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Increased Spatial Coverage in Optical Diagnostics using Glass Wedges

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Abstract: Glass wedges are used increase the dimensionality of various optical measurements. Light refracted through the wedges can be focused to closely spaced points, lines or planes as shown in the applications herein.

1. Introduction

There is a need in many optical diagnostics to improve the measurement dimensionality. Many advanced optical diagnostics are performed at a point; could such measurements be performed along a line, or in a plane? Ideally, three-dimensional, time-resolved measurements would be available to provide needed information to understand volumetric transient dynamics and provide fully resolved gradient information of the quantities of interest.

In this paper a unique optical element is introduced that can provide increased dimensionality to many optical diagnostics. The optical element is an array of glass wedges [1], and the basic optical design is shown in Fig. 1. Light passing through the glass wedges is split to form multiple beamlets by refraction through the various wedge angles. The light can then be focused to points, lines, or planes with a single focusing optic or set of focusing optics. Other optical elements have been used to form multi-point illumination sources including beam splitters, specialty lenses, pellicles, prisms, and diffractive optics [23].

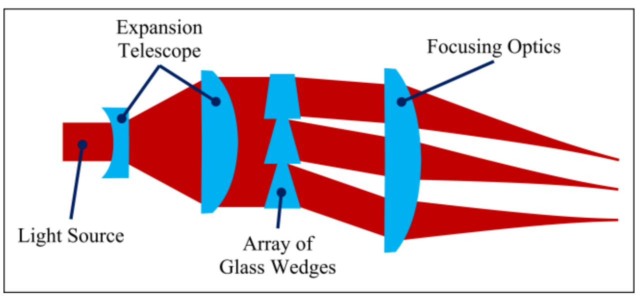

Fig. 1. Basic optical design of an array of glass wedges to create multiple points, lines, or sheets of illumination for multi-dimensional measurements.

To illustrate the characteristics of light transmitted through this type of optical arrangement, a laser diode, beam-expanding telescope, wedge array and focusing optics were setup with a camera was placed near the focal plane (right-hand side in Fig. 1). Images recorded before and after the focal plane are shown in Fig. 2a and show the focusing properties of light transmitted through glass wedges.

2. Demonstration Measurements

Demonstration measurements are presented that highlight the utility of the glass wedges with a variety of light sources and a variety of measurement techniques. The first demonstration measurements are a seedless velocimetry technique particularly suited to supersonic and hypersonic flows; this technique is called femtosecond electronic excitation tagging (FLEET) [4]. In this technique a short-duration, high-intensity laser pulse is used to ionize and dissociate gas-phase molecular nitrogen and the naturally occurring emission is tracked with an intensified, gated camera to extract convective flow velocities.

This demonstration measurement highlights one advantage of the glass wedge optical element, namely that it is compatible with high-peak-intensity light sources. In this case, the light source is a regeneratively amplified femtosecond (fs) laser (60 fs pulse duration, 10 mJ pulse energy, and 1 kHz laser repetition rate). The fs beam is expanded and then passed through a series of glass wedges made of fused silica with physical dimensions of 5 x 5 x 80 mm and wedge angles from -4 to 4 degrees in increments of 1 degree. A photograph of the many FLEET spots created using the glass wedges is shown in Fig. 2b. This emission is imaged from four different perspectives to enable tomographic reconstructions and thus track the FLEET emission centroid in three dimensions as a function of time. The use of the glass wedges in this experiment provides a dramatic improvement in the spatial coverage of commonly used FLEET instruments [5].

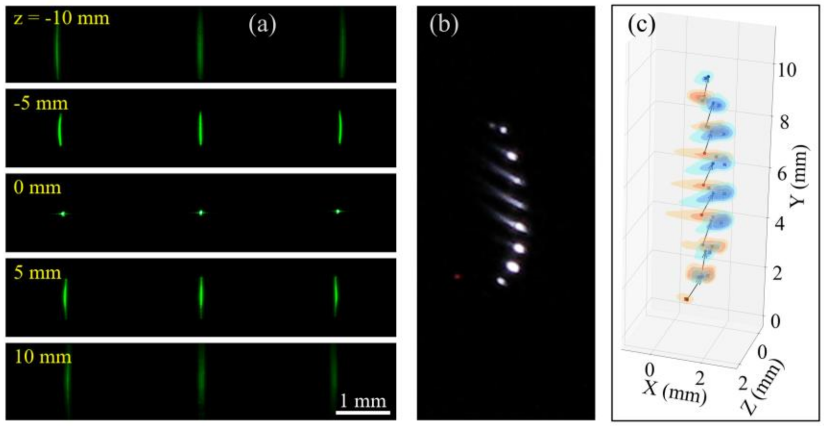

Fig. 2. (a) Focusing properties of light transmitted through glass wedges as discussed in the text. (b) Photograph of multiple closely spaced FLEET lines created using glass wedges. (c) Tomographic reconstructions of FLEET intensity from multi-view imaging to find and track motion of FLEET intensity centroids in three dimensions.

Additional demonstration measurements include the use of a glass wedge array to perform multiple-line nitric-oxide laser-induced fluorescence measurements in a high-enthalpy ground test facility. In this case the fluorescence emission from many lines created by the glass wedges was imaged to extract gas-velocity data; this is an example of molecular tagging velocimetry. The laser used in this work is a pulse-burst laser and the fluorescence excitation wavelength is in the ultraviolet. A final demonstration measurement is multi-planar soot imaging in flames. A high-energy nanosecond-duration laser pulse is passed through glass wedges to create six planes of illumination. In this experiment each plane of illumination had a unique spatial intensity pattern to allow for Fourier-domain extraction of the data from each plane.

3. Conclusions

Glass wedges are shown to be a useful tool to enhance the dimensionality of many optical diagnostics and are compatible with a wide variety of light sources. Three different demonstration measurements are discussed here wherein light if focused to multiple, closely space points, lines, or planes. Glass wedges may be applied advantageously to a variety of optical diagnostics to increase dimensionality, quantity, and spatial coverage of data available from a single experiment.

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