide band width of the attenuator was essential since the laser

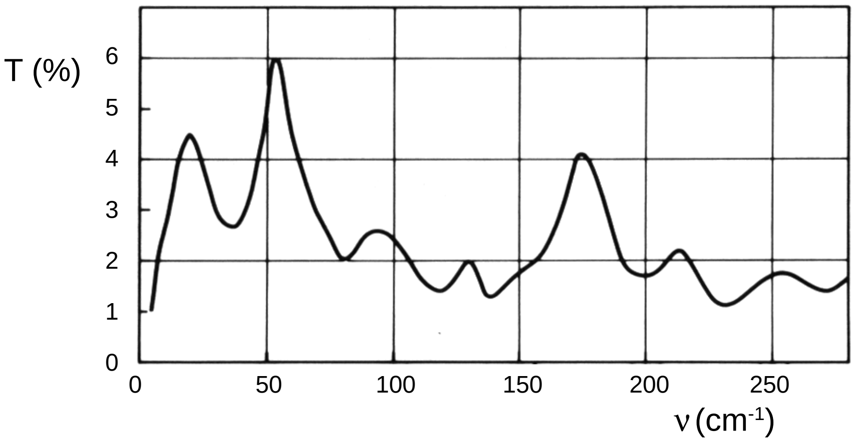

Fig. 2.
Far-infrared transmission spectrum of aluminized plastic foil available from Remis[9], with thickness 100 μm. The spectrum is reproducible in narrow limits.

emitted widely differing lines at many pump transitions. A serious drawback, however, was the limited energy handling capability of the attenuator, since we had to note local melting and permanent damage of the Al film to occur from the stronger laser lines.

Diffractive attenuator

Metallic mesh has long been known to be a very useful optical component 1n the far infrared[10], serving as beam splitter or band-pass and high-pass filter[11]. The use of metallic mesh for precision attenuation has been introduced recently[12]. A commercial step attenuator for mid-infrared CO_2 laser radiation is available since 1984[13].

To guarantee a broad-band function the attenuator operates in the so-called diffractive region $\lambda < g$ of the metallic mesh, where g is the period (Fig. 3).

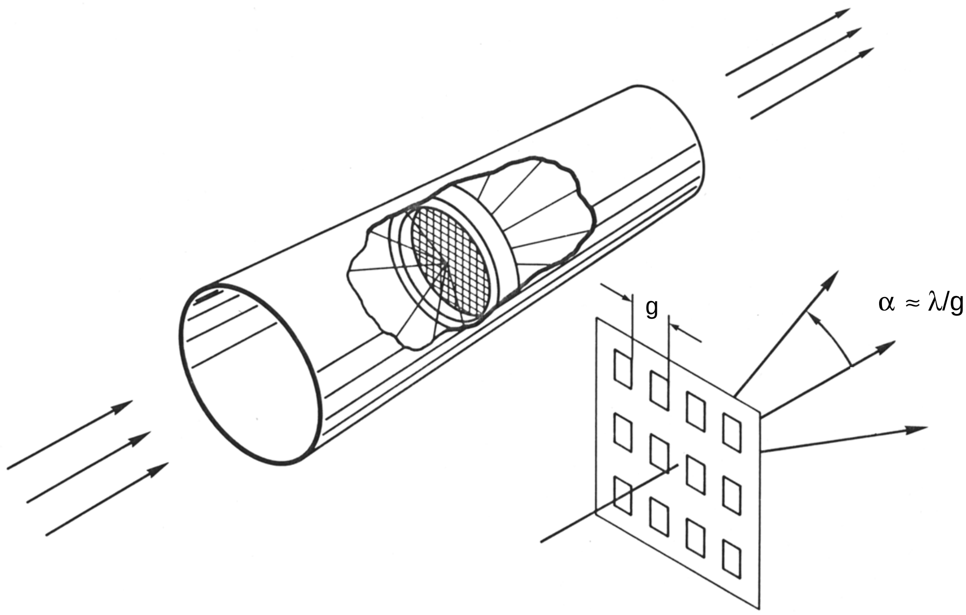

Fig. 3 Schematic view of the diffractive attenuator. The input beam is split into many forword and backward scattering orders. All but the forward-going zeroth order are intercepted and absorbed on the inner wall of the circular housing.

It is straightforward to provide a way of eliminating all diffracted beams except the forward zeroth order beam which is the undeviated output beam. Some care has to be taken to eliminate also the backward zeroth order beam by tilting the mesh so that the incidence is non-normal. This tilting must not exceed more than a few degrees in order to keep tilt effects on the polarization of the forward beam to a minimum. Ideally, the metal mesh should be used at exactly normal incidence, since in this case it is ideally isotropic in respect to polarization, owing to its square symmetry. The polarization sensitivity in respect to a tilt angle depends on details of the unit cell of the mesh structure.

The general problem of light scattering from metal mesh is given by grating theory. A specific treatment of metal mesh has been given by Ulrich[14]. It is noted that coupling to surface (plasmon) modes propagating along the metal mesh is essential for understanding the spectral transmission curve for the zeroth forward order. Theory furthermore bears out properties of the unit cell relating to Wood's anomalies and similar disturbances which should be avoided to obtain possible smooth transmission spectra, i.e., a possibly broad-band performance of the diffractive attenuator.

In our development we have aimed at obtaining step-attenuation with three attenuation steps per decade, equivalent to a transmission T of 50%, 30% and 10%. Converting into attenuation A by using A(db)= -10 log T, we have thus designed A to be 3db, 5db and 10db (the design parameter to vary the diffractive attenuation is the width w of the metal strips). The spectral performance of a typical diffractive neutral density filter is shown in Fig. 4.

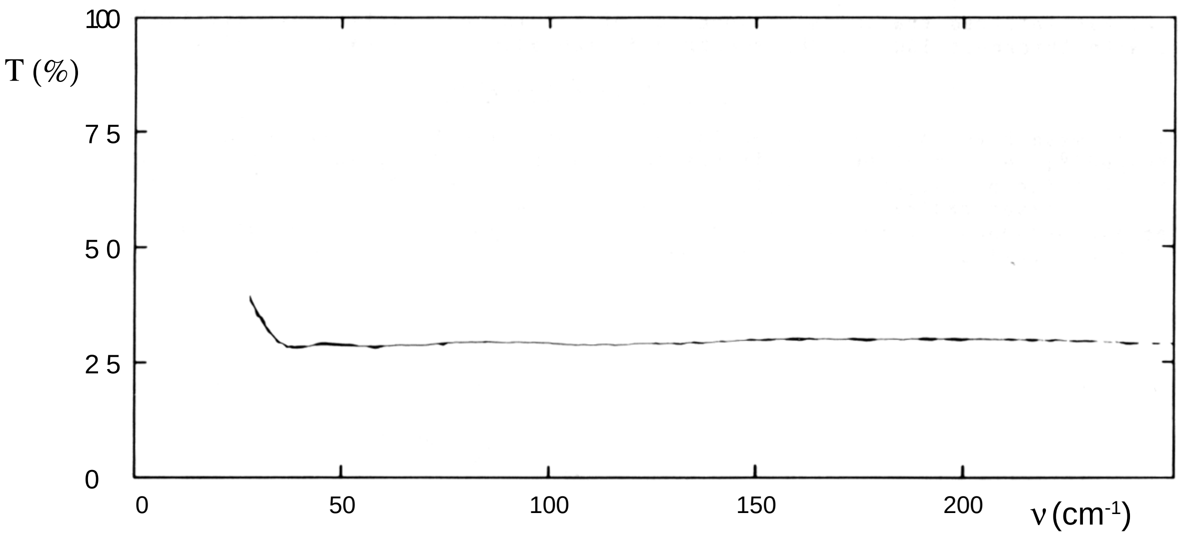

Fig. 4. Transmission curve of a diffractive neutral density filter designed for the far infrared. The results for two orthogonal linear polarizations are seen to be identical.

The transmittance is seen to be nearly constant, about 30% in this case, over a frequency range of nearly one decade. The equivalent attenuation is 5.2 db, with a maximum deviation of ± 0.5 db. The spectral limits are set by two different physical phenomena. On the low frequency end the rise of the transmission (Fig. 4) signals the onset of inductive resonance[14] while at the high frequency end a limit is set by the small value of the first-order diffraction angle α (Fig. 3). Note that a small first-order diffraction angle requires the use of a relatively long tubing for interrupting and absorbing all diffracted orders. With the use of a nearly collimated Gaussian laser beam there is a practical limit that α has to be at least equal to the divergence angle of the laser beam.

To facilitate alignment a relatively large free aperture of 39 mm diameter was chosen for our far-infrared attenuator. This size is matched to the inner diameter of our superfluorescent laser tube[2]. We chose to use five attenuating filters which can be flipped in the beam separately. Instead of using five equal steps of 5 db as in Refs. 12 and 13, we chose here the sequence 3-5-10-10-10 db (Fig. 5).

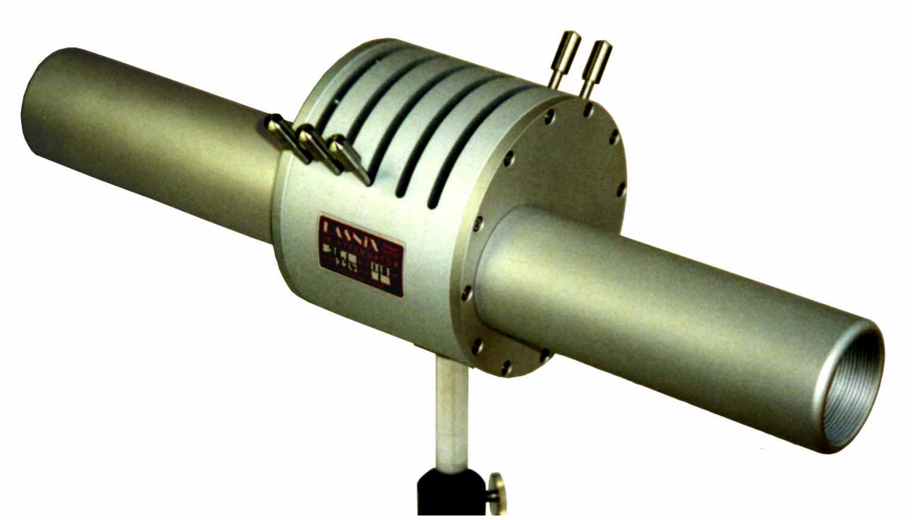

Fig. 5. Diffractive far-infrared attenuator (LASNIX Mod. 224).

In stacking up five diffractive neutral density filters, great care has to be given to avoid standing wave interferences and “crosstalk” between any of the many reflected and diffracted beams. Otherwise the attenuation of the individual elements will not come out to be truly additive. This is accomplished by defined tilt and rotational orientation of the mesh.

The performance of the attenuator proved satisfactory. No beam deviation or offset can arise from the use of substrate-free thin metal mesh. The homogeneity of the mesh guarantees uniform attenuation over the aperture. The polarization distortion was found to be minimal, e.g. less than ±0.05db for an element with an attenuation of 5db (Fig.4). As an example to illustrate the broad range of power setting we show a detector response measurement in Fig. 6.

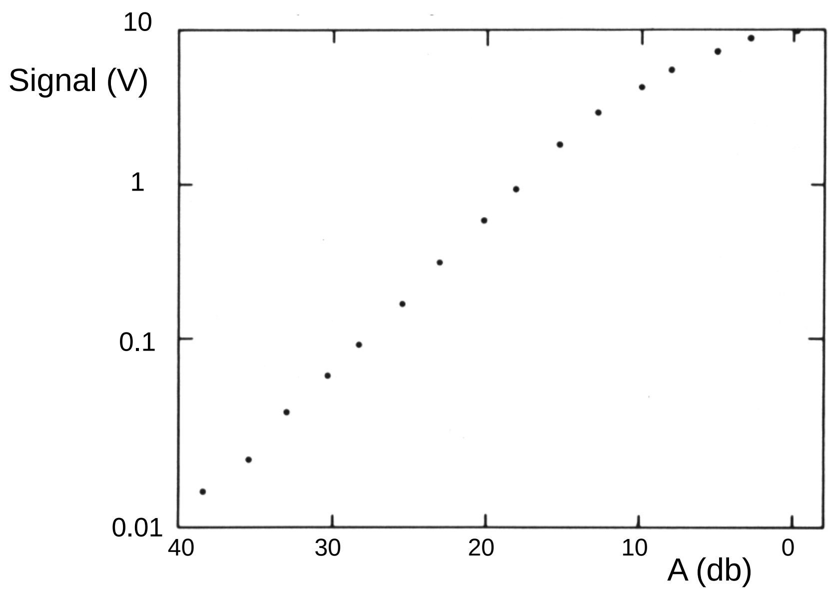

Fig. 6. Response of Golay detector to 118.8 µm FIR laser radiation, attenuated by a five-element sixteen-step diffractive attenuator. Detector saturation becomes visible at 3V.

Two far-infrared attenuators are presently employed, one before and one after the sample cryostat, in order to measure saturated absorption in p-Ge at 110 cm^{-1}. This setup allows to vary the intensity of the sample over nearly four orders of magnitude while leaving the power seen by the detector in a narrow dynamic range.

Lastly it is worth mentioning that the diffractive attenuator can handle high power. Extrapolating from CO_2 laser measurements[12,13] the power handling capability is at least 200 W c.w. and 10 J pulsed, more than presently available in FIR lasers. A distinct advantage is that the attenuator does not introduce any beam distortion or steering, since the attenuator elements are free-standing, without any substrate.

Conclusion

A precision step attenuator based on metal mesh has been developed. The attenuation is flat over nearly one decade of frequency. This frequency range can be tailored to lie anywhere in the near to far infrared.

Acknowledgement

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