TITLE
RECENT ADVANCES IN HIGH SPEED PHOTOGRAPHY AND ASSOCIATED TECHNOLOGIES IN THE U.S.A.

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Recent Advances in High Speed Photography and Associated Technologies in the U.S.A.

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ABSTRACT

In the past decade, high speed photography has been rapidly incorporating electro-optics. More recently, optoelectronics and digital recording of images for specialized laboratory cameras and commercially available systems have helped broaden the versatility and applications of high speed photography and photonics. This paper will highlight some of these technologies and specialized systems.

1. INTRODUCTION

Conventional mechanical and electronic streak and framing cameras remain the main diagnostic tools in high speed photography, but recent advances in electro-optics and microcomputers have greatly enhanced the ease of operation, versatility, data collection, and reduction. Microchannel plate (MCP) image intensified cameras ($I^2C$) are being used for multiexposure and have been coupled to a two-dimensional array charge injection device (CID) to provide nanosecond gating with high optical gain and the advantage of CID digital storage of images. As larger format MCP image intensified biplanar diodes and CID arrays become available, film will be further challenged as the preferred recording medium. $I^2C$ cameras to study detonation rates and devices are reported as well as x-ray images converted to visible wavelengths and recorded with $I^2C$/CID cameras.

Light emitting diodes and laser diodes are being used as lighting systems for small fields-of-view in backlight and Cranz-Schardin cameras. Diodes have the advantage of TTL control, relatively narrow line width (monochromatic), small point source, and nanosecond pulse duration. These attributes are desired in most optical laser photography systems. The power and energy output is still somewhat low but will increase significantly in the next few years. Laser diode pumped, solid state lasers are decreasing laser package size, input power, and complexity while increasing output power and ease of operation.

2. COMBINATION INTENSIFIED/MECHANICAL STREAK CAMERA

Los Alamos researchers$^1,2$ have developed a combination mechanical streak camera with a MCP image intensified biplanar diode. The camera provides a temporal resolution of a few nanoseconds, high optical resolution (60 lp/mm), and streak linearity of 1% over a 125-mm record length (Figures 1 & 2). At the researchers option for low light level experiments, the streak camera can be adapted with a MCP at the film plane (Figure 3). The MCP does reduce the resolution to 16-18 lp/mm typical of an electronic streak camera but retains the 1% streak linearity of the mechanical camera. The MCP is used for optical gain up to 5000. The optical cavity is flushed and mirror turbine is operated with helium.
The camera can use single or multiple slits. The time resolution is 2 nanoseconds over 6 microseconds. The camera is used routinely for Fabry-Perot interferometry (Figure 4) and for recording optical signals from detonation fronts.

3. CINERADIOGRAPHY/CID DIGITAL PULSED IMAGING

Conventional flash x-ray (Figure 5) traditionally uses short (few tens of nanoseconds) x-ray pulses to provide the energy for exposure and the pulse duration for the exposure time of the captured image. These data are recorded on film with the use of intensifier screens to increase image density. x-ray films usually have lower spatial resolution than standard visible optical films. Multiple images of dynamic events require multiple pulses of x-rays on the same film cassette or multiple pulser each with its own film cassette
With multiple pulses on the same film, the contrast is reduced and relating specific data to each exposure is not always obvious. Multiple pulsers each with its own

**FLASH X-RAY**

![Flash X-ray Diagram](image)

**Figure 5. Traditional flash x-ray method**

**Figure 6. Gated MCP/CID camera design**

film cassette, creates a different field-of-view for each frame, making data correlation frame-to-frame nontrivial.

In the last several years, gated MCPs have been matched to CID and CCDs by fiber optic faceplates. The MCP provides the optical intensification and exposure times of 5-100 ns and the CID can be operated in standard RS-170 video I/O mode with only the need to assure that the MCP and CID gate are synchronized properly (Figure 6).

Current MCP/CID camera parameters are: 18mm diam. MCP with up to 18,000 luminance gain at $2 \times 10^{-6}$ ft. candles and CID 244 pixels vertical x 388 pixels horizontal with gating times of 5-100 ns. A MCP/CID camera system is used to view an inorganic phosphor screen (Figure 7) replacing a standard x-ray film cassette.

**CINE RADIOGRAPHY**

![Cine Radiography Diagram](image)

**Figure 7. Flash x-ray technique using a quasi-continuous x-ray source and gated MCP/CID cameras**

This system has several advantages: 1) The recording method (camera instead of film) is separated from the screen. This negates the need to recover a film cassette near a dynamic event (i.e., explosives). 2) Several cameras can view the same intensifier screen with little or no concern for different viewing angles. 3) The x-ray source that is quasi-continuous usually results in a smaller spot size reducing penumbra effects on optical resolution.
High explosive-driven plates have been recorded using a 450 kV Marx bank with 30 ns pulse and 5 microsecond gated camera (Figures 8 & 9). System trade-offs must always be considered but for flash x-ray of many dynamic events, the MCP/CID offers experimental and data reduction advantages without sacrificing resolution.

Figure 8. Static view of explosive driven plate test (HE: PBX 9501, plate: 0.125 in. Al)
Figure 9. Dynamic view of explosive driven plate (x-ray source: 450 kV, 30 ns pulse)

4. NANOSECOND GATED MCP$^1$C CAMERAS

Numerous researchers have used the 1$^2$C in a multipulse mode of 5 ns/pulse to record moving objects, plasmas, or detonation fronts over a fixed field-of-view. Los Alamos is currently using 1$^2$Cs to record detonation fronts of small explosive tracks and shock waves in explosive logic units (Figures 10, 11 & 12), exploding foils, and flyer plates (Figure 13).

Figure 10. Explosive logic unit showing progression of detonation front with 4 pulses from 1$^2$C
Figure 11. Explosive logic unit showing progression of detonation front with 10 pulses from 1$^2$C
Figure 12. Multipulsed T\textsuperscript{2}C of three converging detonation fronts in explosive

Figure 13. T\textsuperscript{2}C single pulse of exploding foil (bottom image) with plasma expanding toward camera and 90° view (top image) of the same event

2. PULSED LASER STEREOPHOTOGRAPHY OF PLASMAS AND DYNAMICALLY MOVING SURFACES

A pulsed laser is used to photograph exploding foils\textsuperscript{7,8,9}, and a transparent plastic plate less than 1 mm\textsuperscript{2} that are accelerated by a foil in contact with and behind the plastic plate. The plastic plate is accelerated to greater than 3 mm/\textmu s with a total flight time of less than 0.5 microsec. At a predetermined time during the dynamic event, an as pulsed ruby laser is synchronized with the exploding foil. A stereocamera is used to record a pair of images of the dynamically moving surface. The stereo image pair is recorded on 4 \times 5 film for later quantification for surface contour.

In many cases the experiment itself is a pseudowhite light emitter, therefore, any light source for photographic purposes must be intense, short duration, and separable from the self light of the experiment. A pulsed laser can provide all the attributes necessary for front light reflected stereophotography of our experiments. The attributes desired from the light source include: short pulse (\textleq 10 nsec), monochromatic, high optical power, and the ability to time synchronize the output pulse. All of these attributes are characteristic of solid state lasers in addition to the spatial coherence that is not desired. As described later, the spatial coherence can be destroyed.

3. EXPERIMENTAL APPARATUS

A small 1 mm \times 1 mm exploding foil is used to accelerate a flow plate of a brittle, e-beam, or electron metal laminate to a high velocity with a high acceleration, but with a total flight length of only a few millimeters. The metal foil is electrically exploded via a generator discharge through a low resistance, low inductance circuit. The electric foil is the resistive element in the circuit. The high current in a few tens of microsecond rapidly deposits energy in the exploding foil causing rapid heating and conversion of
2. PULSED LASER STEREOPHOTOGRAPHY OF PLASMAS AND DYNAMICALLY MOVING SURFACES

A pulsed laser is used to photograph exploding foils5,6,8, and a transparent plastic plate less than 1 mm² that are accelerated by a foil in contact with and behind the plastic plate. The plastic plate is accelerated to greater than 1 mm/μsecond with a total flight time of less than 0.5 microseconds. At a predetermined time during the dynamic event, and as the pulsed ruby laser is synchronized with the exploding foil, a stereocamera is used to record a pair of images of the dynamically moving surface. The stereo image pair is recorded on 4 × 5 film for later quantification for surface contour.

In many cases the experiment itself is a pseudowhite light emitter; therefore, any light source for photographic purposes must be intense, short duration, and separable from the self light of the experiment. A pulsed laser can provide all the attributes necessary for front light reflected stereophotography of our experiments. The attributes desired from the light source include short pulse ≤ 10 ns, monochromatic, high optical power, and the ability to time synchronize the output pulse. All of these attributes are characteristics of solid state lasers in addition to the spatial coherence that is not desired. As described later, the spatial coherence can be destroyed.

8. EXPERIMENTAL DESIGN

A small 1 mm × 1 mm exploding foil is used to accelerate a thin plate of a brittle, or ductile, metal laminar to a high velocity with a high acceleration, but with a total flight length of only a few millimeters. The metal foil is electrically exploded by a capacitor discharge through the low-resistance, low-inductance circuit. The explosive foil is the reactive element in the event. The high current in a few tens of nanosecond rapidly deposits energy in the exploding foil creating rapid heating and conversion of
6. OPTICAL SYSTEMS USING LASER DIODES FOR ILLUMINATION

The average power and duty cycle of laser diodes is low for short, high power pulses (<100 ns). Some diodes can be operated at 1000 times the rated duty factor and high-pulsed power for a few tens of pulses without degradation. For use in backlighting, shadowgraphy, or Cranz-Schardin, semiconductor diodes can provide enough energy to expose conventional infrared film. Semiconductors diodes have several disadvantages for use as a pulsed light source, but the advantages vastly outweigh any drawbacks. The current major markets for semiconductor lasers are: communications, write-once, read-many (WORM) data storage, and CD-players. All three of the commercial applications require narrow bandwidth and long lifetime (typically thousands of hours). These characteristics are not required for high-speed photography illumination.

Currently available semiconductor diodes have the following general characteristics:

<table>
<thead>
<tr>
<th>Semiconductor technology:</th>
<th>GaAs and AlGaAs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength:</td>
<td>840 - 900 ns</td>
</tr>
<tr>
<td>Laser linewidth:</td>
<td>5 ns (typ.)</td>
</tr>
<tr>
<td>Active lasing area:</td>
<td>5 X 10-100 microns</td>
</tr>
<tr>
<td>Rated power:</td>
<td>up to 5 W (pulsed)</td>
</tr>
<tr>
<td>Output of beam profile:</td>
<td>5° X 15° half-angle divergence</td>
</tr>
</tbody>
</table>

The major advantages of semiconductor laser for illumination is: small lasing area (few microns by 10-100 microns, near point source when compared to xenon flash lamps), low voltage operation, ease of generating short high-powered pulses separated by a few tens of pulse widths. Semiconductor laser output is not usually of high spatial and temporal coherence. These are desirable characteristics for conventional illumination.
Figure 17. Cranz-Schardin camera using laser diode illumination

Figure 18. Cranz-Schardin photograph of a crack propagation in glass by impacting steel sphere

Figure 19. Cranz-Schardin photograph of steel sphere penetrating plate

Figure 20. Simultaneous Cranz-Schardin orthogonal views for ballistic range

Semiconductor lasers can be fabricated in a one- or two-dimensional array of 10 to 100 diodes (<1 mm²) and can be pulsed simultaneously for increased output power (250 W, 40 ns) of 100 ergs. Since most film can be exposed by energies of 0.1 to 5 ergs/cm².
semiconductor lasers provide satisfactory energy for most film types and formats. The pulsed circuit for driving the semiconductor laser is a simple R-C that is switched by an SCRs or FETs in parallel to reduce circuit inductance and a capacitor to define the desired pulse width. Damage to semiconductor laser occurs by one of two modes, i.e. facet damage or thermal damage of lasing medium and junction. For single, short pulses, thermal damage is of no concern and facet damage is related to the square-root of the pulse length. Conventional geometrical optical lighting systems require that coherence be destroyed to eliminate "laser speckle" and interference fringes. Laser speckle size is related to wavelength, coherence length, and f-number of the optical system. In front illuminated photographs, laser speckle poses the most likely problem, but semiconductor laser arrays on a single chip usually are not temporally or spatially coherent enough to significantly contribute to image degradation. Commercially available backlit and Cranz-Schardin cameras using semiconductor laser for illumination of 100 mm² to 0.3 m² areas are now available. A Cranz-Schardin Camera System (Figure 17) is currently being used to study crack propagation (Figure 18), particle velocity (Figure 19), and stereo-Cranz-Schardin projectile velocity and yaw (Figures 20, 21, & 22).

Figure 21. Cranz-Schardin photograph of 0.50 caliber projectile
Figure 22. Simultaneous orthogonal view of figure 21.

7. SUMMARY

Improvement in temporal and spatial resolution of optical signals and images continues to progress. The trend over the last few years has been to exploit and incorporate several different basic technologies into a system that provides the desired requirements while at the same time digitizing and interfacing the output to a computer interface. This trend will probably continue.

8. ACKNOWLEDGMENTS

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