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# SEERI 2012 Summer Student Presentation

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NNSA National Nuclear Security Administration

SEERI

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# Introduction/Outline

- **Third year undergraduate student at UC San Diego**
  - Majoring in Physics and Mathematics
- **Grew up in the Albuquerque area**
- **Third summer here at Sandia**
  - SEERI Program
  - Org. 1344
- **Telecommuted during 2011-2012 school year**

# Introduction/Outline

- **Projects for the past year:**
- **Axness-Kerr Photocurrent Model development**
  - Review of work from last summer
  - Approximate Solution to moving boundary problem
  - New semi-closed form solution for $N/N^+$ region
  - Current Work
- **Summer 2012 Saturn / Hermes Projects**
  - Pinhole camera mount for off-axis imaging of Saturn source
  - Research into sensitivity of Image Plate
  - Pinhole design for on-axis imaging with AWE Fiber-Optic Cable
  - Image Processing and Creation of Matlab GUIs

# Axness-Kerr Photocurrent Model

- **Work from last summer:**

- **Xyce**
  - Parallel Electronic Simulator
  - My work: Compact photocurrent models
    - *Capture Fundamental Device Physics*
    - *Closed Form or Semi-Closed form solutions for device models*
    - *Modular components of large scale circuit simulations*
  - In particular: Photocurrent generation in Bipolar Junction Transistors
    - *Physics is applicable to other Silicon devices (diodes)*
- **A-K Photocurrent Model**
  - Approximates carrier transport equations with Ambipolar-Diffusion Equation
- **End of last summer:**
  - Implemented standalone version of model (including SACADO compatibility for eventual communication with Xyce solvers)
    - *Solution of Quasi-Neutral device regions with Discrete Fourier Transform (Fourier Sine Series)*

# Axness-Kerr Photocurrent Model

- **Ambipolar Diffusion Equation (1-D)**

$$\dot{u} = D_a \frac{\partial^2 u}{\partial x^2} - \mu_a E \frac{\partial u}{\partial x} - \frac{1}{\tau} u + g(t)$$

- **Carrier mobilities are fixed from diffusivities by Einstein relation**
  - **Carrier Diffusivities and Lifetimes can be used as calibration parameters**
  - **g(t) is the carrier generation rate (due to electron-hole pair production)**
- **Quasi-Neutral region widths are given by the physical region width less what is lost to the depletion region**
  - *Effective widths depend on device bias*
  - *Moving Boundary problem*
  - *Also would like solution for* $\tau = \tau(t)$ *as to include neutron damage effects during pulse*



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# Axness-Kerr Photocurrent Model

- **Solution to MBP**
  - Stop-start method
  - Pick a basis set: $\{\psi_n(x)\}$
  - Solve for a given initial condition (find coefficients s.t. $u(x,t)=\sum_n a_n(t)\psi_n(x)$ )
  - For next time interval find new basis functions: $\{\phi_n(x)\}$
  - Rescale and project onto new basis:

$$u(x,t_k^+)=u(\frac{L_k}{L_{k-1}}x,t_k^-)=\sum_n a'_n(t)\phi_n(x)$$

  - Renormalize to enforce charge conservation

$$\int_0^{L_{k-1}} dx\ u(x,t_k^-)=\int_0^{L_k} dx\ u(x,t_k^+)$$

  - This is then the initial condition for the next time-step

# Axness-Kerr Photocurrent Model

- **Solution for epitaxial devices (where the subcollector contributes a large portion of the device photocurrent)**

$$\dot{u} = \hat{L}\, u(x,t) + g(t)$$

$$\hat{L} = \begin{cases} D_1 \partial_x^2 - \dfrac{1}{\tau_1} & 0 \le x \le L_1 \\ D_2 \partial_x^2 - \dfrac{1}{\tau_2} & L_1 \le x \le L_2 \end{cases}$$

- **Homogeneous Dirichlet Boundary Conditions at** $x = 0, L_2$
- **Additionally at** $x = L_1$
  - $N_1 u\big|_{x=L_1^-} = N_2 u\big|_{x=L_1^+}$
  - $D_1 \dfrac{\partial u}{\partial x}\bigg|_{x=L_1^-} = D_2 \dfrac{\partial u}{\partial x}\bigg|_{x=L_1^+}$

# Axness-Kerr Photocurrent Model

- **Solution for epitaxial devices (continued)**
- **Separate variables and solve spatial eigenvalue equation:** $\hat{L}\,\psi(x) = \lambda\,\psi(x)$
  - Two solution sets, depends on if $\frac{1}{\tau_1} < \lambda \leq \frac{1}{\tau_2}$ or $\lambda > \max(\frac{1}{\tau_1}, \frac{1}{\tau_2})$
  - $\hat{L}$ is Hermitian so the $\{\psi_n\}$ form an orthonormal basis ( $w(x) = \begin{cases} 1 & 0 \leq x \leq L_1 \\ \frac{N_2}{N_1} & L_1 \leq x \leq L_2 \end{cases}$ )
  - The rest of the problem is a straightforward solution by eigenfunction expansion
  - Taking the limit as $t \to \infty$ and identifying one part of the infinite sum with the steady state solution allows for a perturbation-from-equilibrium solution and better convergence rates



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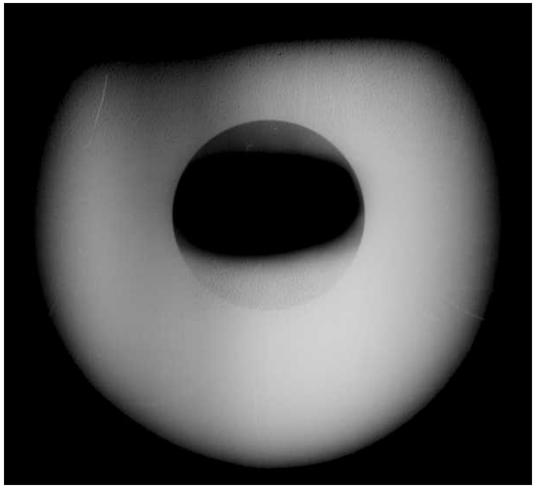
# Axness-Kerr Photocurrent Model

- **Current Work:**
  - **Modifying code to integrate into Xyce**
    - *Cleaning up*
    - *Adding a P-N-$N^+$ diode version of the code*
  - **Writing scripts to use DAKOTA (Design Analysis Kit for Optimization and Terascale Applications) for parameter calibration for comparison against device response data**

# Summer 2012 Experimental Design Work

- **Off-Axis Imaging Experiment on Saturn**
  - Thin Tantalum cylinders are used as β to γ converters on Saturn in reflex-triode mode.
  - Wanted to get images of side of Tantalum to characterize effects of seam on radiation intensity
  - Designed mount to hold tungsten pinhole camera (using Image Plate) inside Saturn vacuum chamber.
  - Alignment and focus were correct.
  - Underestimated dose, film was overexposed.



Overexposed image of side of Saturn source.

# Summer 2012 Experimental Design Work

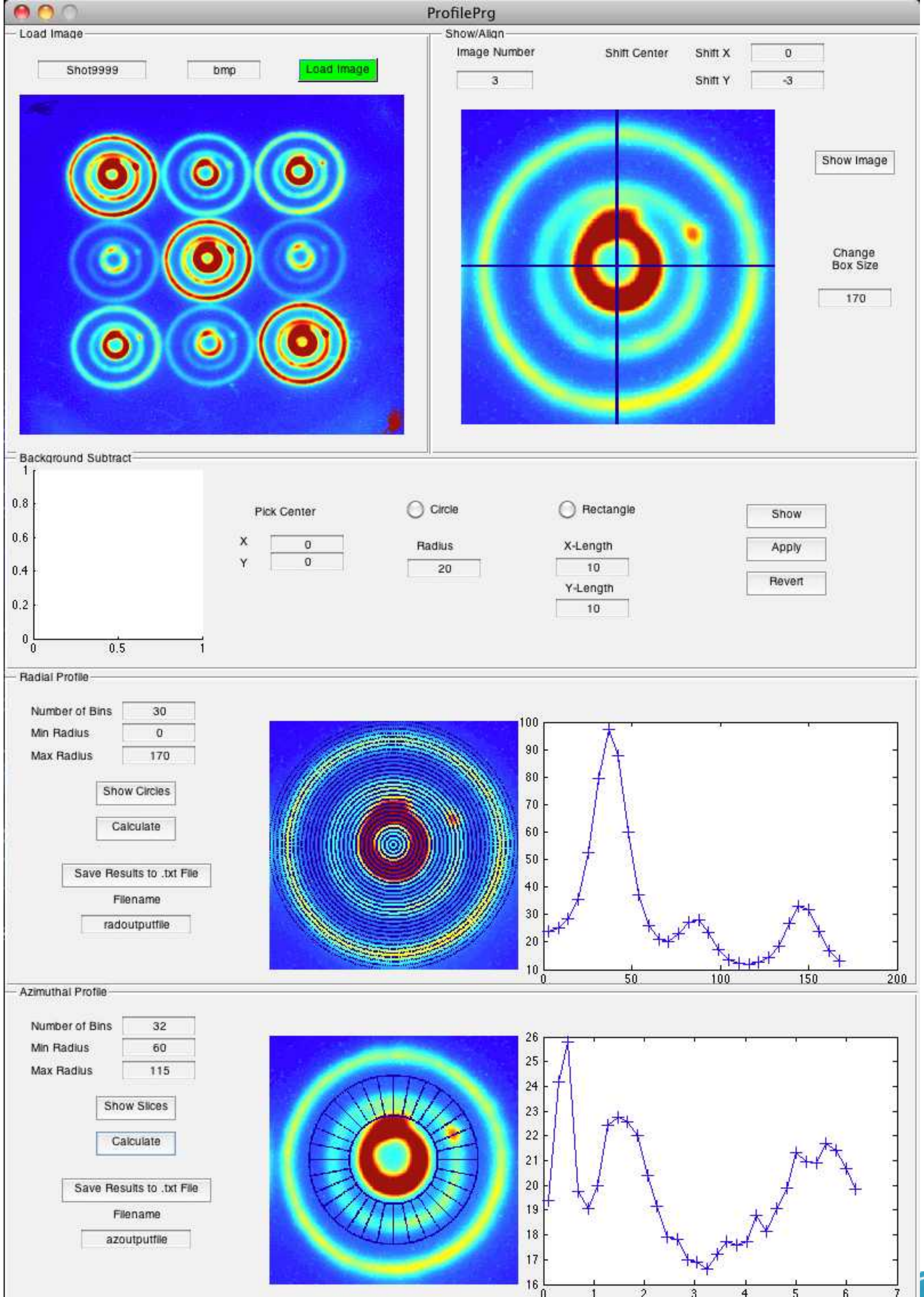
- **Image Plate sensitivity analysis**
- **Use Fujifilm BAS (Bio-Imaging Analysis Systems) Image Plate to image radiation sources when it is inconvenient to use a scintillator & camera setup**
  - Similar to X-ray film
  - Data is read using a special scanner (UV laser excites electrons out of metastable state causing photon emission)
  - High resolution (down to 25 µm square pixel size)
  - Can be erased with UV light (reusable)
- **Characterized image plate response (grey-scale value) as a function of energy deposited in active layer**
  - Compared energy deposition calculations using ADEPT and X-ray absorption/attenuation coefficients from NIST (National Institute of Standards and Technology)
  - Found that NIST tables well characterized energy deposition in active layer for photon energies < 200 keV.

# Summer 2012 Experimental Design Work

- **Saturn On-Axis Imaging mount/pinhole design**
  - Worked on designing a pinhole camera for an on-axis imaging system for Saturn
  - Will use a plastic scintillator and radiation hard fiber-optic cable supplied by AWE to provide images of Saturn source during tests
  - Mount goes directly into shielding below test fixture, less then a foot from the Saturn source.
  - Provides quick feedback about characteristics and quality of shot to customer
    - *Faster then waiting for processing of TLDs*
    - *Provides very high spatial resolution*
  - Will use image plate to characterize pinhole camera characteristics (resolution and radiation leakage) before using full setup of scintillator and cable.

# Summer 2012 Experimental Design Work

- **Saturn data image processing**
  - Preprocessed images using NIH tool 'ImageJ'
  - Utilized a number of Matlab GUI's written by previous SEERI student Andrew Sharp
  - Modified several GUI's for increased compatibility and functionality
  - Wrote code for an additional GUI that provides azimuthally averaged radial profiles and radially averaged azimuthal profiles of data from images of Saturn's 'rings'
  - Processed images using new tool
    - *By looking for differences in radial profile as a function of time can determine if rings flex inwards or outwards at all during shot*
    - *By analyzing azimuthal profile of source can learn about formation of 'hot spots'-areas of high source intensity caused by non-uniformity of converter material*



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Shift X
0
Shift Y
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32
Min Radius
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Max Radius
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Show Slices
Calculate
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azoutputfile

# Acknowledgements / References


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- References:
  - SAND 2012-2161

# Questions