Integrated 64-Channel Optoelectronic Interconnects and Application to Digital Halftoning Image Processor

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Acknowledgements/Thanks

ARL Collaborators from SEDD Microphotonics Branch:
Dr. George Simonis, Dr. Wayne Chang, Dr. Jiang Liu, et al

D/EE&CS and PRC: lab equipment

ARL Colleagues:
Dr. Mikhail Vorontsov, Mr. Gary Carhart

Thanks especially for the VCSEL and detector arrays from the Microphotonics Branch

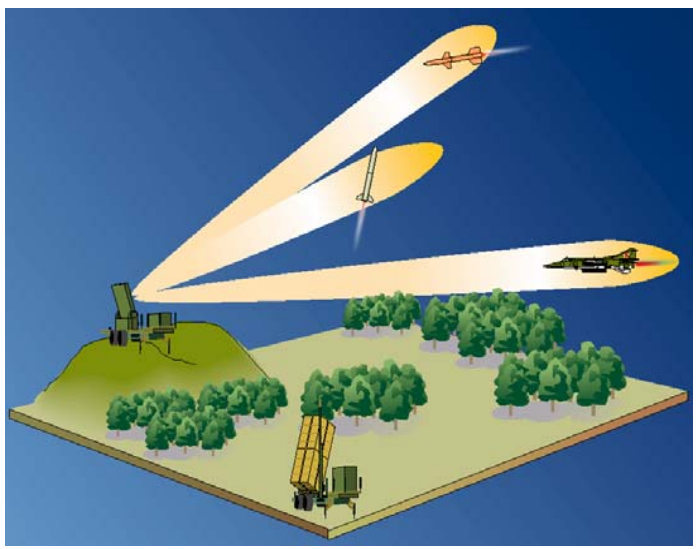
Agenda

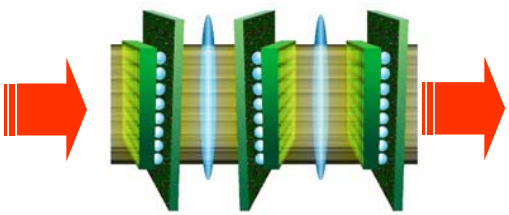
- Motivation
- The Problem
- Digital Halftoning
- Opto-Electronic Digital Halftoning Processor
- Optical Processing
- Summary

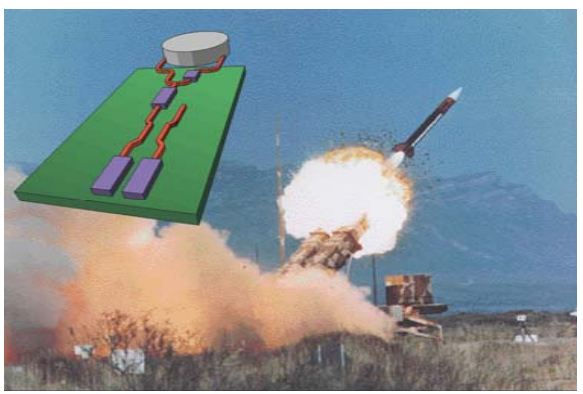
Motivation

Acquiring, processing, and transporting massive amount of information are of critical importance in military applications.

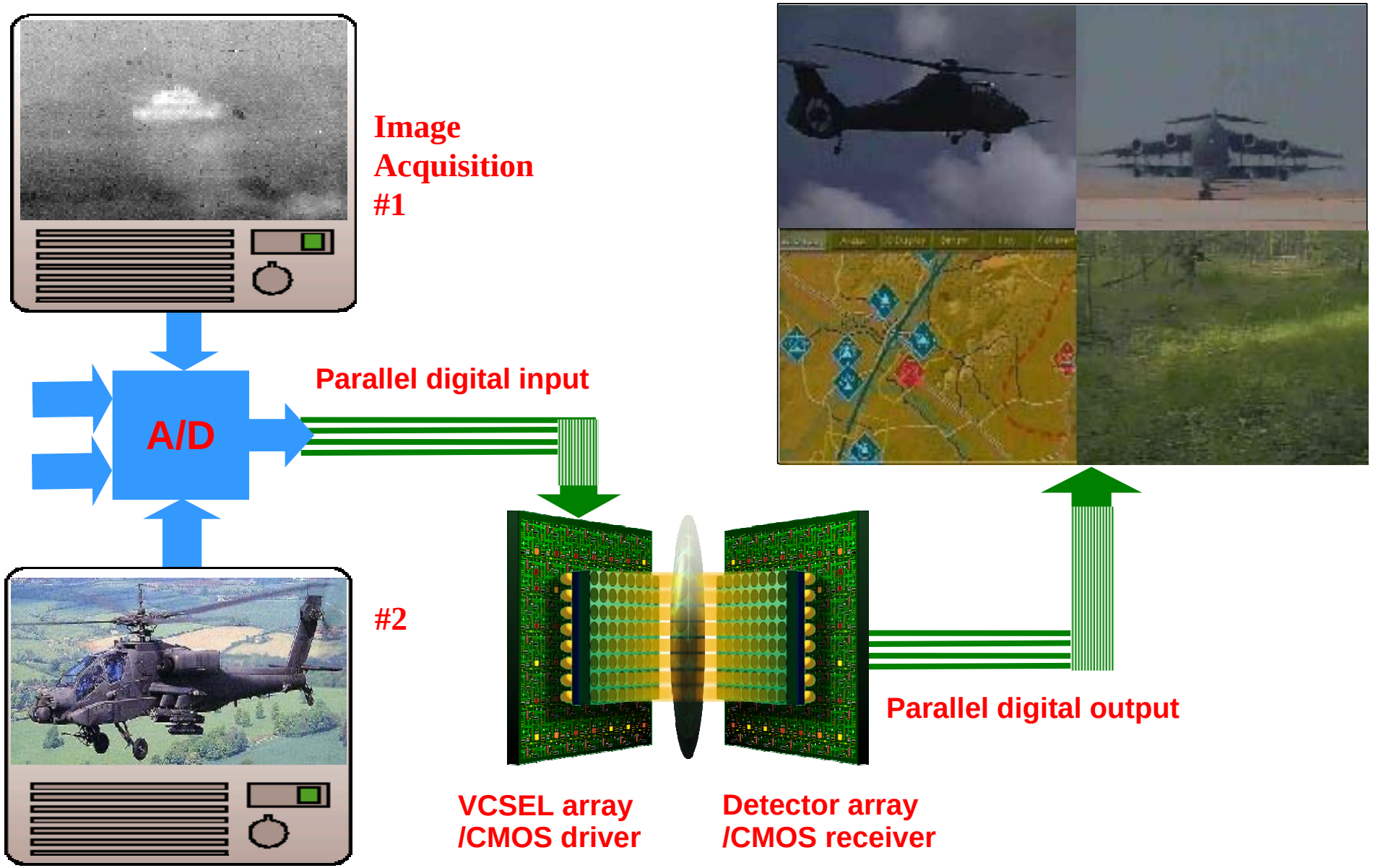
Advanced optoelectronic (OE) interconnects provide the promising solution for future high-bandwidth chip-to-chip, board-to-board data communication







Parallel Image Transfer and Processing through Optoelectronic Interconnects



The Problem

- **Problem**

  -- given a continuous tone input image, $x(m,n)$ with intensity values in the interval $x(m,n) \in [0,1]$, where $[a,b] = \{x: a \leq x \leq b\}$, find a bilevel image $y(m,n)$ constrained to $y(m,n) \in \{0,1\}$, such that some predefined distortion measure $d(x,y)$ is minimized.

- **Digital Halftoning**

  -- an algorithmic process which creates the *illusion* of a continuous tone image from the judicious arrangement of binary picture elements.

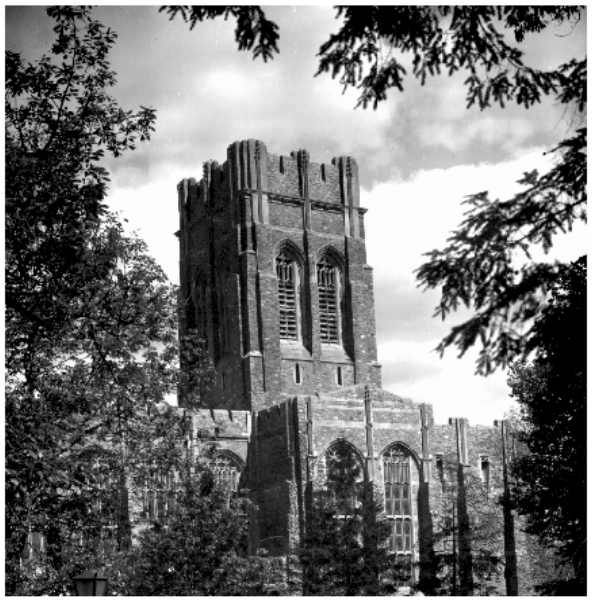
- **Error diffusion**

  -- a method of quantization in which the error associated with the nonlinear quantization process is diffused within a local region and subsequent filtering techniques employed in an effort to improve some performance metric such as signal-to-noise ratio.

- **Goals**

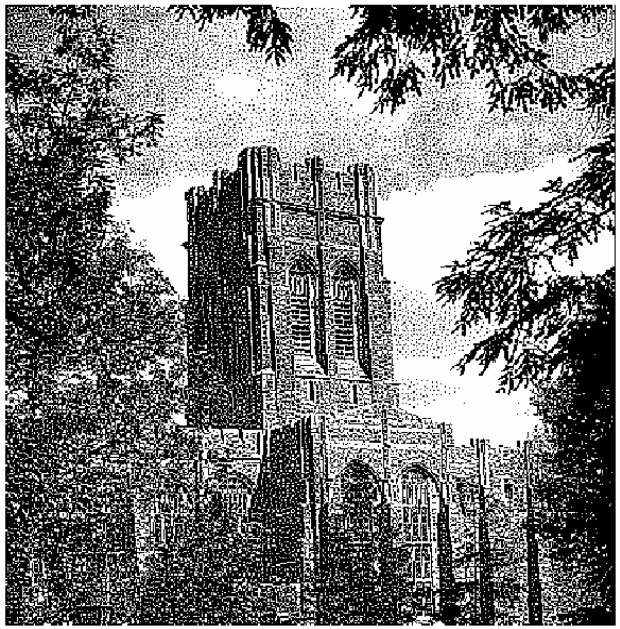
  -- improve halftone image quality
  -- reduce the computational complexity of error diffusion
  -- provide a means of implementing arbitrary size and shape diffusion kernels

Digital Image Halftoning



Continuous-tone input image

- **Maps**
- **Images**



Binary-valued output image

- **Lossy compression**
- **Reduced data-rate requirement**

Goal: Create illusion of continuous image using binary data

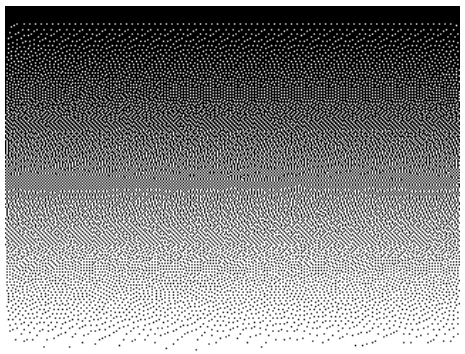
Halftoning Methods

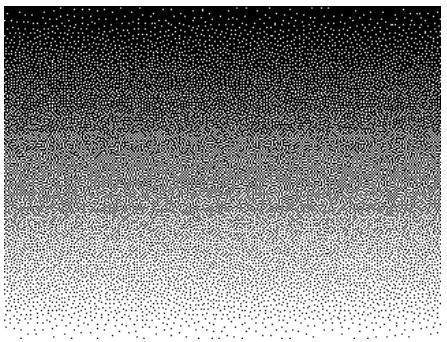
Source

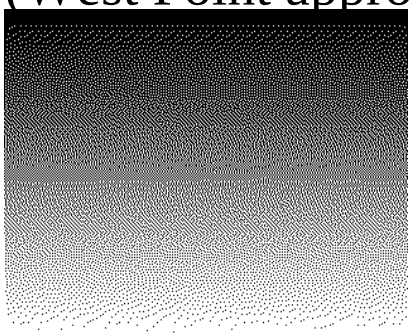
Conventional
Ordered Diffusion

Iterative
Convolution

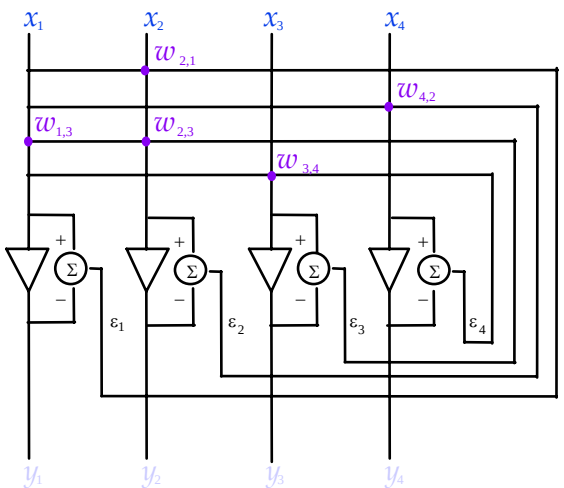
Error Diffusion
(West Point approach)







Error Diffusion Neural Network



In equilibrium, the *error diffusion neural network* satisfies

$$\mathbf{u} = \mathbf{x} + \mathbf{W}(\mathbf{y} - \mathbf{u}) = \mathbf{x} + \mathbf{W}\mathbf{y} - \mathbf{W}\mathbf{u}$$

which results in an equivalence to the Hopfield-type network

$$(\mathbf{I} + \mathbf{W})\mathbf{u} = \mathbf{x} + \mathbf{W}\mathbf{y}$$

$$\mathbf{u} = (\mathbf{I} + \mathbf{W})^{-1}(\mathbf{x} + \mathbf{W}\mathbf{y})$$

Therefore, the energy function can be written as

$$E = -\mathbf{y}^T\mathbf{A}\mathbf{W}\mathbf{y} - 2\mathbf{y}^T\mathbf{A}\mathbf{x}$$

where

$$\mathbf{A} = (\mathbf{I} + \mathbf{W})^{-1} \qquad \mathbf{A}\mathbf{W} = \mathbf{I} - \mathbf{A}$$

Therefore

$$E = -\mathbf{y}^T(\mathbf{I} - \mathbf{A})\mathbf{y} - 2\mathbf{y}^T\mathbf{A}\mathbf{x} = -\mathbf{y}^T\mathbf{y} + \mathbf{y}^T\mathbf{A}\mathbf{y} - 2\mathbf{y}^T\mathbf{A}\mathbf{x}$$

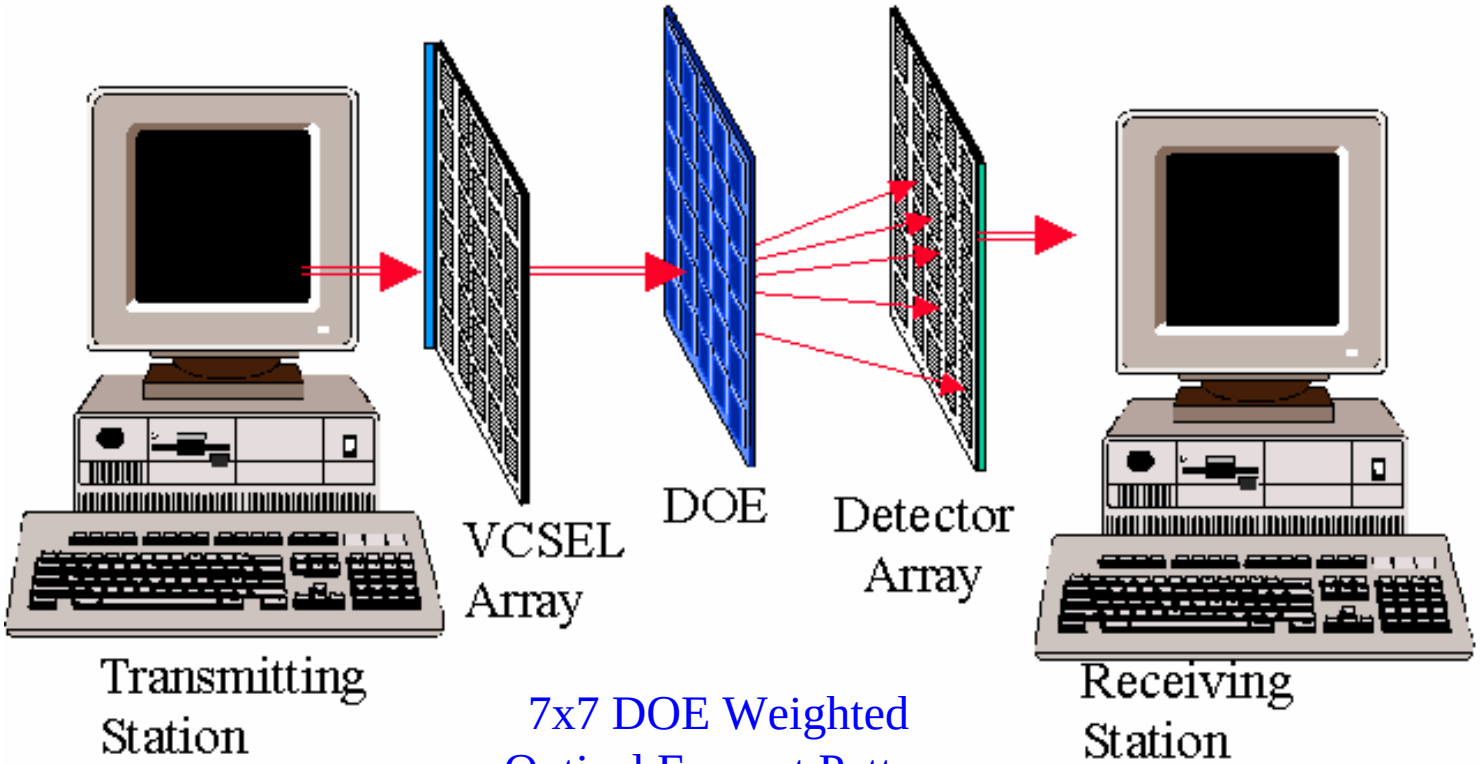
We can write an alternate form of the energy function

$$E' = E = \underbrace{\mathbf{y}^T\mathbf{y} - \mathbf{x}^T\mathbf{A}\mathbf{x}}_{constant} = \mathbf{y}^T\mathbf{A}\mathbf{y} - 2\mathbf{y}^T\mathbf{A}\mathbf{x} + \mathbf{x}^T\mathbf{A}\mathbf{x} = \underbrace{(\mathbf{y} - \mathbf{x})}_{error}{}^T\mathbf{A}\underbrace{(\mathbf{y} - \mathbf{x})}_{error}$$

$\mathbf{W}$ - sparse and circulant

$\mathbf{A}$ - full-rank

Opto-electronic Processor Setup



7x7 DOE Weighted
Optical Fan-out Pattern

- **Maps**
- **Images**

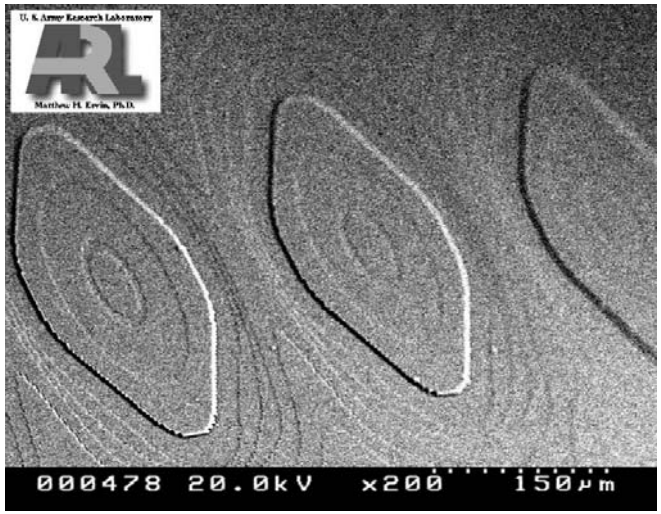
Binary-valued output image with adequate quality.

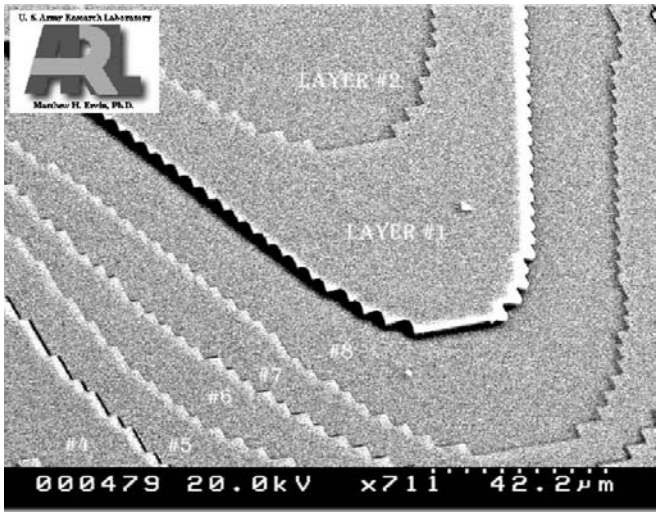
Detectors initially CCD

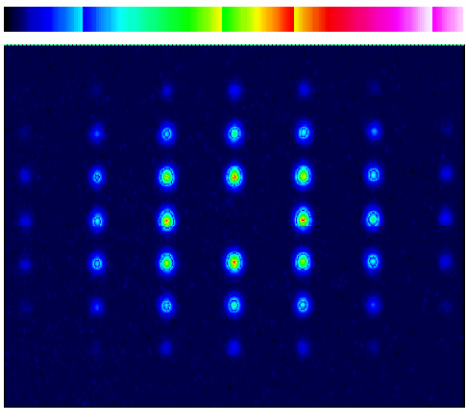
Digital Image Halftoning Scheme

Opto-electronic Processor

- Single and Multiple Diffractive Optical Element fanout achieved
- Parallel VCSEL lighting accomplished
- Computer control of VCSEL array onto CCD







.0003	.0019	.0051	.0068	.0051	.0019	.0003
.0019	.0103	.0248	.0328	.0248	.0103	.0016
.0051	.0248	.0583	.0766	.0583	.0248	.0046
.0062	.0305	.0766	.0000	.0766	.0305	.0062
.0051	.0248	.0583	.0766	.0583	.0248	.0046
.0019	.0103	.0248	.0328	.0248	.0103	.0016
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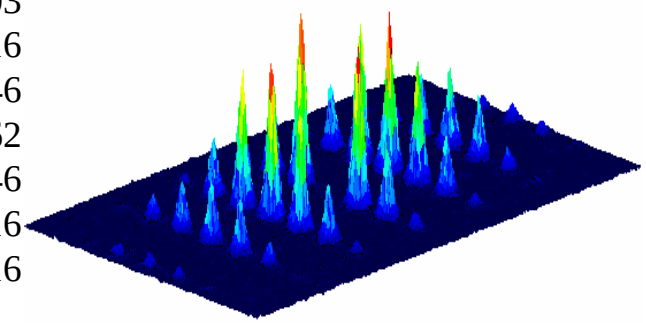
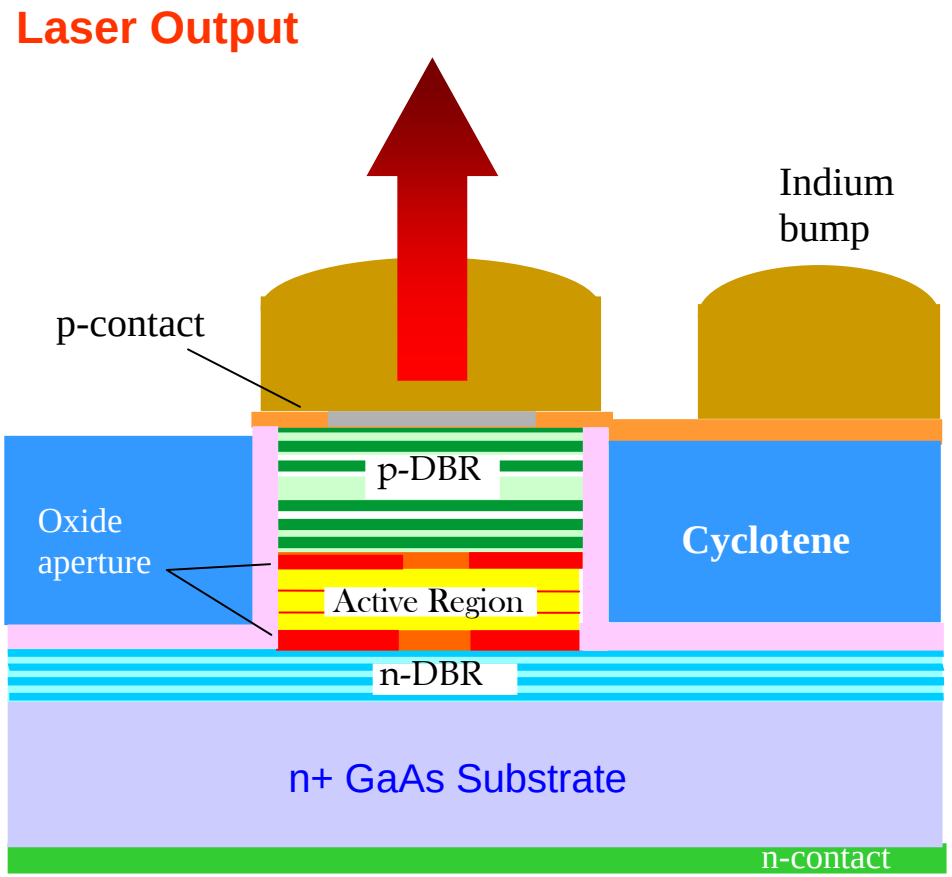
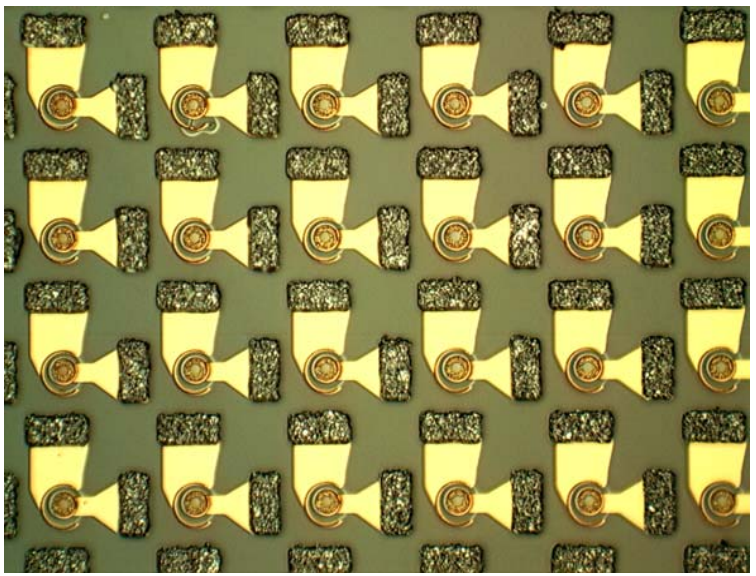


850 nm Top-Emitting VCSEL

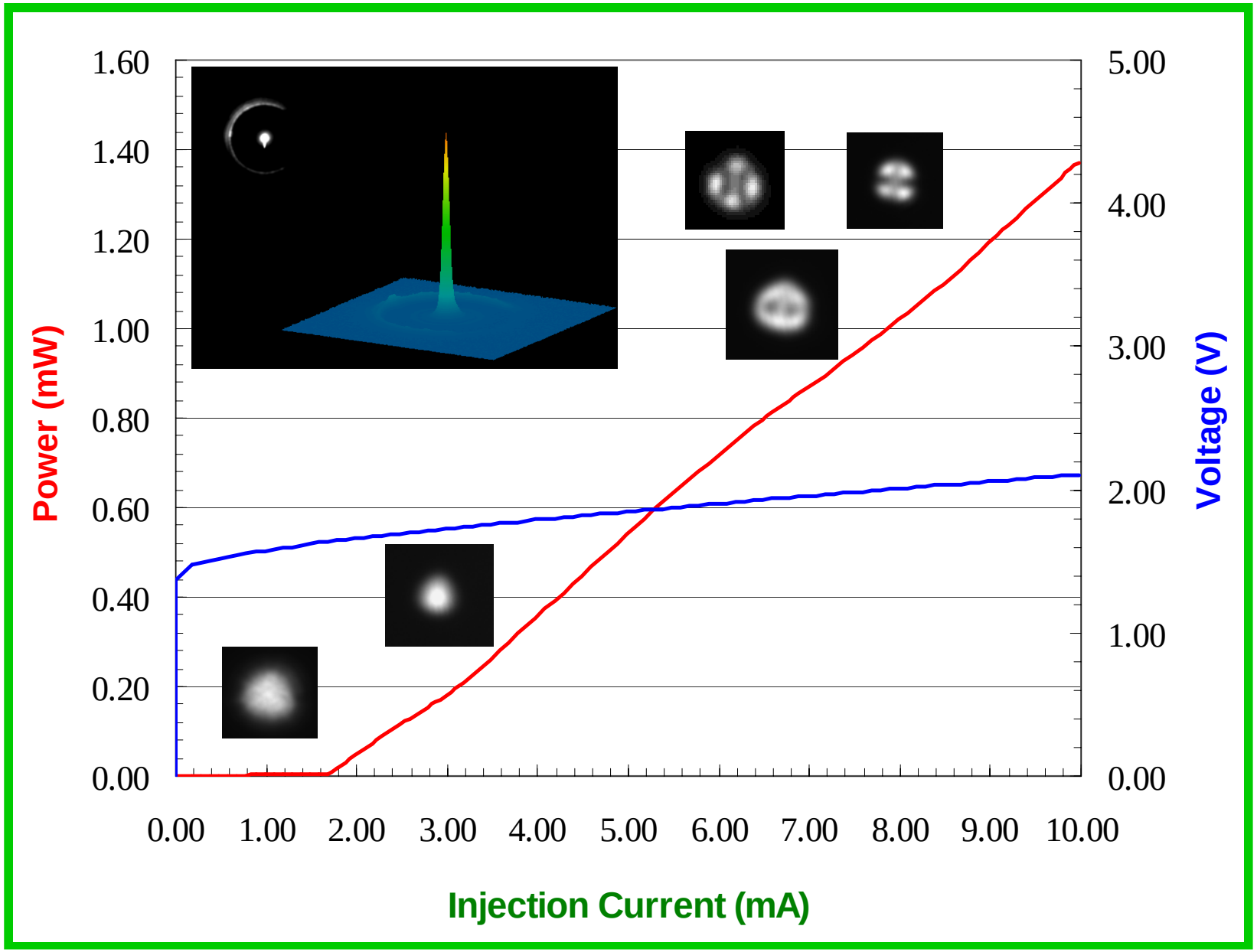


Cross-sectional view of a VCSEL device

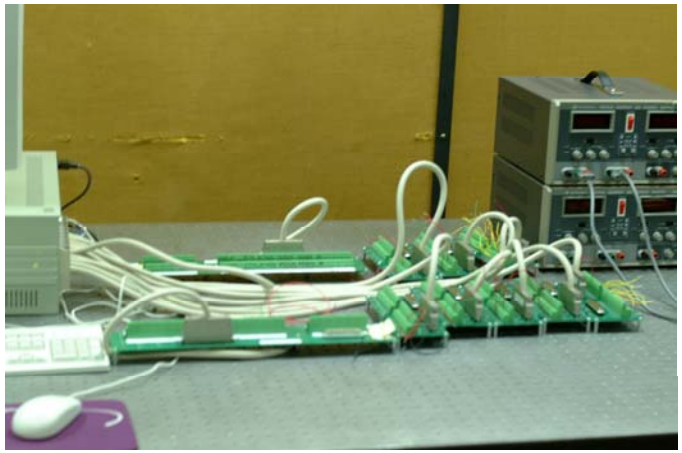


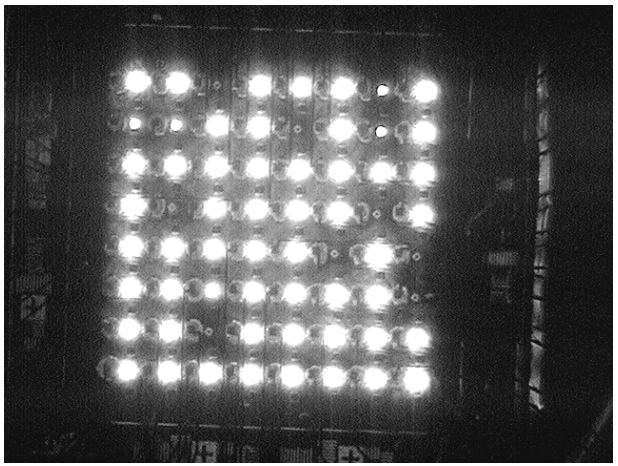
Top view of the partial 8x8 VCSEL array
125 mm pitch, 32 mm mesa

I-V-L Characteristics of 850 nm Top-Emitting VCSELs

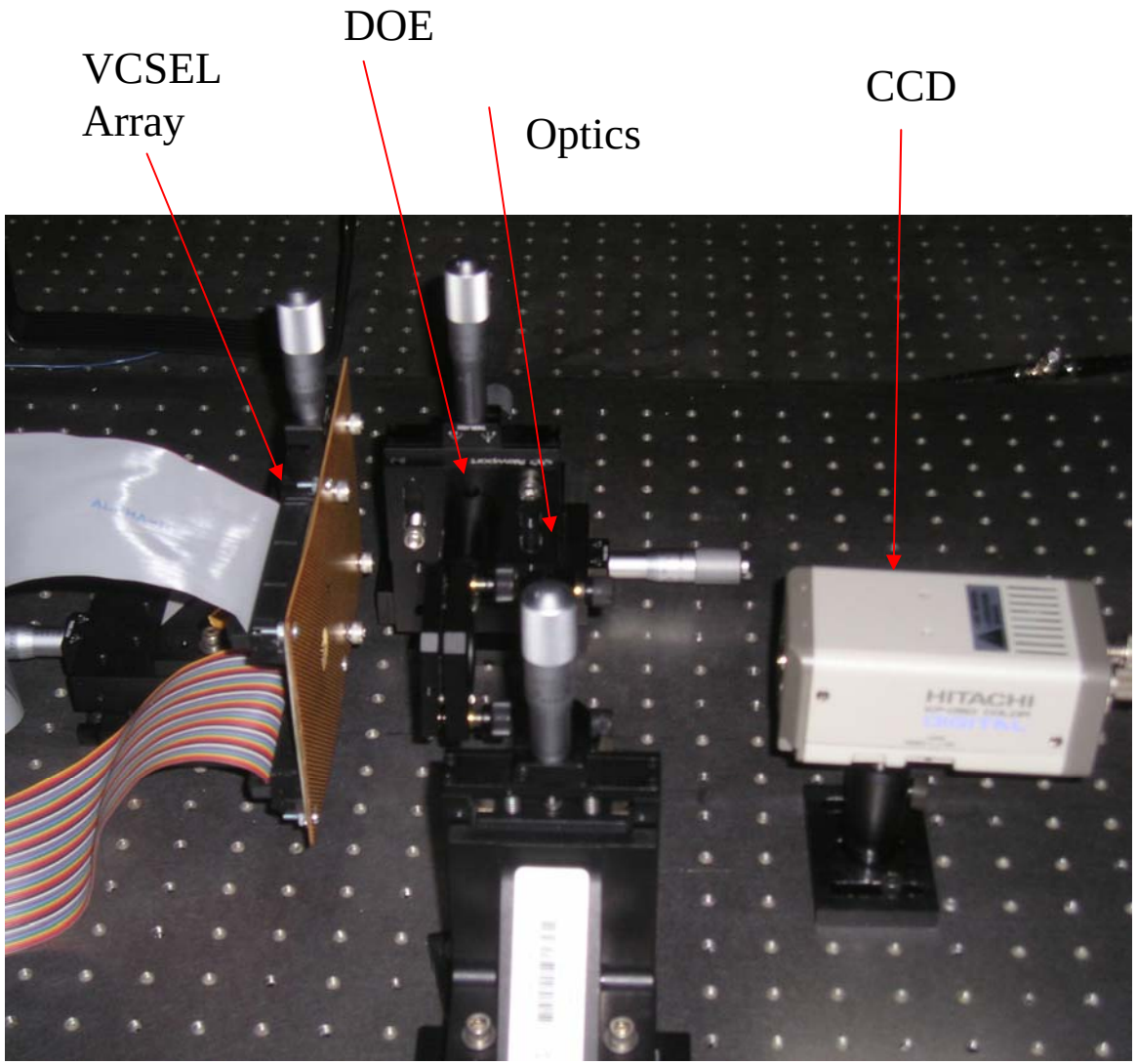


Experimental Setup



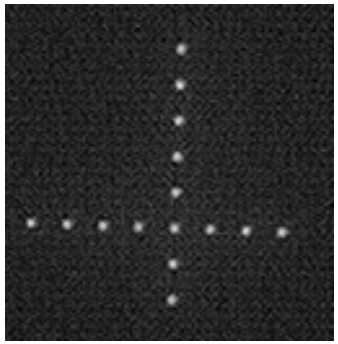


12 May 2005 ARL VCSEL #3



Optical Processing - Horizontal

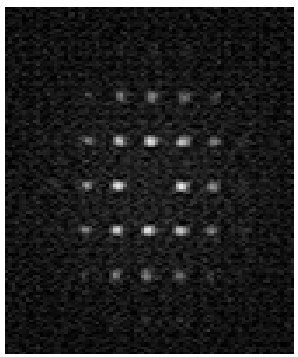
H1 H8



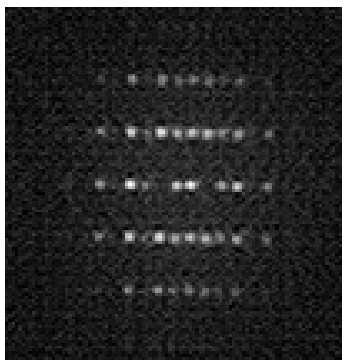
A1 A8

Determining VCSEL physical location to DOE fanout location

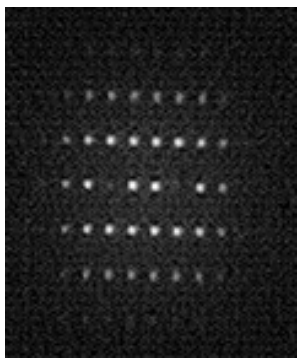
1 row (3rd) and 1 column (5th) of VCSEL array lit in pairs



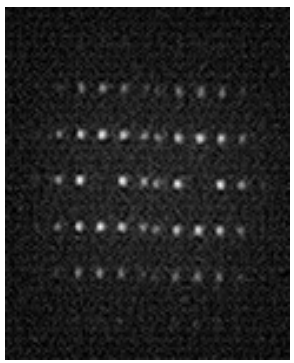
C1 lit @ .15 mA



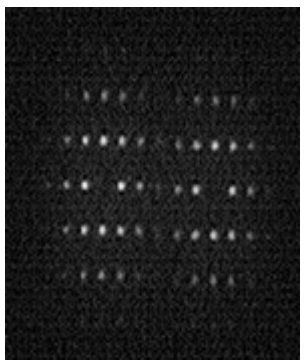
C1 lit @ .15 mA
C2 lit @ .15 mA



C1 lit @ .15 mA
C3 lit @ .15 mA



C1 lit @ .15 mA
C4 lit @ .15 mA

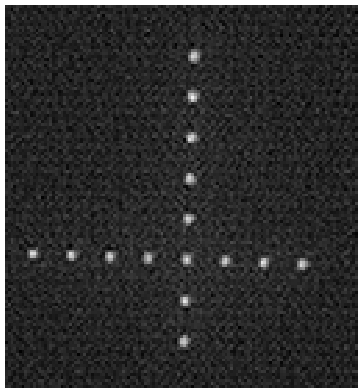


C1 lit @ .15 mA
C5 lit @ .15 mA

Horizontal: 1 VCSEL move = 1.5 DOE spacing
(VCSEL pair separated by 1 gives DOE spacing by 3)

Optical Processing - Vertical

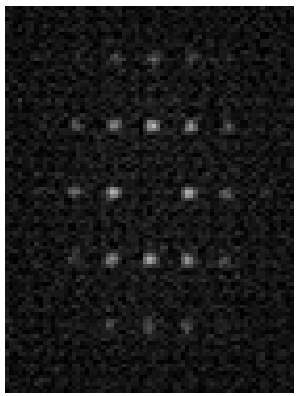
H1 H8



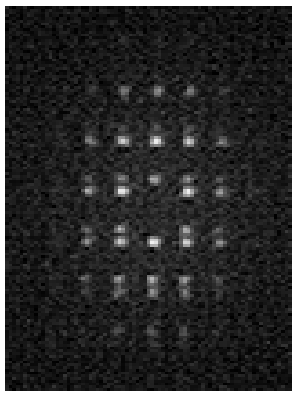
Determining VCSEL physical location to DOE fanout location

1 row (3rd) and 1 column (5th) of VCSEL array lit in pairs

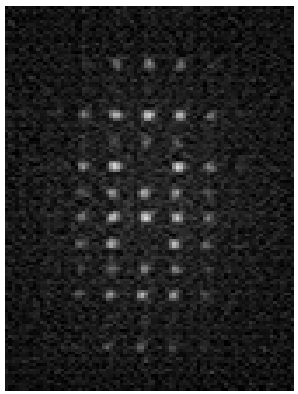
A1 A8



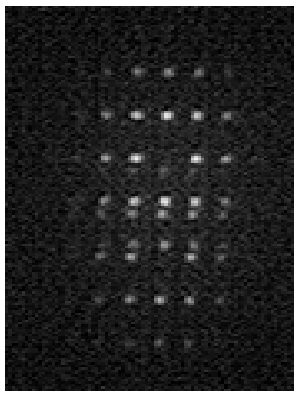
A5 lit @ .15 mA



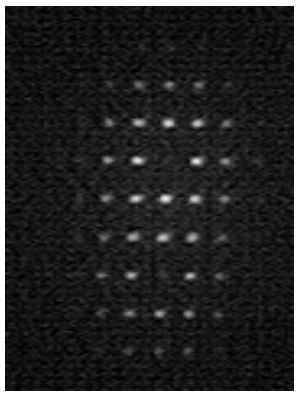
A5 lit @ .15 mA
B5 lit @ .15 mA



A5 lit @ .15 mA
C5 lit @ .15 mA



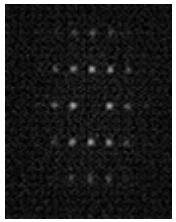
A5 lit @ .15 mA
D5 lit @ .15 mA



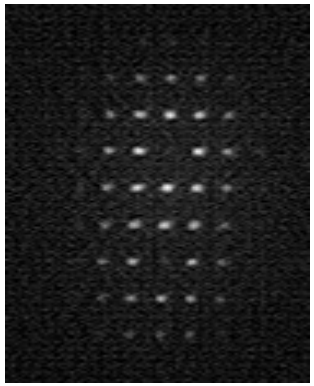
A5 lit @ .15 mA
E5 lit @ .15 mA

Horizontal: 1 VCSEL move = .75 DOE spacing
(VCSEL pair separated by 4 gives DOE spacing by 3)

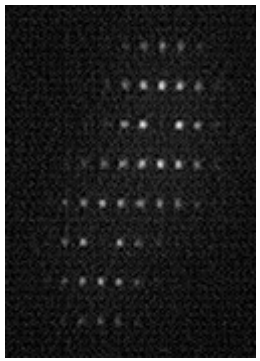
Optical Processing - Position



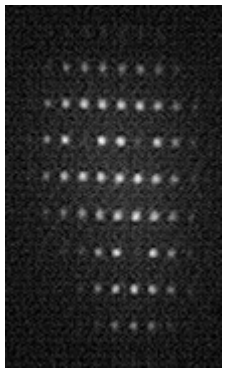
Lower left VCSEL lit



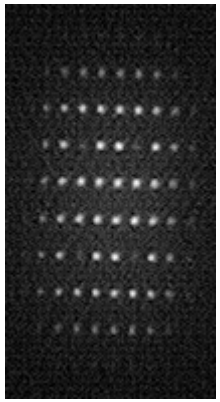
Left 2 VCSELs



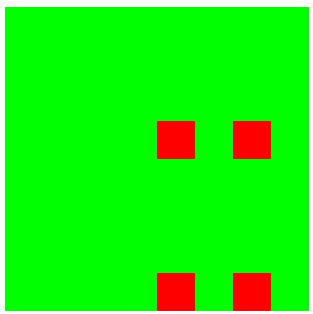
Lower left and upper right



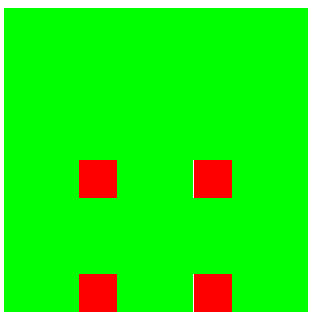
All but lower left



All 4 lit

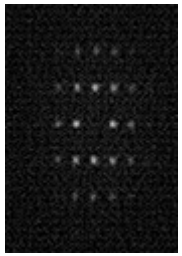


VCSEL physical spacing

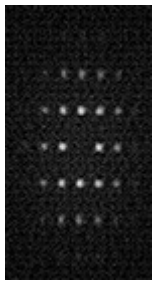


DOE optical spacing

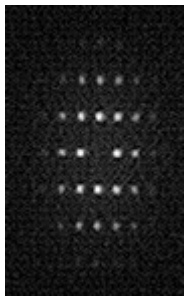
Optical Processing - Intensity



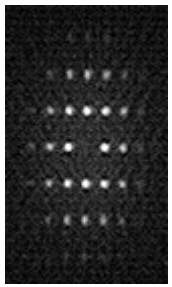
.10 mA



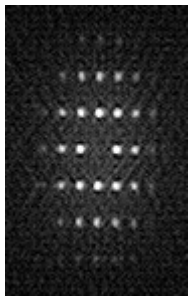
.15 mA



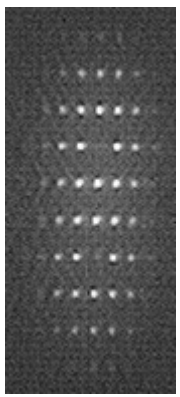
.20 mA



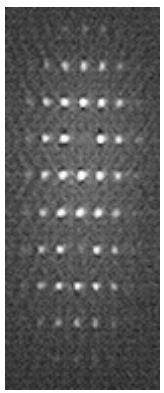
.25 mA



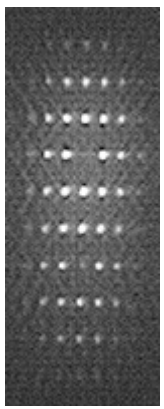
.30 mA



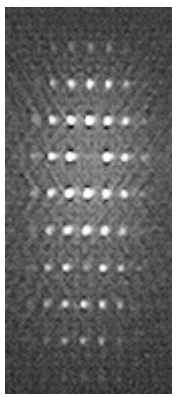
Upper
.3 mA
Lower
.3 mA



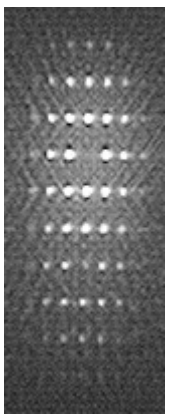
Upper
.4 mA
Lower
.3 mA



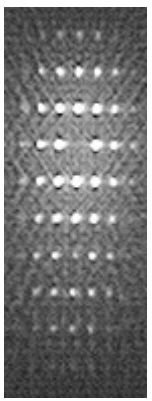
Upper
.5 mA
Lower
.3 mA



Upper
.6 mA
Lower
.3 mA



Upper
.7 mA
Lower
.3 mA



Upper
.8 mA
Lower
.3 mA

Subjective inspection shows DOE fanout intensities for both single and multiple VCSELs as expected.

Opto-electronic Processor Future Work

- **Realignment for DOE spacing**
- **Analysis of halftoning system performance**
- **Full implementation of digital halftoning system under computer control using VCSEL and detector arrays**

SUMMARY

- VCSEL physical spacing and DOE optical spacing characterized for current setup
- DOE fanouts utilizing superposition from multiple (up to 4) VCSELs in various configurations demonstrated