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Holographic Behavior in Ultrashort Pulse-pair 2d-Velocimetry

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Abstract: Two-dimensional velocity interferograms of shocked silicon surface illuminated by a pair of 3ps pulses separated by 270 ps can be treated as holograms to numerically refocus narrow cracks otherwise blurred in ordinary image.
OCIS codes: (090.2880) Holographic interferometry, (100.6890) Three-dimensional image processing, (120.7250) Velocimetry, (320.7100) Ultrafast measurements

1. Introduction

An important optical diagnostic used in shock physics has been a Velocity Interferometer System for Any Reflector (VISAR) [1-4]. This measures target motion to high precision using phase shifts of fringes produced by interfering light reflected from the target at two different times, slightly delayed. Until recently, this diagnostic has been limited to measuring motion at points or lines across a target [1-3]. Recently our group introduced a two-

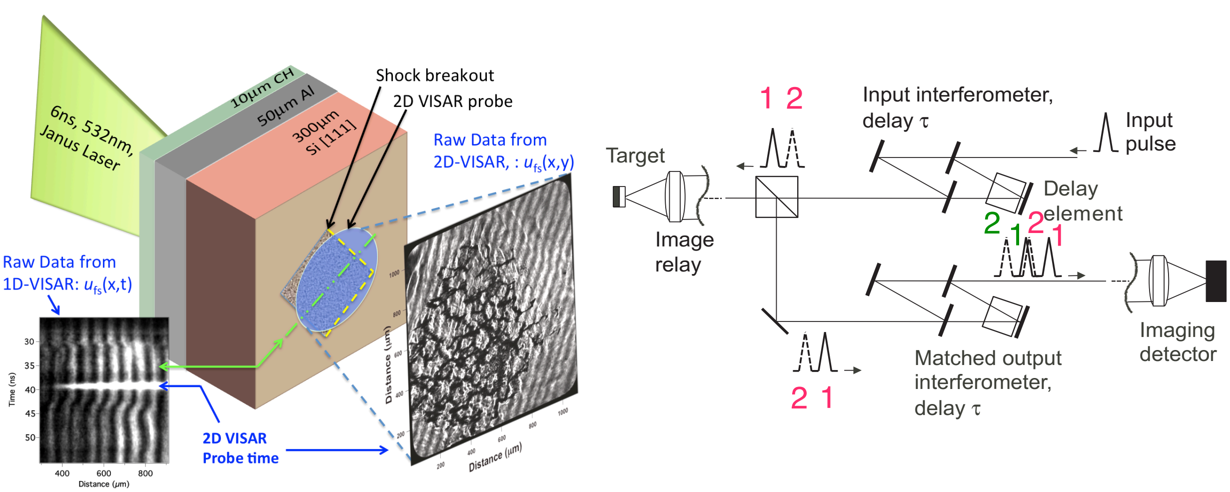


Fig. 1. (Left) The onset of fracture networds in shocked Si is observed by 1d- and 2d velocity interferometers (VISAR) at LLNL's Jupiter Laser Facility. The conventional 1d-VISAR lacked sufficient spatial resolution to observe the cracks but provided time history. (Right) The white light or dual interferometer velocimeter scheme uses matched-delay illuminating and detecting interferometers to produce fringes in spite of pulsewidths (3 ps) shorter than the interferometer delay (270 ps). From a single illuminating pulse, two pulses 1 and 2 separated in time reflect off the target, interrogating its motion. After passing through 2nd interferometer four pulses are created. Only the inner pair overlap to interfere. Target motion during pulse pair separation creates fringe phase shift proportional to velocity.

dimensional version of a VISAR [5-10]. We have used it at the Rochester's Omega Laser system [10], and at LLNL's Jupiter Laser system [11], to measure 2d velocity and reflectivity maps on targets of silicon, and diamond, to study the shock wave uniformity, and the fracture dynamics. Our system has a higher spatial resolution than conventional line-VISARs, because we use optical lenses and a 4000x4000 pixel CCD detector rather than electron beam optics and a phosphor screen such as a framing camera or streak camera. But because the detector has by itself no time gating, instead of recording a time history of velocity as in a point or line-VISAR, we use 3 ps pulsed illumination to freeze the target motion and measure velocity and reflectivity in a snapshot.

We have discovered an interesting and useful improvement to the 2d-VISAR, which is a numerical holographic post-processing (easily implemented via Fourier transform) of the complex 2d-image data which normally outputs

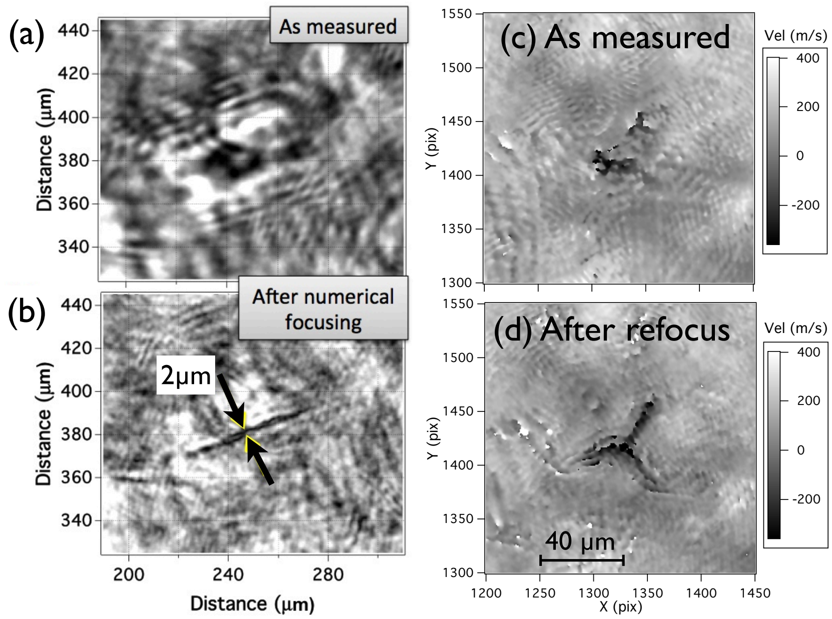
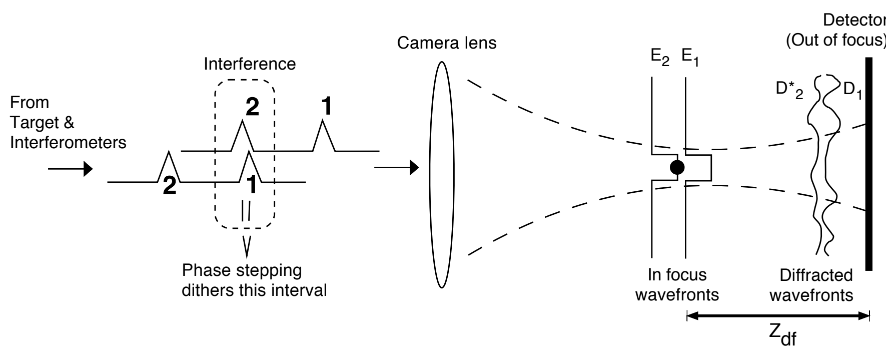


Fig. 2. Comparison of raw (a), (c) and numerically refocused (b), (d) images, which are subsets of a larger image of shocked Si data (shot 020910-04). (a) Raw & (b) refocused magnitude |**W**(x,y)| of a linear crack feature. The numerically refocused crack has width of about 2 pixels, ~1 μm. (c) Raw & (d) refocused velocity change (proportional to phase) from local average, of an interesting trigonal crack feature. Scale is 0.53 μm per pixel. The feature manifests the trigonal symmetry of Si at [111] orientation.

from the VISAR analysis. If the original data was taken in an out of focus condition, we have demonstrated the ability to bring narrow features such as cracks back into focus, after the fact, when otherwise they would be blurred. This is a very useful ability, since it is often difficult to precisely focus specular targets (such as clean silicon or diamond) and anticipate their motion prior to the moment of illumination, especially with the narrow depth of field of high numerical aperture lenses typically used to collect a large solid angle of light reflected from a target. This ability could also be useful for exploring the 3d debris region of a shocked textured target, or targets having 3d shape not residing in a single plane.

Fig. 3. During the experiment the target image in the camera was assumed defocused by amount Z_{df} so that diffraction ring components (D_1, D_2) are recorded by detector. Only the inner two pulses (electric fields at focus E_1, E_2) interfere to produce the fringing signal which varies with quadrature phase stepping in the 2nd interferometer. All four phase stepped images are recorded simultaneously by 4 quadrants of detector. Constant diffraction ring contributions by dust specks along path cancel in the push-pull math. The black dot represents change in target reflectivity due to a crack opening (Fig. 2a), and tophat phase represents a possible surface profile feature. Localized velocity features (Fig. 2b) can also be measured.



In our technique the “reference” is not a smooth wavefront but is instead a delayed version of the signal wavefront. The reference and signal beams share the same path, and consequently a defocused (ghost) image of the target is superimposed with the focused image. But for narrow features (which vary strongly with focus adjustment), the narrow features are approximately isolated.

2. Comparison to Prior Holography

Holography has been used previously to measure ejecta from shocked surfaces [12], and a shock front [13]. These use a conventional two beam (reference and object) arrangement to create fringes on the detector. In contrast, our technique uses a single beam path for both signal and “reference” wavefronts, and a double pulse pair instead of a single illumination pulse. The work of Greenfield et al. [14], at LANL also uses pulsed illumination to freeze motion of a shock sample observed in 2d by an interferometer. However, their system does not record simultaneous phase quadrature, as our system does. Consequently, their spatial resolution is significantly less because they (essentially) need to use adjoining pixels to provide the phase quadrature.

Recent ultrashort pulse digital holography work [16], at Kyoto Institute of Technology is related to our effort, but differs fundamentally topologically by using a single illumination pulse where we use a pair, and having the target internal to the interferometer instead of external as in our technique. With a single illumination pulse they are measuring a single target image and not an average velocity (change in position over significant time). They cannot measure the target velocity interferometrically to the same precision that we can with a double pulse. And we can measure a velocity map simultaneous to a snapshot image (reflectivity & phase).

Secondly, since our target is external to the interferometer, our target can be a large and safe distance away from the operators and equipment, and target position or surface texture does not change the interferometer alignment. This is because in our configuration homodyning is performed (it interferes with a delayed image of itself) so it can work with complicated wavefronts from diffusively scattering targets.

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