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Simple scheme for variable high-power laser beam attenuation

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A venetian style infrared attenuator placed prior to a pinhole spatial filter results in variable high-power laser attenuation. This attenuation scheme has a wide dynamic range, results in high-quality Gaussian beams, does not introduce beam walk-off error, and is independent of polarization.

Often, less than the maximum amount of energy that can be delivered by high-power pulsed or continuous lasers is required for an experiment. However, optical power attenuation of these beams is not a straightforward task. The high intensities will result in damage to reflection or absorption-based partially transmitting attenuators. The finite wedge of transmitting substrate optical attenuators will, when rotated, similarly rotate the angle at which the transmitted beam exits the device. The latter is unacceptable for attenuation of critically aligned laser beams. Another means of effective attenuation is to decrease the excitation power or current delivered to the laser. This too can be troublesome since optical frequency, spatial beam, and temporal pulse characteristics change with a change in the excitation power. Thus again, critical alignment can be lost and changing pulse and optical frequency characteristics are generally difficult to characterize. Finally, use of attenuators based on the reflection and/or partial transmission of a particular polarization component of the laser beam require that either the beam be polarized to start with, or half of the total power must be eliminated with one of the two polarizations in order to utilize such an attenuation device.

Described here is a simple scheme for the attenuation and spatial filtering of high-intensity pulsed laser beams. This attenuator offers the advantages of being relatively inexpensive, has a very wide range of attenuations, does not introduce beam angle changes, and is not very sensitive to polarization. The attenuation scheme is based upon the use of a "pinhole" spatial filter. The operating principle of the common pinhole spatial filter is perhaps most easily understood in terms of the Fourier-transform properties of a lens.[1]

Simply stated, the intensity pattern found at the front image plane of a lens is proportional to the spatial frequency power spectrum of the spatial intensity entering the lens at the back image plane. The spatial filter works by focusing a beam, typically a Gaussian spatial profile with superimposed spatially variant "noise," through a pinhole aperture. The Fourier transform (to within a magnification and/or phase factor) of this spatially variant beam is found at the image plane of the lens. The Fourier-transformed Gaussian is itself a Gaussian, while that of the spatial noise forms an annulus around the Gaussian since this noise is composed of higher spatial frequency components than that of the central Gaussian beam. A pinhole aperture is placed at the image plane. The pinhole diameter is chosen such as to allow passage of the central Gaussian while blocking the noise composed of higher spatial frequency components.

To obtain variable attenuation, a "venetian blind" style attenuator, of the type commonly used for attenuation of reference beams in infrared absorption spectrophotometers, is placed prior to the focusing element of the pinhole spatial filter. The venetian attenuator device has a spatial periodicity along one axis. The repeating unit is that of a rectangle wave, the duty cycle (transmitting versus blocking) of which can be adjusted with modest tilting of the plane of the device. This device is placed far enough in front of the lens that the transform of this spatial variant device will nearly coincide with that of the Gaussian laser beam. The spatial intensity distribution of the laser beam just after the venetian attenuator is the product of the laser beam intensity prior to the device, and the periodic total transmission and total attenuation of the opaque strips. The laser beam is attenuated by tilting the angle of the venetian blind plane which varies the duty cycle of the rectangle wave pattern.

The Fourier transform of the spatial intensity pattern is found at the image plane of the lens. Since the spatial intensity pattern is the product of a Gaussian, though perhaps noisy, and a rectangle wave, the image at the transform plane is proportional to the convolution of a Gaussian with the Fourier transform of a rectangle wave. The latter transform is that of a series of harmonics with amplitudes decaying as the inverse order of their harmonic.[2] The venetian blind device is periodic along only one axis and the image in the transform plane is also only periodic along this axis. This image is a series of Gaussian spots, symmetrical about the center and most intense zero-order spot. To either side of this central spot are the first-order spots, followed by the second-order spots, etc. The intensities of these higher orders are inversely proportional to their orders. The pinhole is of a diameter and position such as to allow passage of only the central, zero-order Gaussian spot. The pinhole will filter out noise of higher spatial frequencies as well.

This attenuation scheme has been tested using a pulsed TEA carbon dioxide laser. The laser was operated in the Gaussian TEM_{00} mode by placing a circular aperture inside the laser cavity and very close to the minimum beam waist position of the hemispherical cavity configuration. The laser delivered a self-mode locked pulse of 170-ns duration and with a total energy per pulse of about 25 mJ. Pulse repetition rate was 3.75 Hz. Even with the intracavity aperture, the beam from this laser was only roughly Gaussian in form and had a noticeable amount of high spatial frequency noise and a distinct radial asymmetry, both of which varied on a pulse-to-pulse basis. A Perkin–Elmer venetian blind style infrared attenuator was placed 92 cm in front of a 30.48-cm *f.l.*, *f*/12 BaF_2 lens used as the transform lens of the pinhole spatial filter. The pinhole was made by drilling a 0.7-mm-diam hole in 1.2-mm copper sheet stock. The diameter of the hole, as well as its symmetry, was checked under a microscope. Copper is useful due to its high reflectivity in the 10.6-μm infrared wavelength region.

The pulsed laser beam profile was monitored using a carbon paddle. Just prior to the venetian blind device, the laser beam had a diameter of roughly 1.5 cm. This was enough to illuminate several of the venetian blind slits, spaced six per cm when the device was perpendicular to the laser beam axis. The beam profile at the lens image plane was observed by smudging carbon onto the copper sheet stock. Higher diffraction orders were observed on either side of the zero-order spot. The zero-order spot could be identified by its high intensity relative to the higher-order spots. Past the pinhole aperture, the beam appeared to be radially symmetric and without spatial noise. Variable attenuation of the pulse energy was accomplished by tilting the venetian blind device relative to that of the laser beam using a motorized micrometer to smoothly vary the angle. Changing the angle of the device changes the attenuation as well as the spatial frequency. However, since only the zero-order spot is transmitted through the pinhole, changing the spatial frequency is inconsequential. The transmitted pulse energy was found to be smoothly variable from 0% through over 90% of the energy transmitted through the spatial filter without the venetian blind device.

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[1] S. H. Lee, in *Optical Information Processing Fundamentals*, edited by S. H. Lee (Springer, New York, 1981), Chap. 1.
[2] A. D. Poularikas and S. Seely, *Signals and Systems* (PWS Engineering, Boston, 1985).

Shutter ratio of a gated ITT F4128 microchannel-plate photomultiplier

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The shutter ratio of a proximity focused ITT F4128 microchannel-plate (MCP) photomultiplier is investigated for gated photocathode-to-MCP gap voltages. At counter potentials of greater than 3 V, the shutter ratio is better than 10^{13} for incident light with a wavelength longer than 600 nm.

Proximity focused MCP photomultipliers and image intensifiers can be gated either by pulsing the voltage applied between the photocathode and the MCP input[1–10] or by switching the MCP supply voltage.[11–13] The efficiency of gating is characterized by the shutter ratio. This quantity is defined as the ratio between the number of photoelectrons created in the gated-on mode (= quantum efficiency times number of incident photons) and the number of electrons which are detected in the gated-off mode for the same optical input (= number of output electrons divided by the MCP gain). Shutter ratios of 2×10^8 are reported for the case of controlling the photocathode-to-MCP voltage.[14] For an MCP photomultiplier with a gain of 10^5, a combination of both the methods mentioned yielded a total shutter ratio of 1×10^{12}.[14] For high-speed applications, however, the gating of the photocathode-to-MCP gap voltage is preferable, since lower voltage excursions are needed, thus leading to less e.m. pickup on the output of the photomultiplier. In the following, we report spectrally resolved measurements of the shutter ratio of a proximity focused ITT F4128 MCP photomultiplier gated by pulsing the photocathode-to-MCP voltage.

The photomultiplier investigated is a two-stage MCP device. The MCPs have no protective coating against the ion back current. The photocathode-to-MCP spacing is 0.2 mm and the nominal accelerating voltage across this gap is 150 V. The photocathode diameter of our detector is only 10 mm instead of 18 mm for the standard version. At nominal supply voltages (MCP voltage of 1760 V which corresponds to a gain of 1×10^5, MCP-to-anode voltage 300 V), a rise time of 180 ps was measured.[15] The shutter ratio was measured using pulsed and cw light sources, varying the potential of the photocathode between -150 (gated-on state) and $+40$ V (gated-off state).

(1) Measurements using cw light sources: A cw Ar^{3+} laser (operated at 458, 488, or 514 nm), a HeNe laser (632 nm), a diode laser (780 nm), and an incandescent lamp with different edge filters were used as light sources. During the measurements, the sources were arranged to illuminate the whole photocathode uniformly. The power of the light beams incident on the photocathode was determined by exchanging the detector with a calibrated power meter. In addition, the light beams were attenuated by calibrated neutral density filters and the signals from the gated-on photomultiplier were measured. The output signal was registered either with a 50-Ω input oscilloscope in the gated mode of operation (gate duration 50 ns) or with a 22-MΩ impedance dc voltmeter in the case of dc operation of the photomultipler. The results from the powermeter measurements and those