

Swiss Photonics Workshop on SLM



**SILICON
LIGHT
MACHINES**

Grating Light Valve Technology & Applications

Ecole Polytechnique Fédérale de Lausanne

October 2017



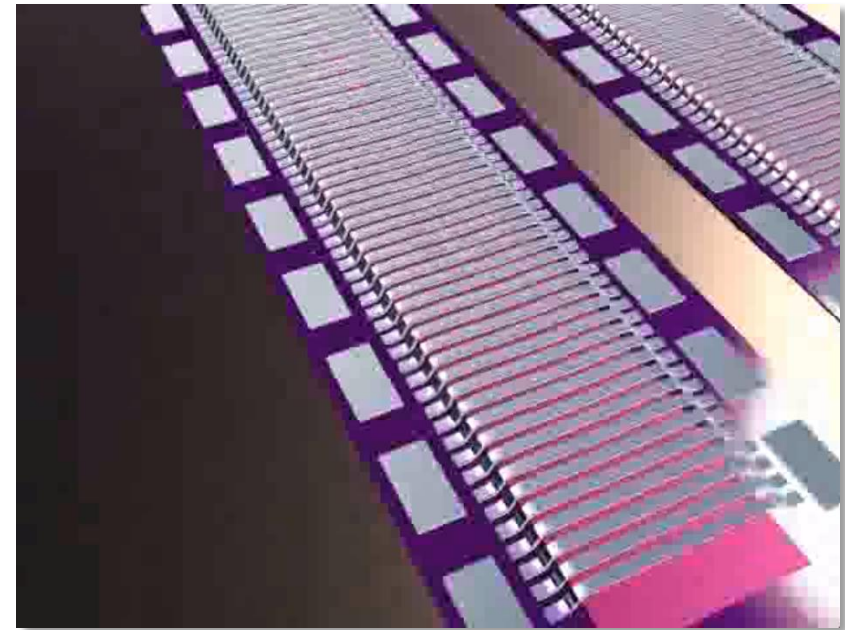
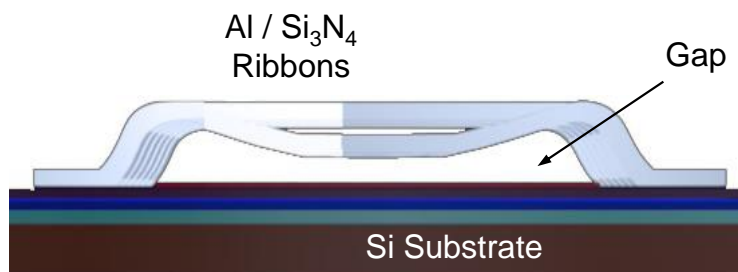
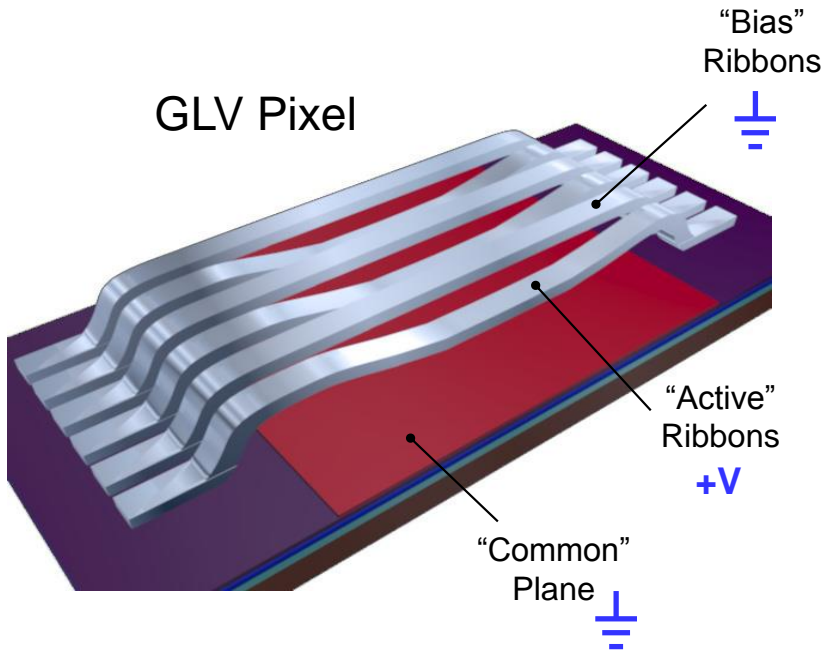
ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

Outline



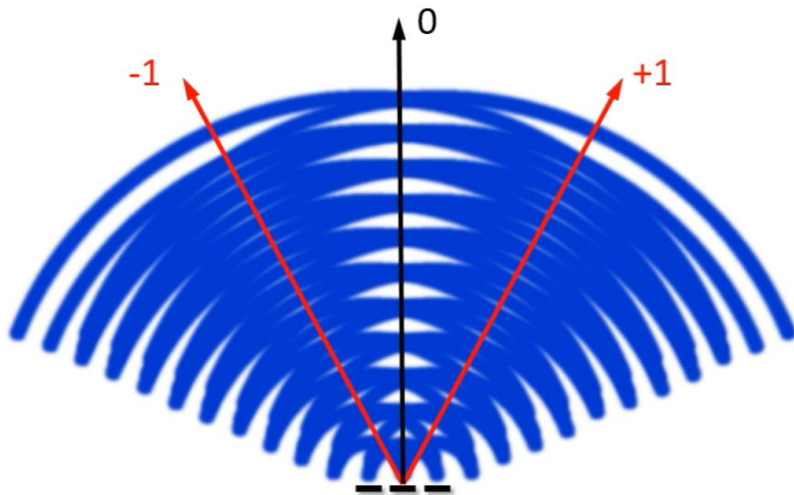
- **GLV Technology**
- **Direct Write Applications**
- **Emerging Applications**
- **Technology Roadmap**
- **Conclusions**

Grating Light Valve (GLV™)



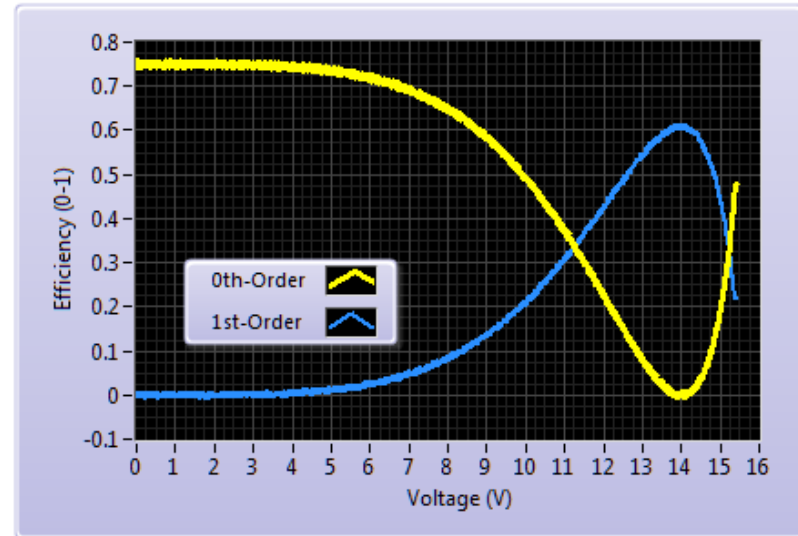
- The GLV is a high-speed diffractive MEMS light modulator fabricated from aluminum & silicon-nitride

Light Modulation with GLV

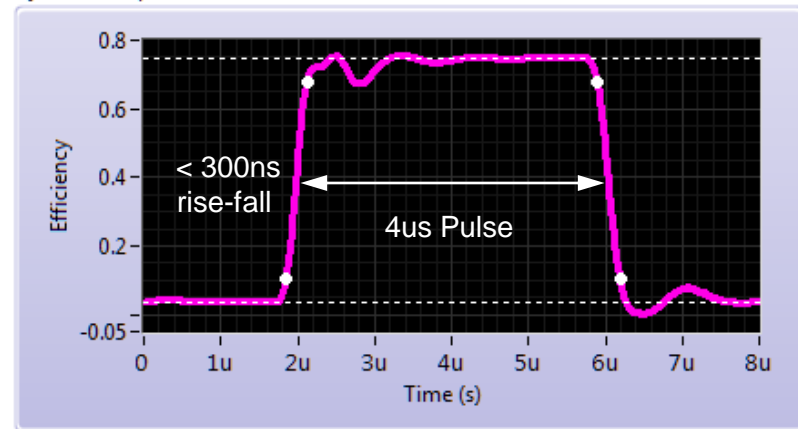


- The GLV uses phase interference to modulate light intensity reflected into fixed diffraction angles at high speeds

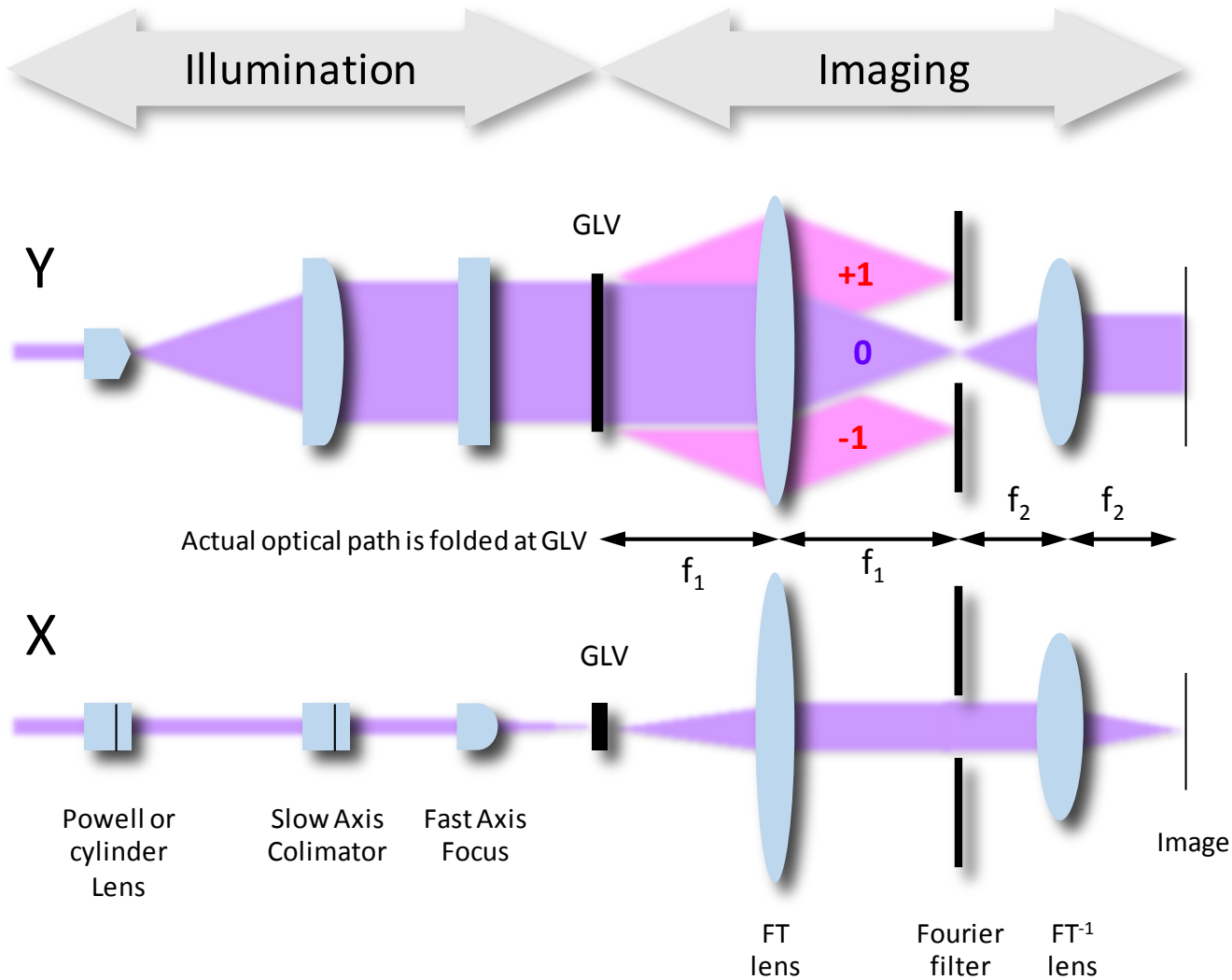
Intensity-Voltage Curves



Dynamic Response



GLV Illumination & Imaging



GLV-Based Laser Displays



Sony Laser Dream Theater
(10x50m)



E&S Digistar Planetarium Projector

- The original application of the GLV was in laser-based displays

SCREEN & Silicon Light Machines



SCREEN

The SCREEN logo is displayed in a large, bold, blue, sans-serif font within a white rectangular box. In the background, there is a faint, stylized illustration of a globe and a person in traditional attire.

**SILICON
LIGHT
MACHINES**

Precision Equipment Supplier

- Founded 1943 (roots in Kyoto from 1868)
- >5000 employees, >\$2.5B annual revenue
- Semiconductor fabrication equipment
- Printed circuit board tools
- Flat panel display tools
- Graphic arts systems

Optical MEMS Specialists

- Unique diffractive MEMS technology
- Building optical MEMS for >20 years
- Semiconductor, electronics & optics
- Demanding industrial applications
- Began working with SCREEN 1997
- SCREEN subsidiary since 2008

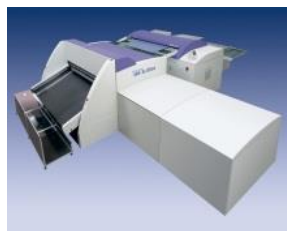
SLM-SCREEN Collaboration



1997 2000 2003 2006 2009 2012 2015 2018

Begin joint development	Gen 1 GLV 1080-ch 8-bit AMP 40W IR	Gen 2 GLV 1080-ch 10-bit AMP 8-bit PWM 80W IR	Gen3 GLV 1080-ch 10-bit AMP 8-bit PWM 100W IR Hi Efficiency	Gen 1 iGLV 8192-ch 10-bit AMP 8-bit PWM (analog) 4W UV	Gen 2 iGLV 8192-ch 10-bit AMP 8-bit PWM (digital) 8W UV
--------------------------------	--	--	---	---	--

PlateRite Ultima



PlateRite 8800



PlateRite Niagara



PlateRite Ultima 48000



PlateRite 8900



DW-3000

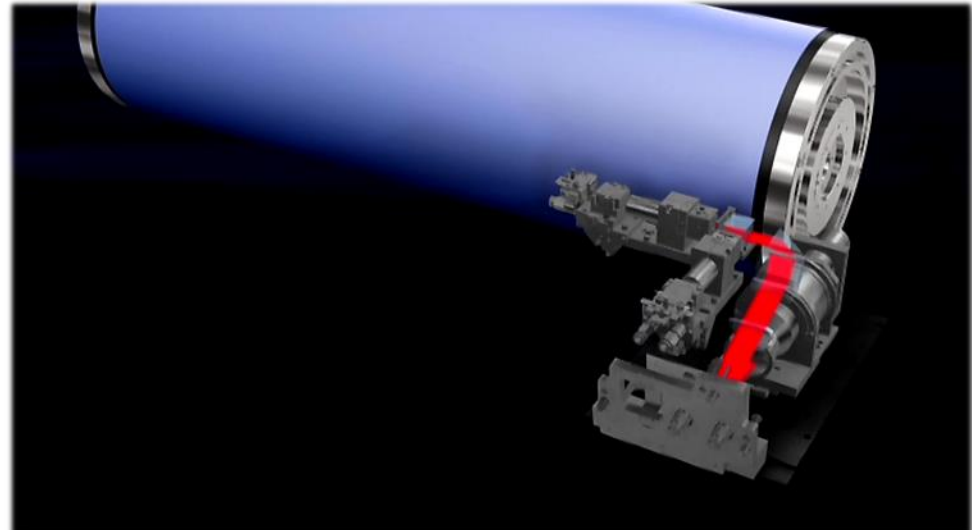


🔍 **Silicon Light Machines has been building spatial light modulators to enable SCREEN's highest-performance digital print systems for nearly 20 years.**

Computer-to-Plate (CtP)



SCREEN

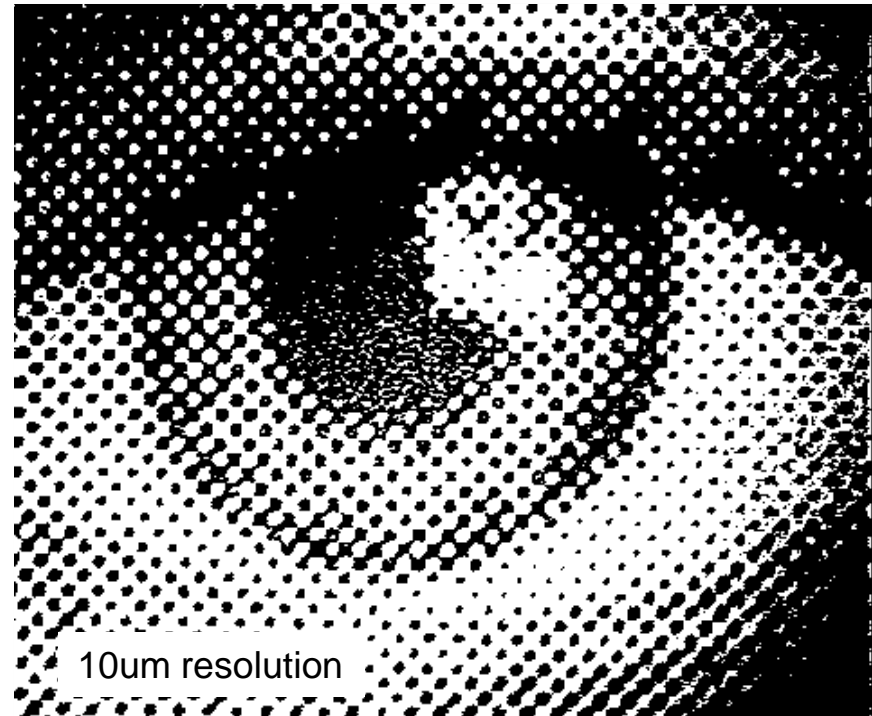


Images courtesy of SCREEN Graphic and Precision

- **1088 Channel GLVs used in SCREEN CtP digital systems**
 - High resolution: 2400 dpi (10um features)
 - High throughput: >70 meter-scale flexible aluminum substrates per hour
 - High-power: 80-100W infrared per GLV (power densities up to 10kW/cm²)
- **SCREEN has global #1 market share of CtP plate-setters**
 - OEM for AGFA & Fuji and others
 - Thousands of GLV-based systems in use today around the globe

Computer-to-Plate at 2400 dpi

Offset Printing Plate (Al)



- **Precise amplitude & PWM control of GLV = high-resolution halftone images**
 - Large format (1m)
 - Short print time (30s)

High Resolution Mask Writing

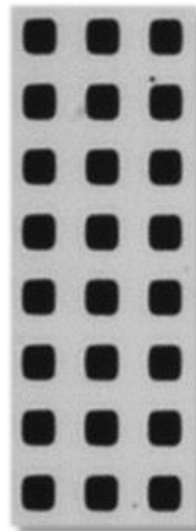


HEIDELBERG
INSTRUMENTS



Images courtesy of Heidelberg Instruments GmbH

2µm
squares



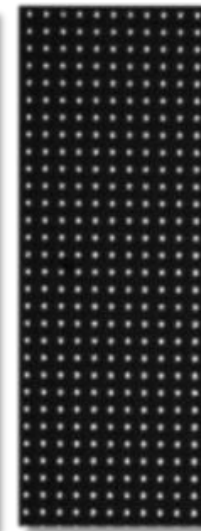
1µm
line/space



700 nm
line/space

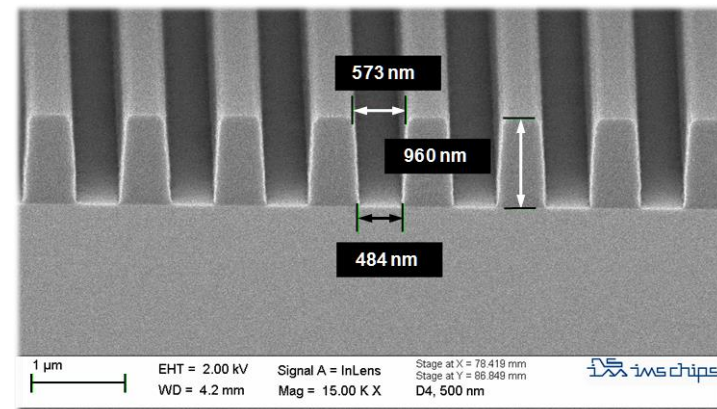


700 nm
dots



Heidelberg VPG mask writer based on GLV technology

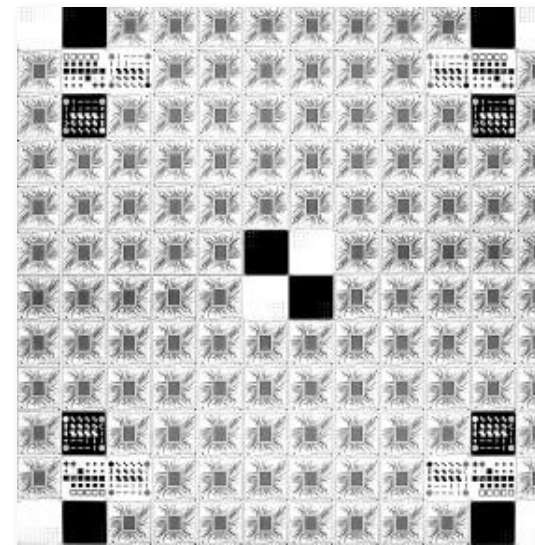
- 500 nm minimum feature
- 10 nm addressable grid
- Semiconductor, TFT, PCB
- 1088 Ch. GLV x 10-bit



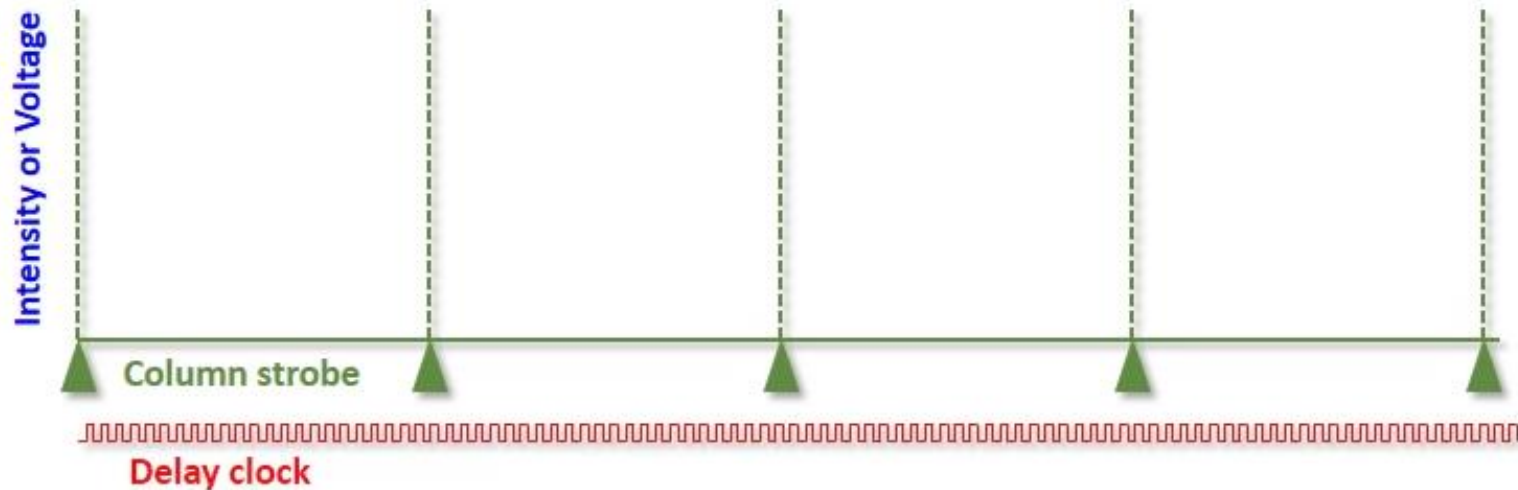
Heidelberg Instruments Mask Writer



- **High resolution & accuracy**
 - Semiconductor photo masks
- **Optimization for Mura**
 - TFT and imager photo masks
- **Variety of mask size and substrate thicknesses**
 - Packaging photo masks
 - PCB photo masks



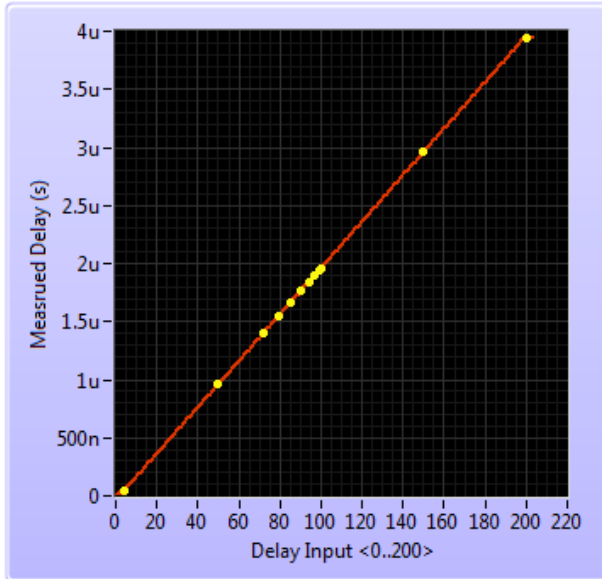
Pulse Width Modulation (PWM)



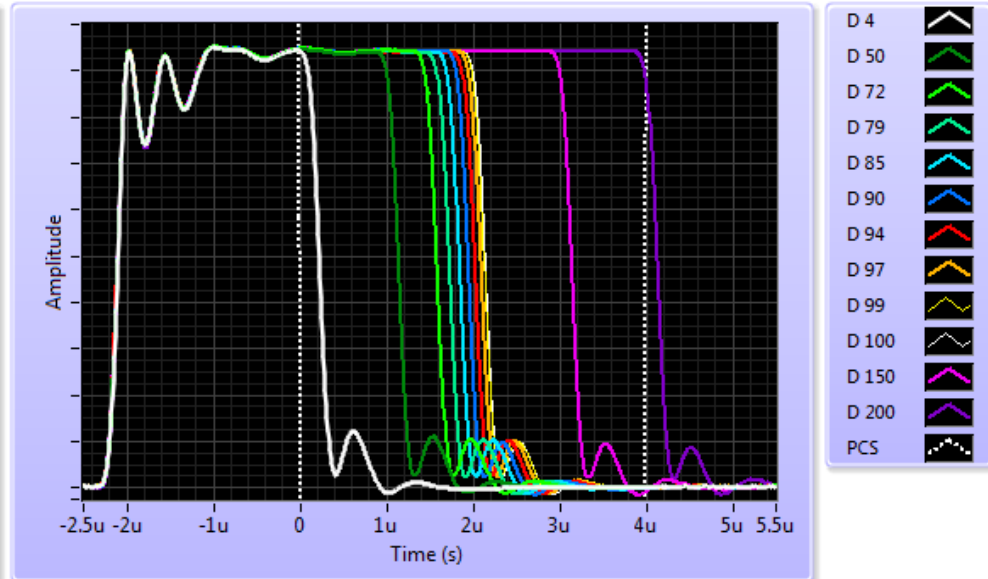
- **The GLV's high speed enables pulse-width modulation (PWM)**
 - Allows optical transition to be placed anywhere within one column period
 - Column strobe & delay clock are control signals derived from stage
- **Useful in direct-write systems with continuous media motion**
 - Enables higher spatial resolution (effectively more pixels)
 - Maintains high throughput (i.e. single pass, not multiple exposures)

Pulse-Width Modulation (PWM)

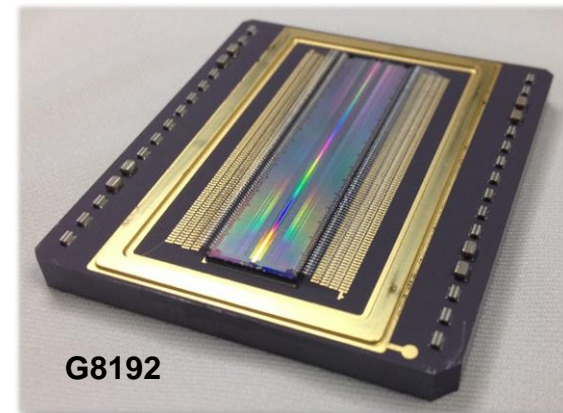
Delay Sweeps



Pulse Profiles

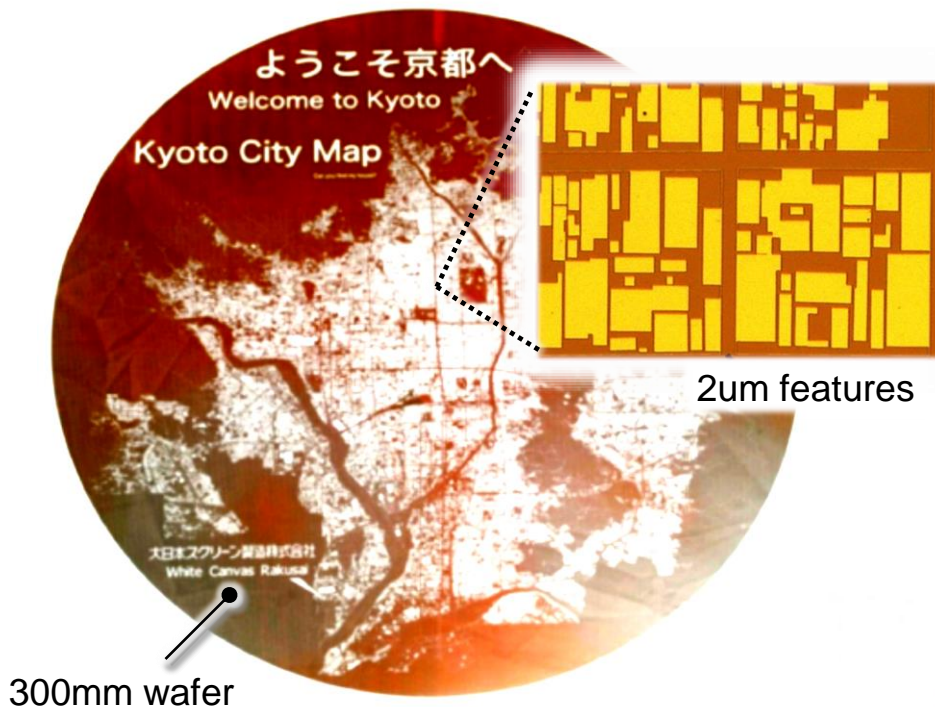


- Dynamic PWM of G8192 device
- 355nm pulse edges can be programmed over 4us column
 - Delay resolution is 20ns



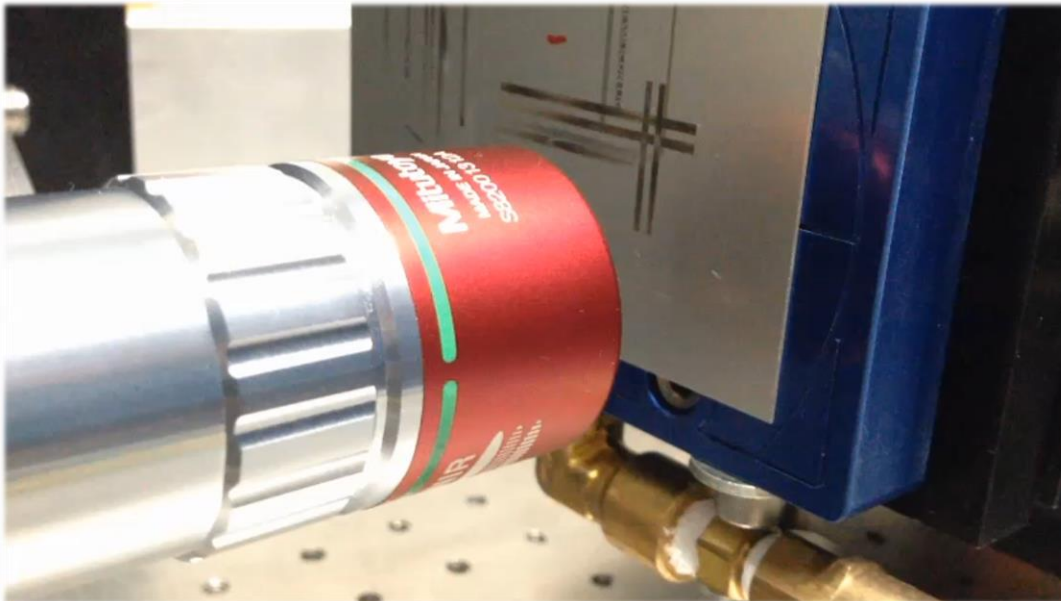
G8192

Ultra-Violet Direct Imaging



- **SCREEN 355nm direct imaging tool advanced packaging**
 - 2um minimum features on 0.5um placement grid
 - 65 wafers per hour @ 100mJ/cm² hour
- **Kyoto city map shown printed onto wafer using DW3000**
 - Individual houses are resolved on this map.

Aluminum Laser Marking



Wavelength	532 nm
Pulse width	6 ps
Repetition rate	500 kHz
Demag	20 x

SILICON LIGHT MACHINES

- **GLV used for Al laser marking**
 - Pico-second 532nm pulsed laser
 - Modification of sub-surface Al microstructure beneath oxide
 - Throughput improvement over single beam galvo-scanner



3D Printing



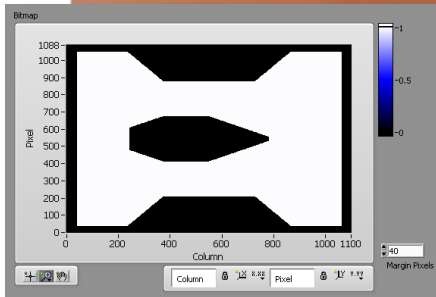
GLV-Based 3D Printer Bed



GLV-Printed Chess Piece

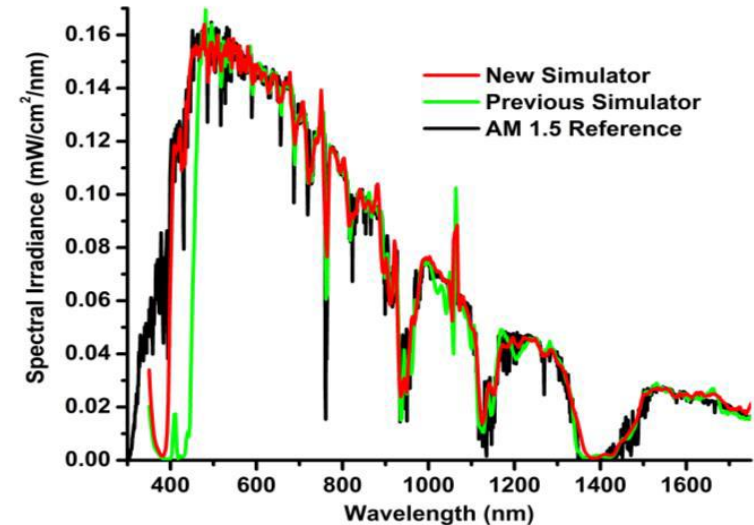
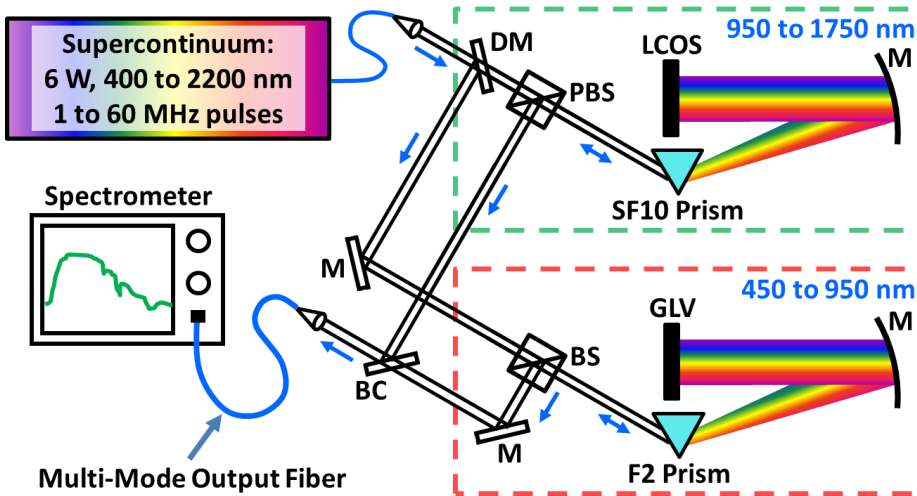


AM VENTURES



- **GLV used in polymer selective laser sintering (SLS)**
- **Faster write times than single-beam galvo scan**
- **Improved sinter quality with line beam**
- **Analog gray scale enables variable power sinter**

Super-Continuum Spectral Shaping



A Programmable Solar Simulator for Realistic Seasonal, Diurnal, and Air-Mass Testing of Multi-Junction Concentrator Photovoltaics
 Tunde Dennis¹, Chandan Yamasakar¹, Tim Geier¹, Alan Pappas¹, Lars Eng¹, Brent Fisher¹, and Matt Meitl¹
¹National Institute of Standards and Technology, Boulder, CO 80501, USA; ²Transtar, Inc., Englewood, CO 80150, USA; ³Silicon Light Machines, Sunnyvale, CA 94089, USA; ⁴Sempium, Inc., Durham, NC 27713, USA

Abstract — We built a spectrally programmable supercontinuum laser system for the generation of realistic solar spectra for the testing of multi-junction concentrator photovoltaics. The system is based on a programmable supercontinuum laser with a multi-junction concentrator photovoltaic cell as a load. The system is designed to provide a realistic solar spectrum for testing of multi-junction concentrator photovoltaics. The system is designed to provide a realistic solar spectrum for testing of multi-junction concentrator photovoltaics. The system is designed to provide a realistic solar spectrum for testing of multi-junction concentrator photovoltaics.

1. Introduction
 Characterizing the optical and electrical performance of a photovoltaic device or system requires a broadband spectrum which is close to that of the natural solar spectrum. This spectrum is often referred to as the AM1.5 reference spectrum. The spectrum is often referred to as the AM1.5 reference spectrum. The spectrum is often referred to as the AM1.5 reference spectrum.

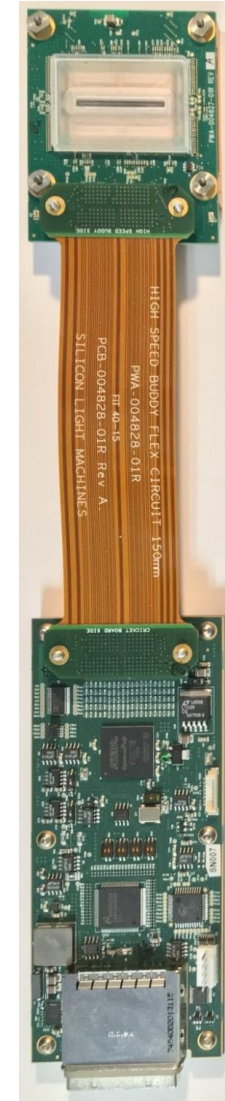
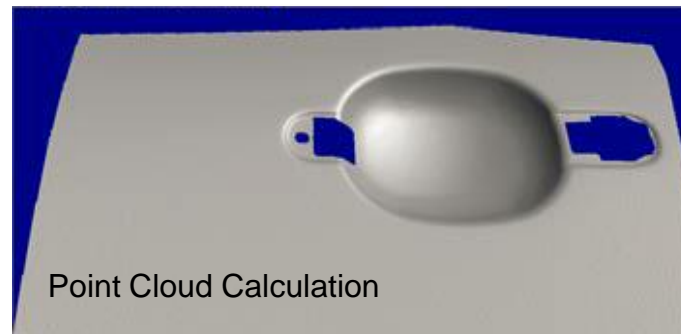
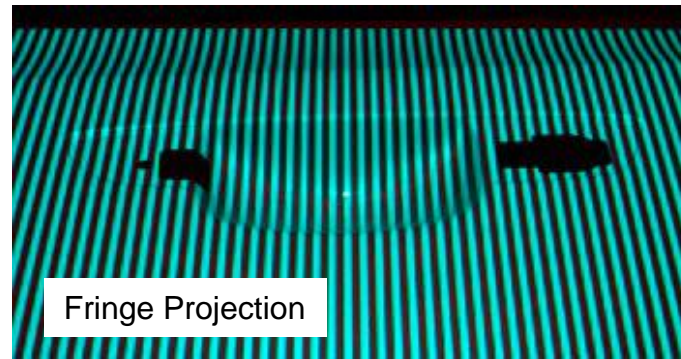
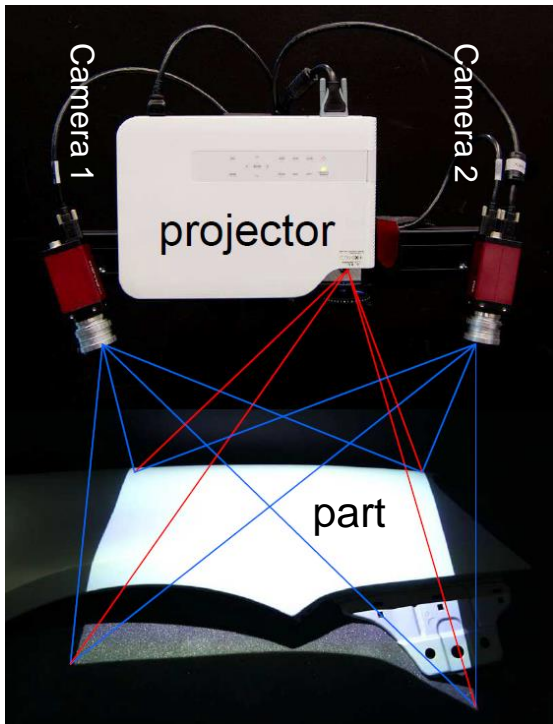


T. Dennis,
 B. Fisher,
 M. Meitl,
 J. Wilson

- GLV has been used to spectrally shape output of super-continuum laser
- Solar simulator for characterization of multi-junction solar cells

- Improved flexibility & precision over lamps & LEDs
- National Institute of Standards and Technology

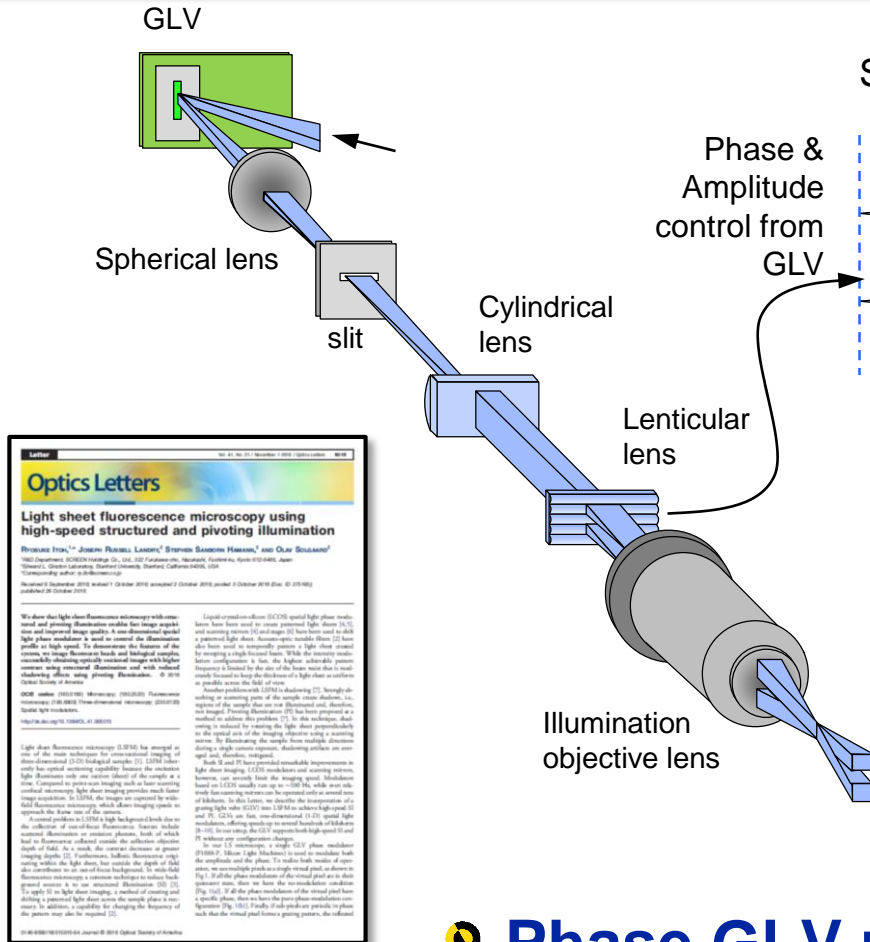
Structured Illumination / 3D Imaging



SLM 1088-HS Module

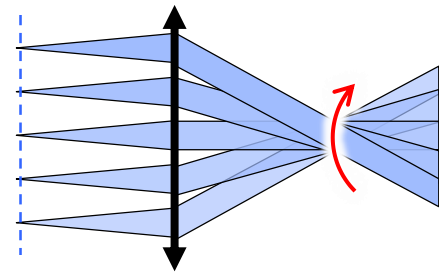
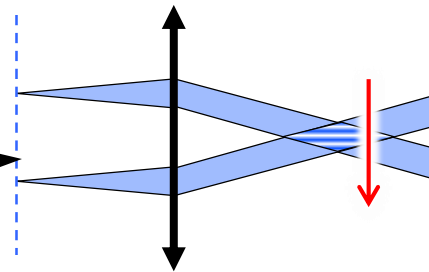
- SLM's high-speed 1088-ch. GLV allows 10^5 illumination updates per second
 - 350kHz x 10-bit amplitude resolution
 - More patterns = improved surface knowledge
 - Amenable to in-line (continuous) inspection

Light Sheet Microscopy

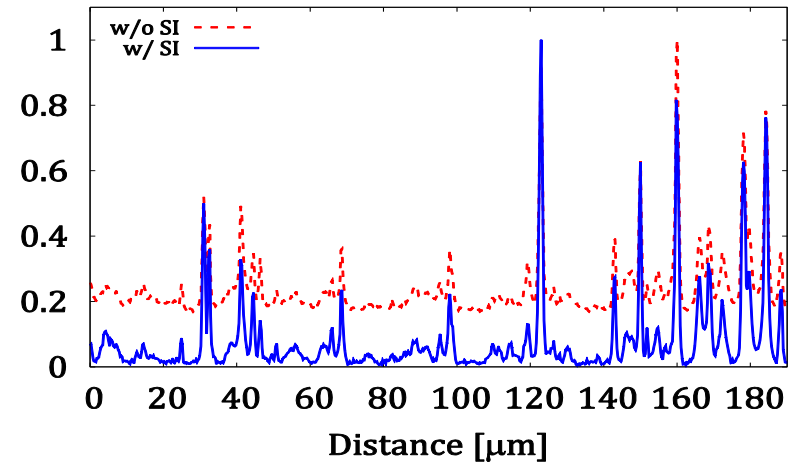


Structured Illumination (SI)

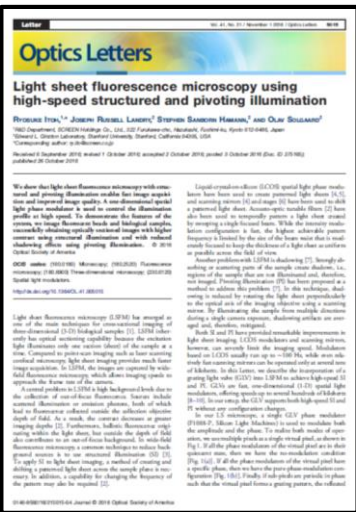
Pivoting Illumination (PI)



Normalized Intensity



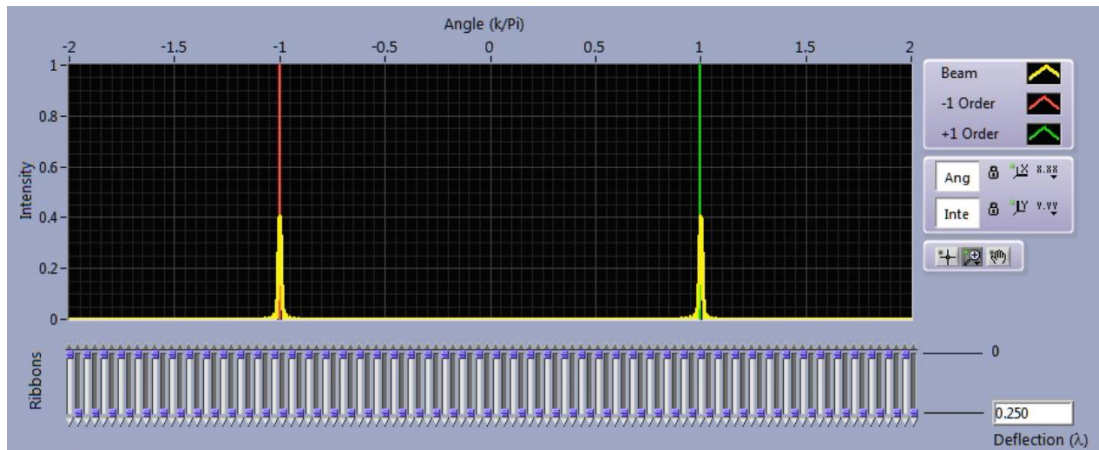
Phase GLV used for structured illumination for background suppression & shadow mitigation in biological fluorescence images



R. Itoh,
J. Landry,
S. Hamann,
O. Solgaard

Light Detection and Ranging (LIDAR)

Angular Modulation with Phased-Array Grating



GLV can be used for beam steering (and detection) in LIDAR

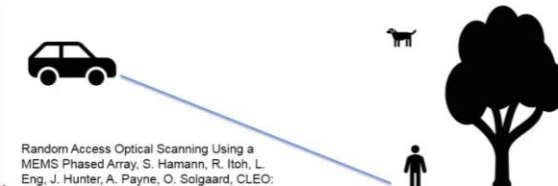
- Advantages are very high scan speeds
- High sensitivity & angular resolution

Solgaard Group at Stanford studying random-access LIDAR

- GLV allows arbitrary phase configurations

Optical Scanning for Light Detection and Ranging (LIDAR)

- Autonomous vehicles
- Drones
- Undersea exploration
- Aerial mapping

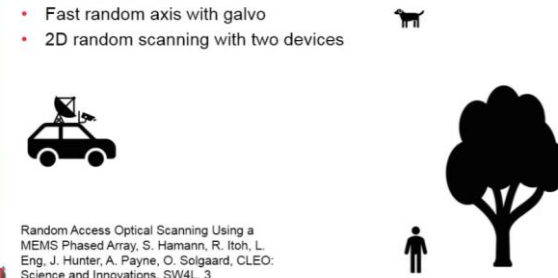


Random Access Optical Scanning Using a MEMS Phased Array, S. Hamann, R. Itoh, L. Eng, J. Hunter, A. Payne, O. Solgaard, CLEO: Science and Innovations, SW4L. 3

Solgaard Lab, Stanford

Random Access Scanning

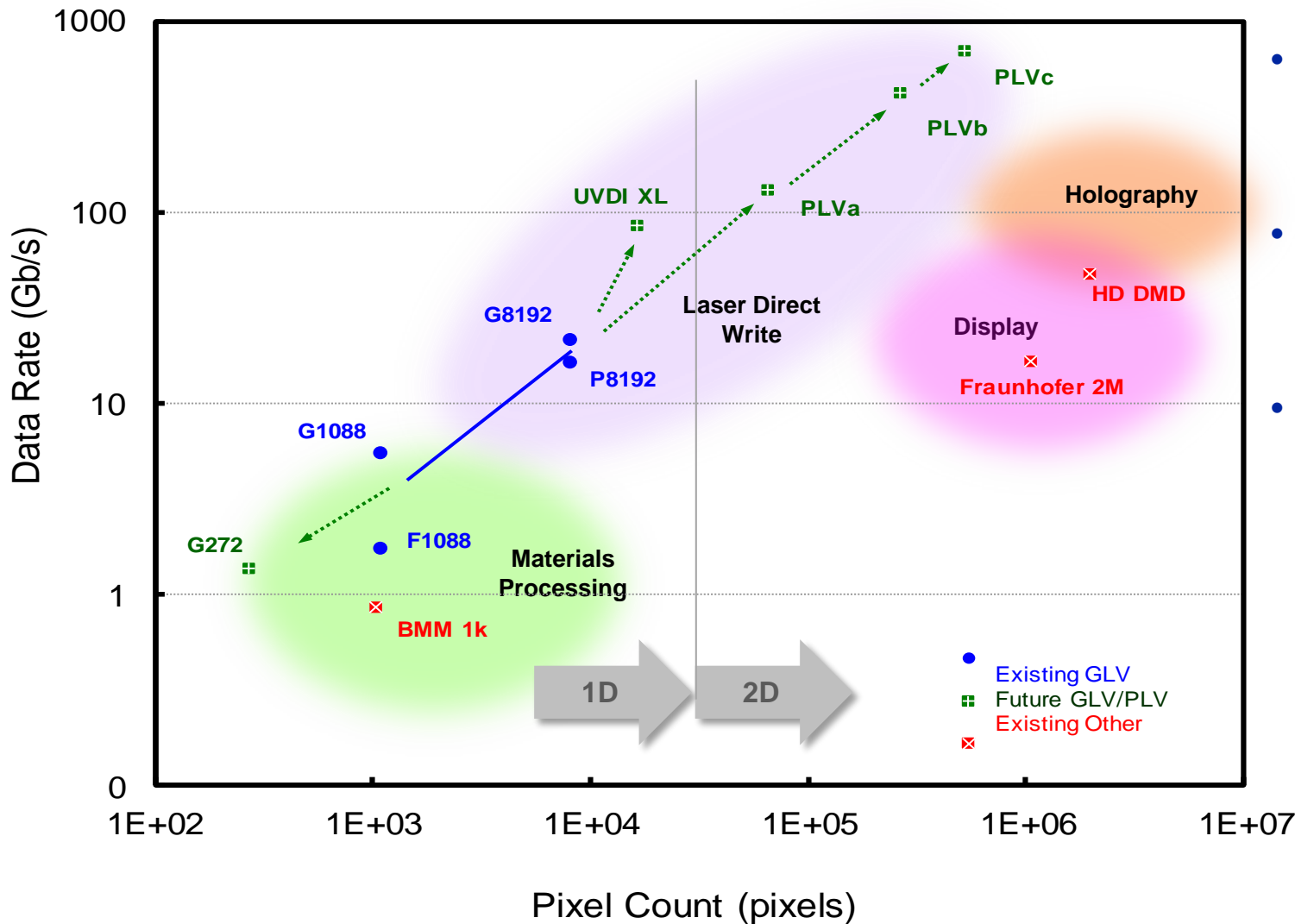
- Use with camera and RADAR
- Watch areas of interest
- Velocity as well as position
- Fast random axis with galvo
- 2D random scanning with two devices



Random Access Optical Scanning Using a MEMS Phased Array, S. Hamann, R. Itoh, L. Eng, J. Hunter, A. Payne, O. Solgaard, CLEO: Science and Innovations, SW4L. 3

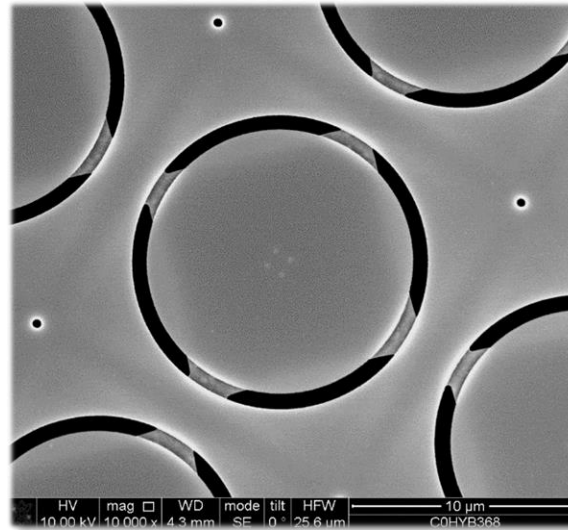
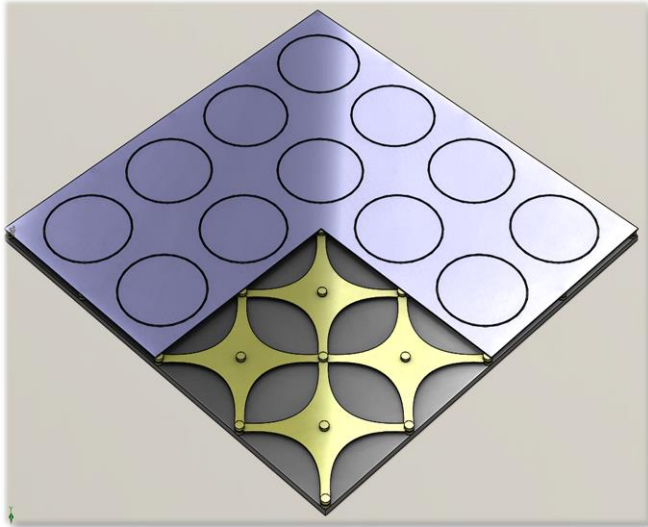
Solgaard Lab, Stanford

SLM Technology Roadmap



- Roadmap encompasses GLV and PLV technologies
- Transition from 1D to 2D modulators between 10^4 - 10^5
- PLV allows continued growth in throughput and power handling

Planar Light Valve (PLV)



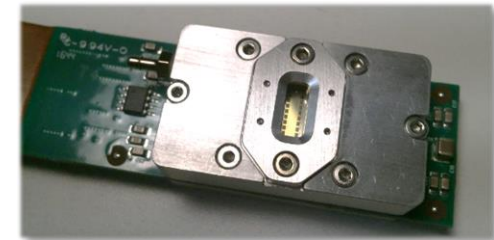
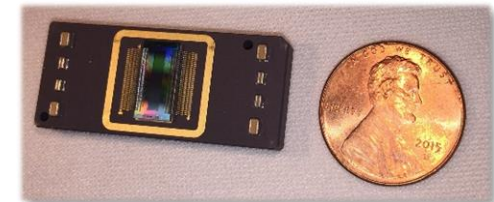
Inherited properties...

- High Speed
- Analog gray-scale
- Non-contact MEMS
- High power handling

New properties...

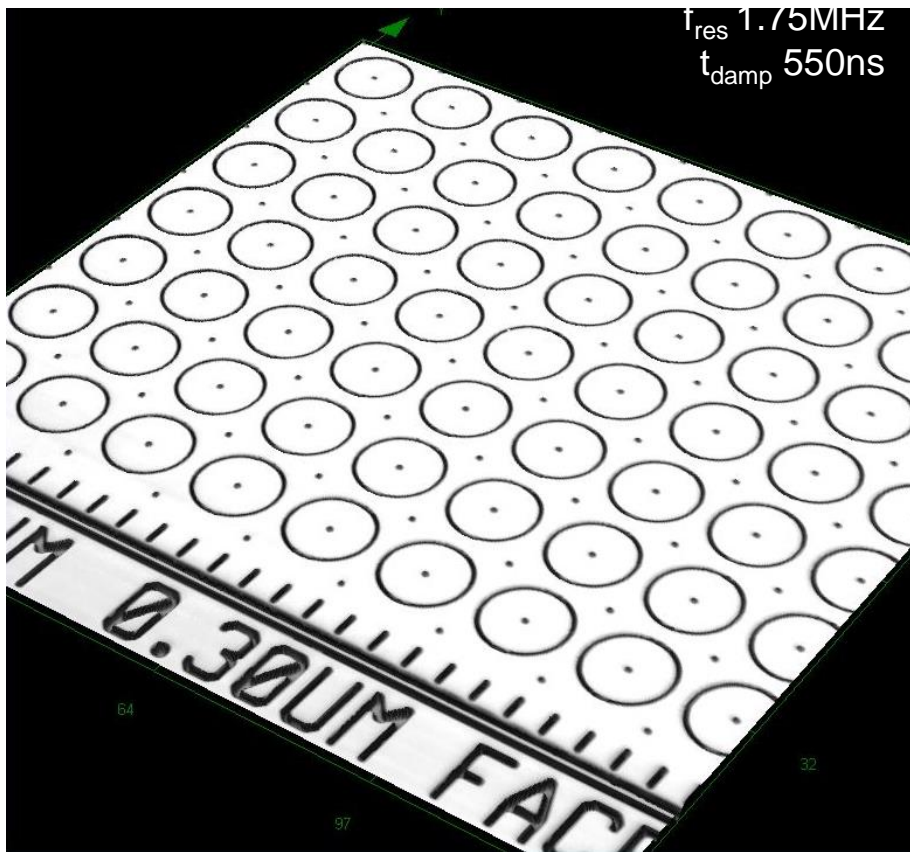
- Higher pixel counts
- Non-critical illumination
- Increased étendue
- 2D phase modulation

- **Planar Light Valve is 2D analog 1D GLV**
 - Retains GLV advantages & brings new properties
- **PLV enables further improvements in throughput & power-handling**
 - More pixels, non-critical illumination
- **SLM developing 8192-channel PLV module**
 - 32 x 256 modulator for 405nm
 - 8-bit amplitude control x 250kHz refresh rate

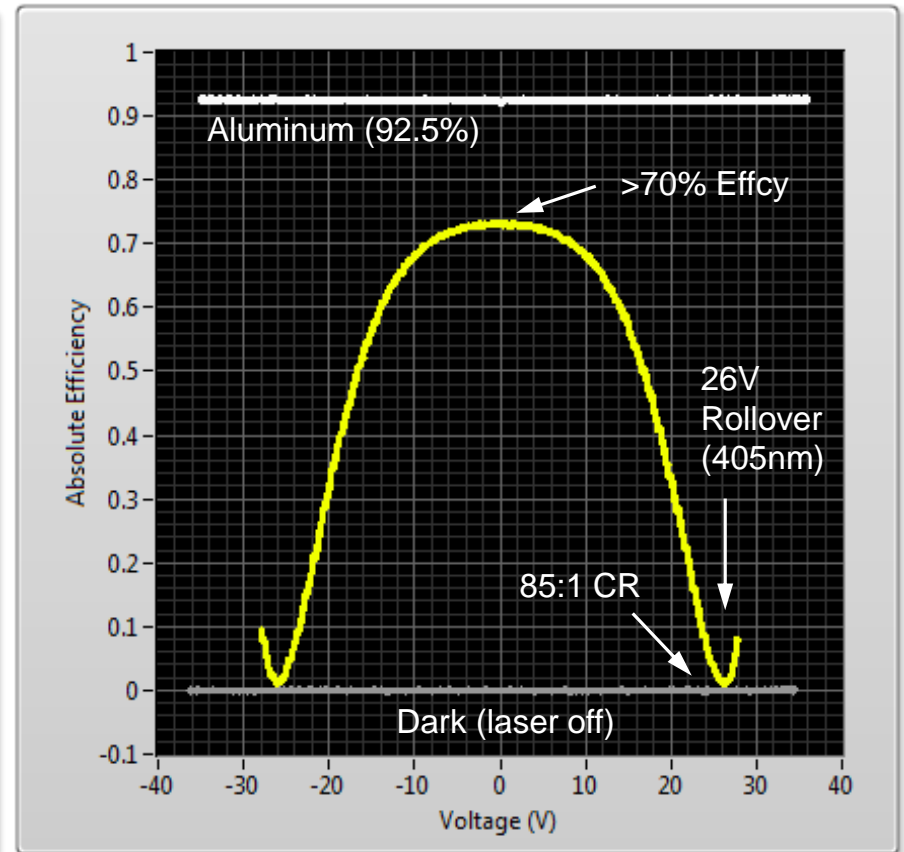


PLV Optical Response

15um Pitch PLV



IV Curve



 **0th order contrast ratio > 50:1, efficiency > 70%**

Summary



- **The Grating Light Valve has unique attributes...**
 - High-speed (10-1000X faster than other modulators)
 - Analog gray-scale (precision dose control, system calibration)
 - High-power handling (100W per module in IR)
 - Non-contact operation, high reliability
- **GLV is well-suited to direct-write lithography**
 - GLV has been used for years in SCREEN's CtP plate-setters
 - GLV enabling new UV lithography tools (UVDI & mask writing)
- **GLV an attractive option for emerging applications**
 - Laser making, 3D printing, machine vision, spectral shaping, etc.
- **PLV: path to increased throughput & power handling**
 - Planar Light Valve is the 2D analog of the 1D GLV
 - More pixels, non-critical illumination
- **SLM focused on next-generation light modulators**
 - High throughput devices for SCREEN and for other customers