UNM SCHOOL of ENGINEERING
Department of Electrical & Computer Engineering
LESA
Lighting Enabled Systems & Applications

Plenoptic Sensor Development for Color-Tunable Lighting

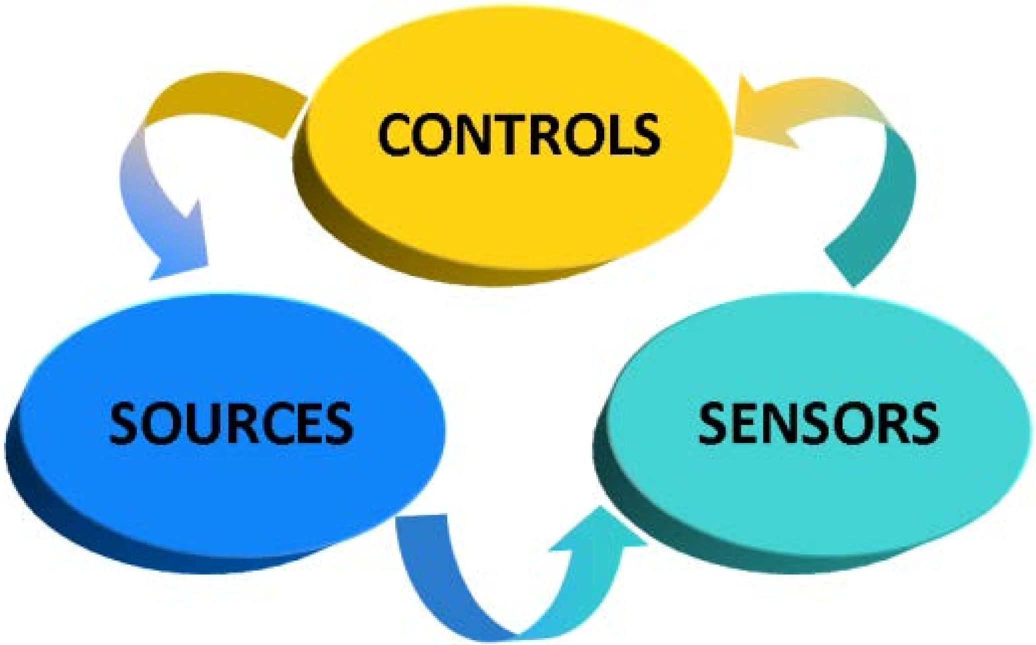
Payman Zarkesh-Ha

Associate Professor
Department of Electrical & Computer Engineering
University of New Mexico
Albuquerque, NM

Collaborators: Steve R. J. Brueck and Alexander Neumann

Topic of Interest: Sensors

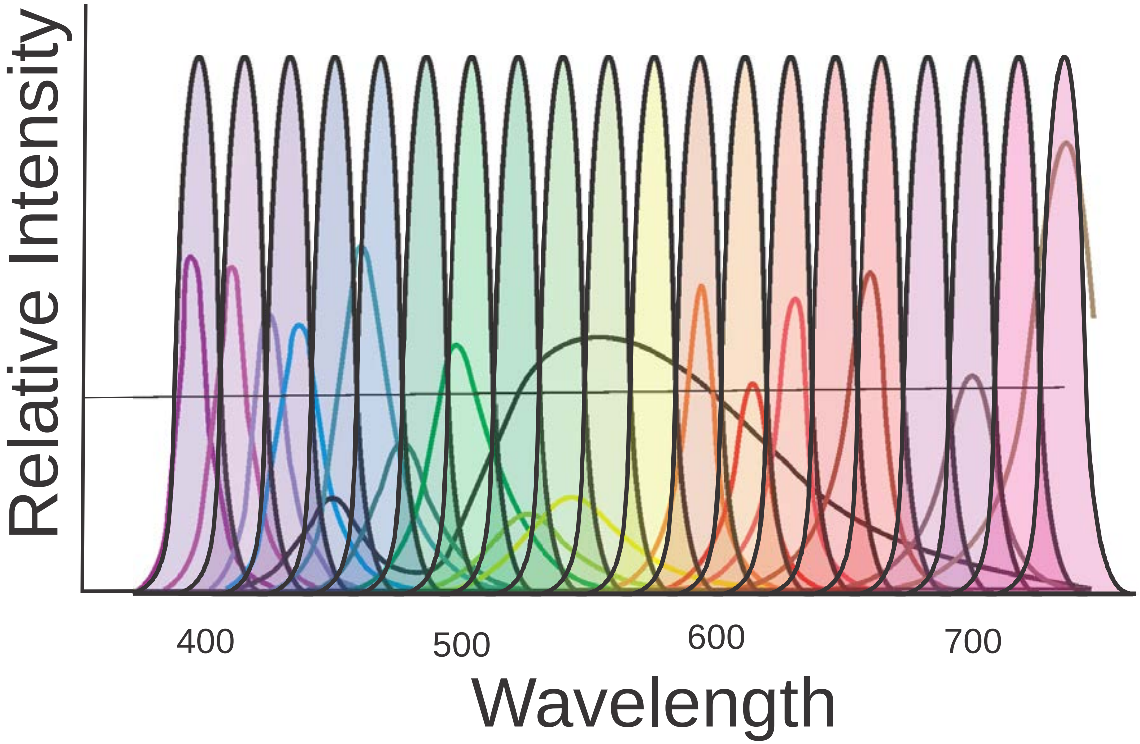
- Sensors are needed for color tunable LED systems with control feedback.
- Overall goal: deliver high quality lighting to improve human health and productivity.



Need High Resolution Color Sensor

- **Existing off-the-shelf RGB color sensors are not capable for advanced multi-LED color tunable light fixtures.**

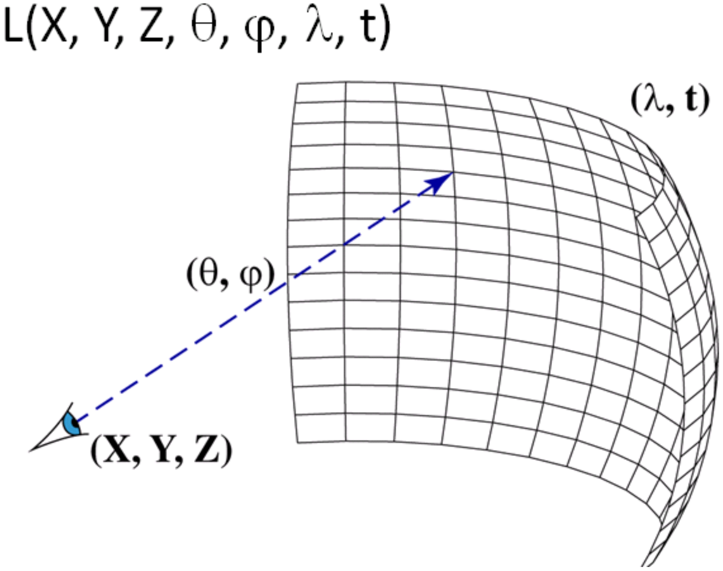
High Resolution Color Sensor



Sensors Requirements

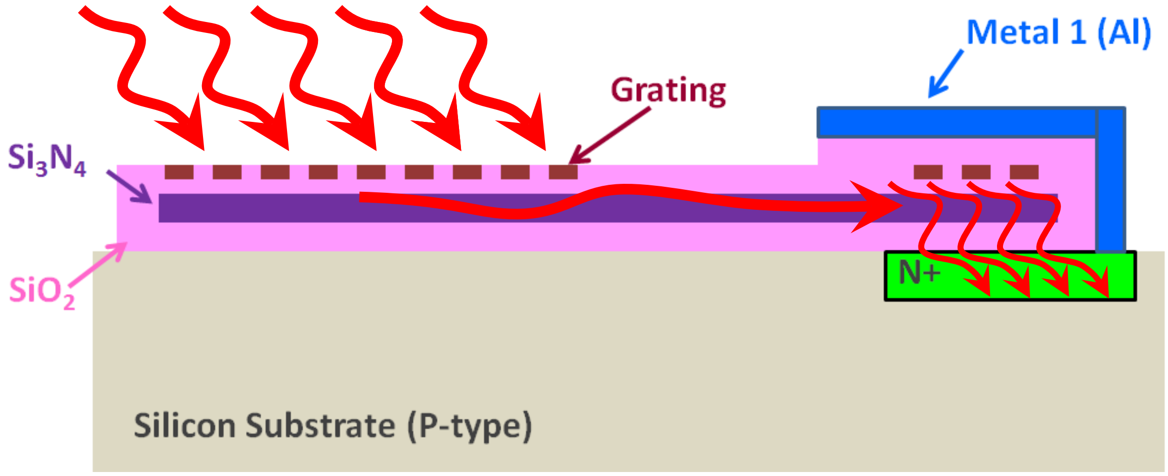
- **Sensor requirements:**
  - **High Resolution (<20nm in wavelength)**
  - **Low Cost (<0.08 $/sqft)**
  - **Additional Functionality (light-field sensing)**

- **Plenoptic sensor:**
  - **Intensity**
  - **Wavelength**
  - **Angle**
  - **polarization**

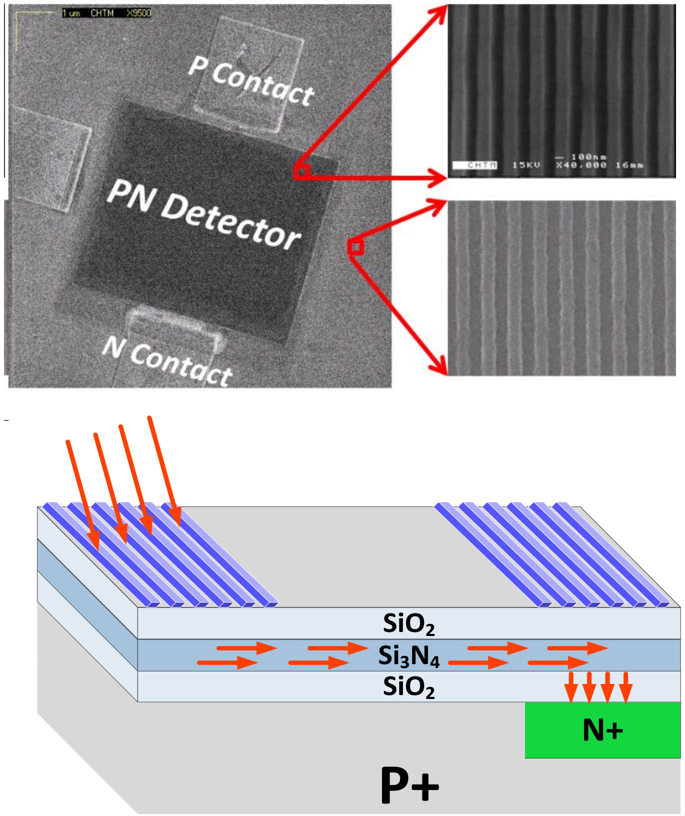


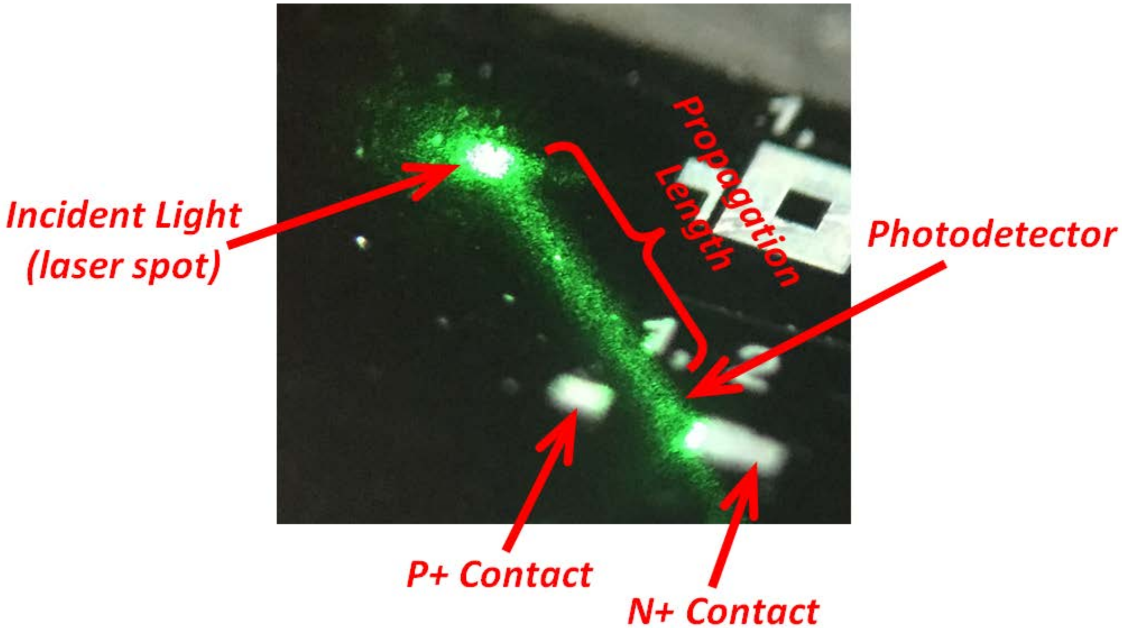
Our Approach: Guided-Mode Resonance Filter

- Superior color selectivity and angular detection
- Achievable optical gain (2D lensing)
- Small and fast detector
- Additional electrical gain with APD
- Possible waveguide optical processing



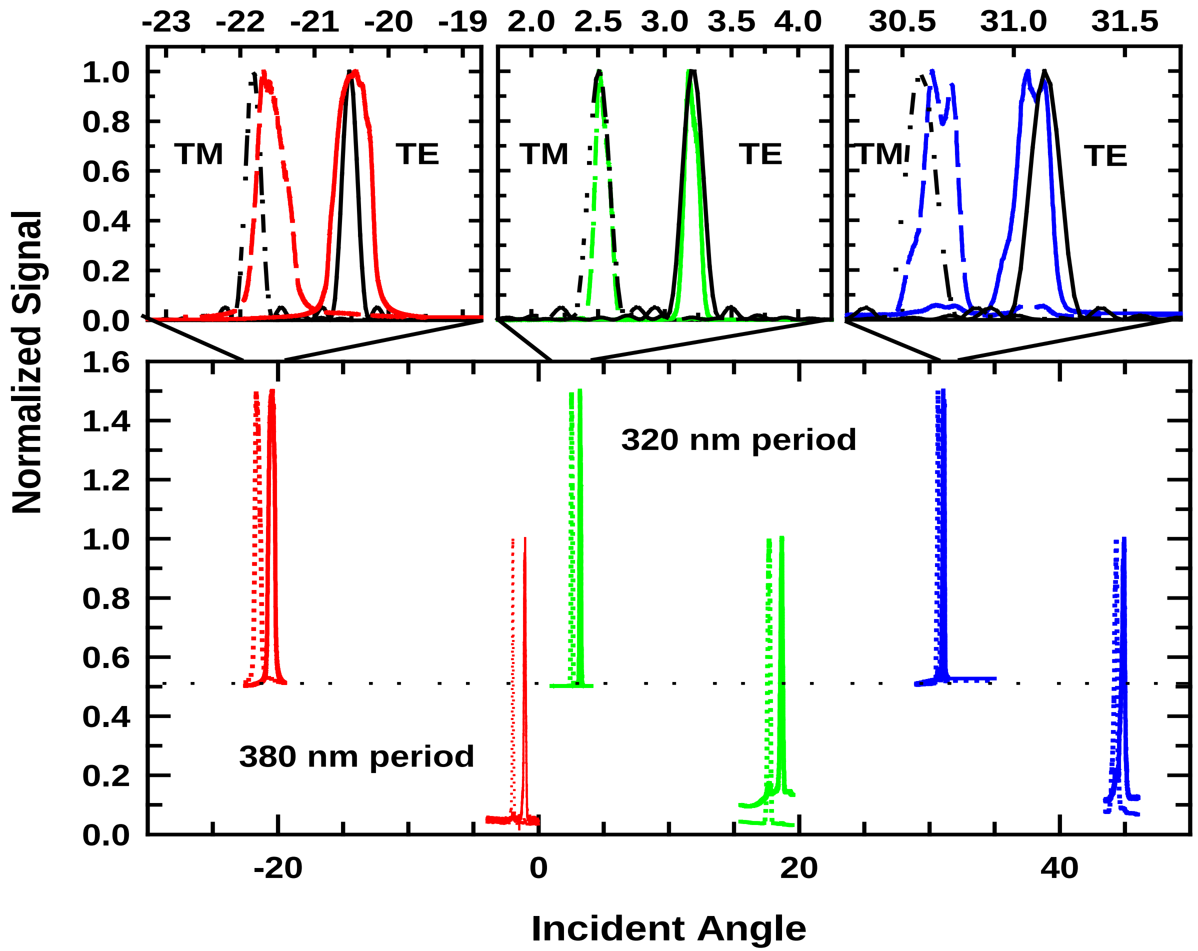
First Integrated Waveguide on Silicon Detector





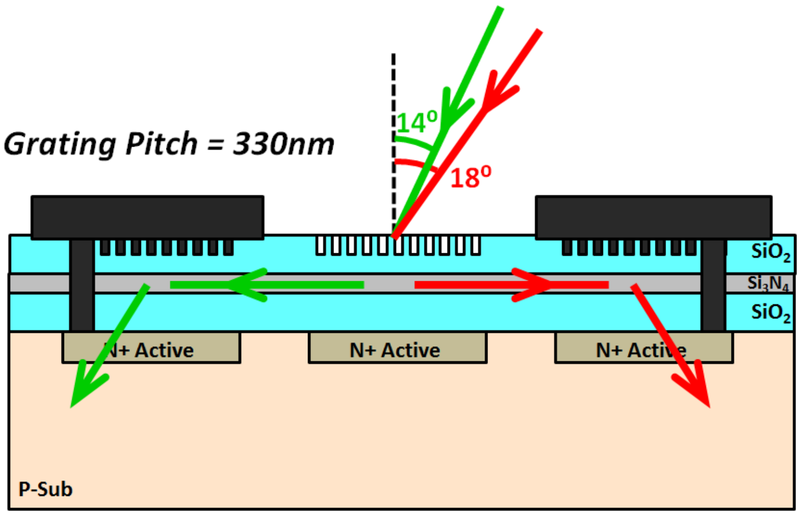
[1] A. Neumann, J. Ghasemi, S. Nezhadbadeh, X. Nie, P. Zarkesh-Ha and S.R.J. Brueck, CMOS-compatible plenoptic detector for LED lighting applications , Opt. Express 23, 23208 (2015).
[2] J. Ghasemi, A. Neumann, S. Nezhadbadeh, X. Nie, P. Zarkesh-Ha, and S. J Brueck "A CMOS-Compatible Plenoptic Sensor for Smart Lighting Applications," CLEO (2015).

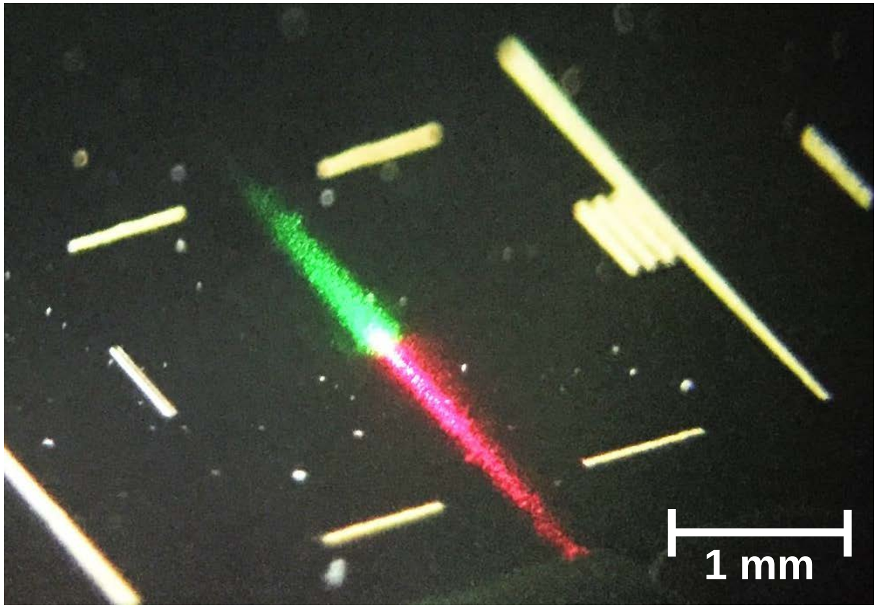
Experiments: Superior Angular Selectivity



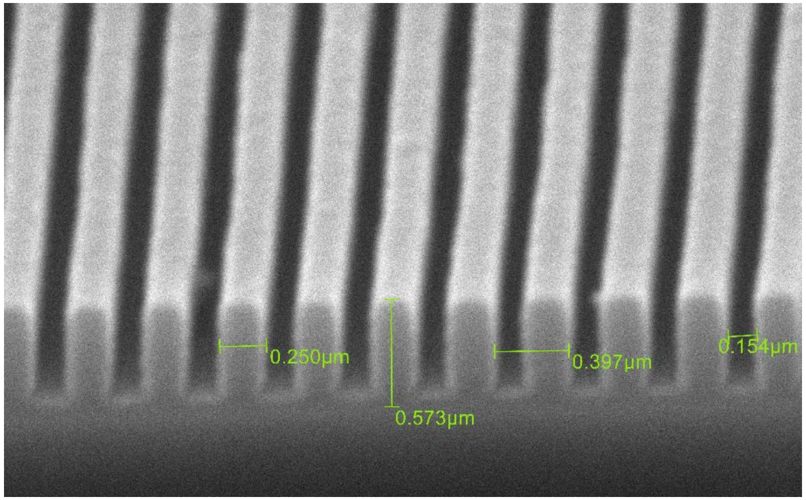
J. Ghasemi, A. Neumann, S. Nezhadbadeh, X. Nie, P. Zarkesh-Ha, and S. J Brueck “A CMOS-Compatible Plenoptic Sensor for Smart Lighting Applications,” CLEO (2015).

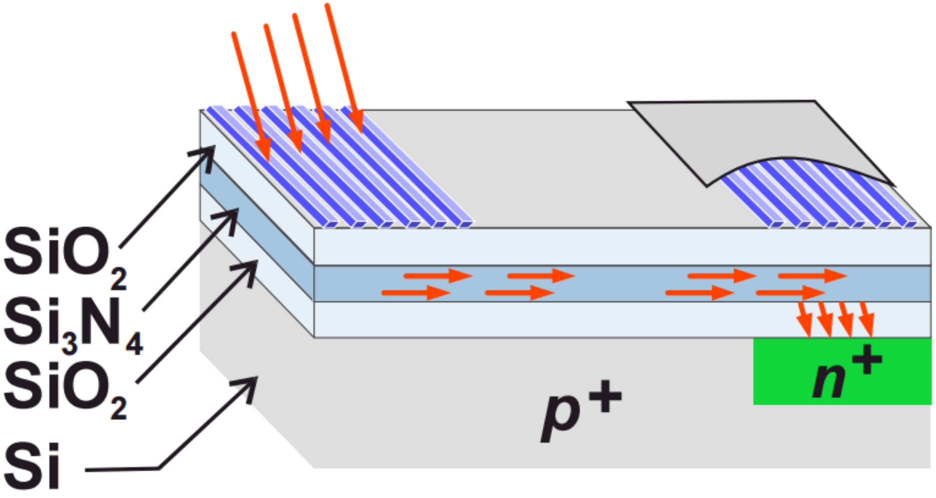
Integrated Waveguide with Double Detector





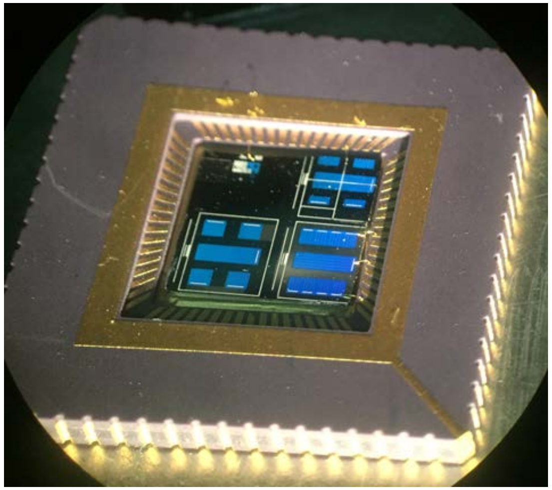
Progress Toward a Sensor Integration



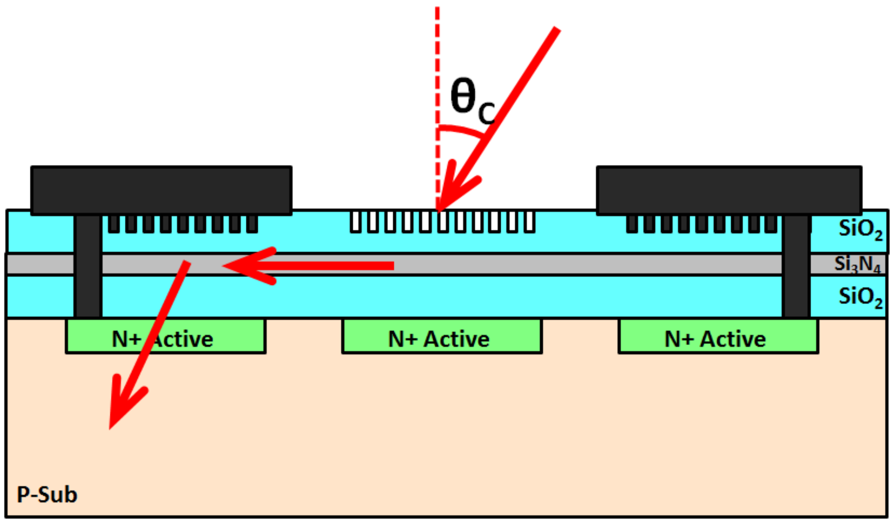


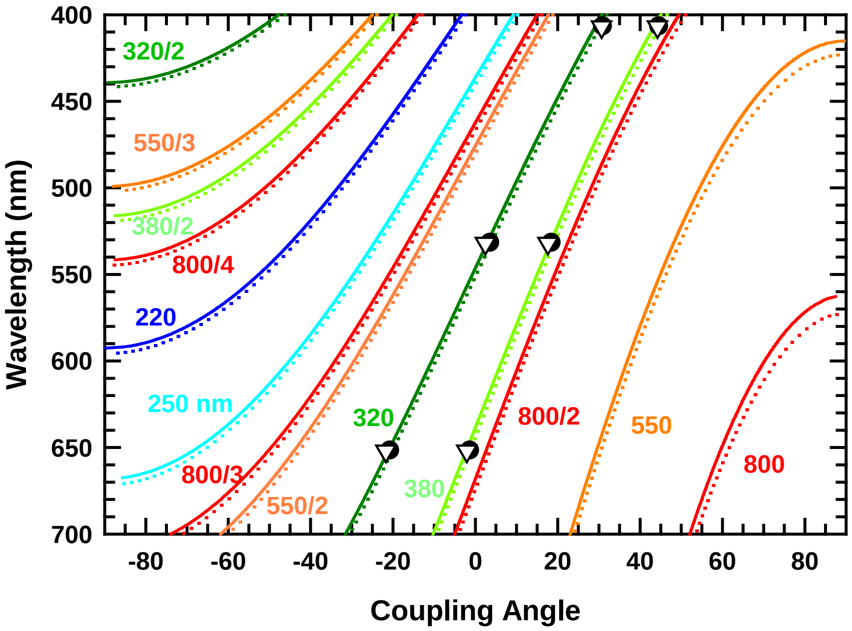
Selective Grating

Packaging Devices



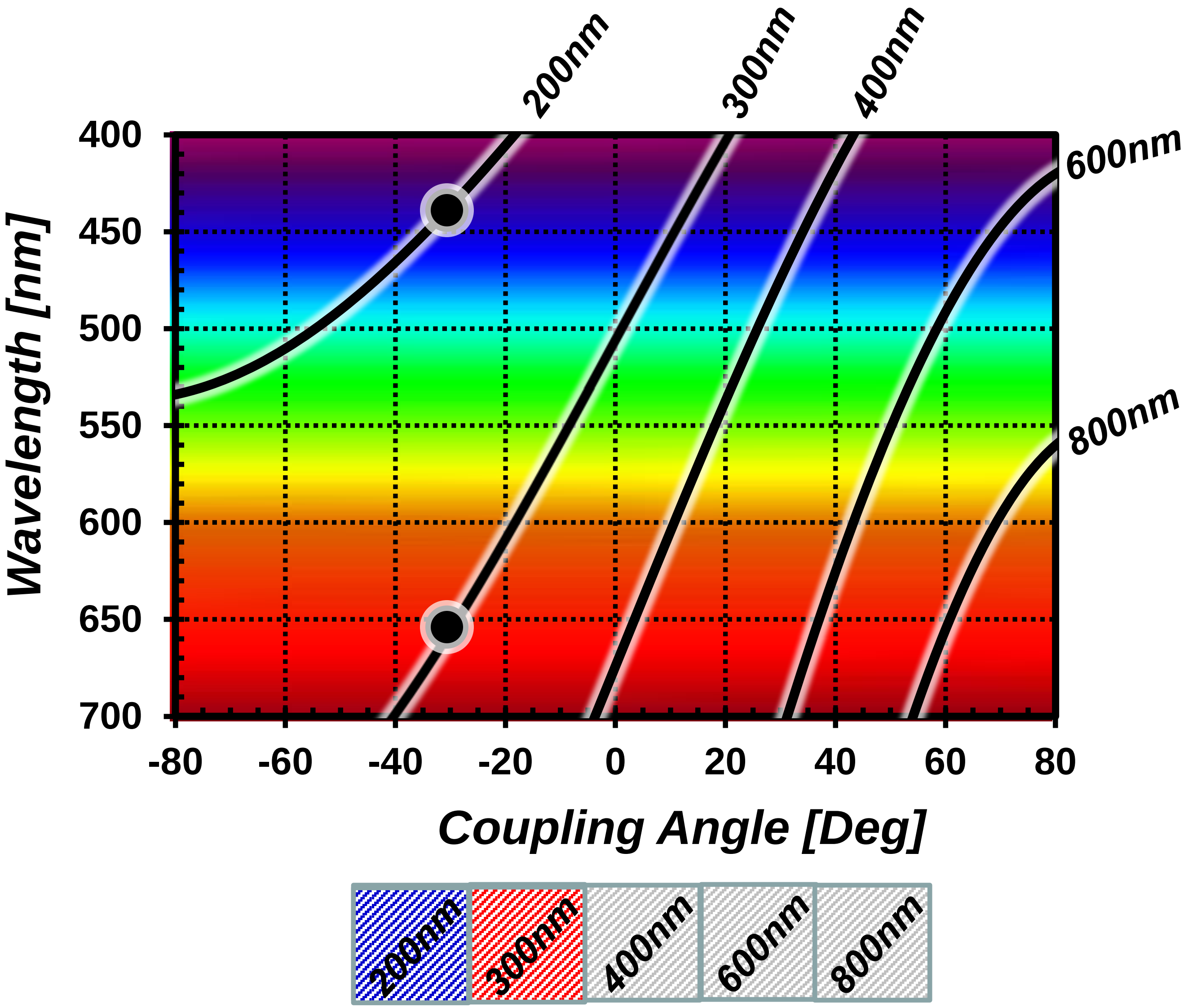
Guided Mode Filter Design Consideration



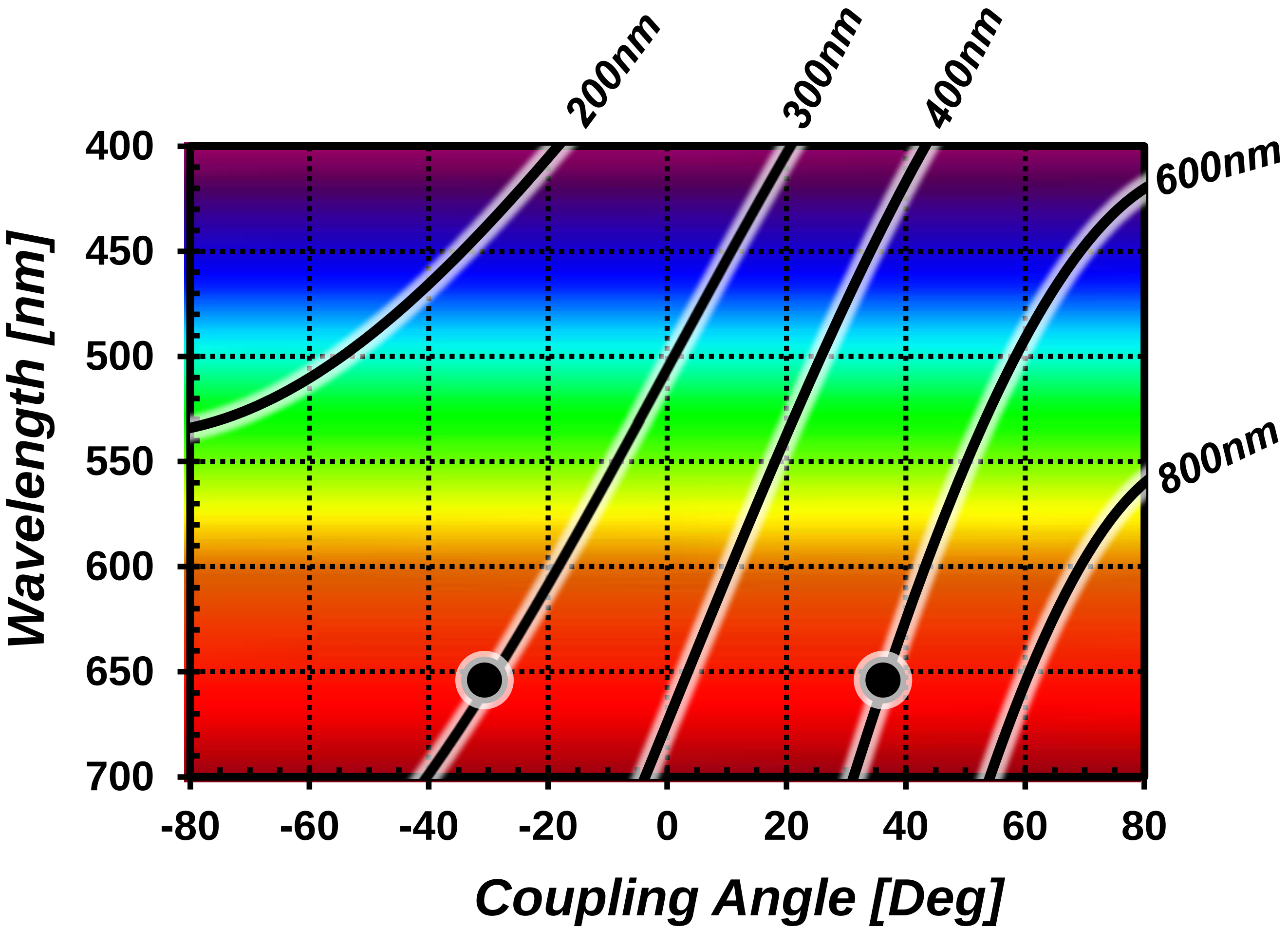


$$\sin\theta_C \pm \frac{\lambda}{d} = \pm n_{Guide}$$

Plenoptic Sensor: Example 1

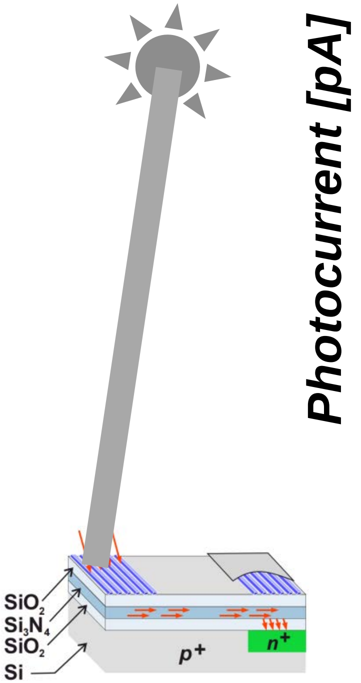


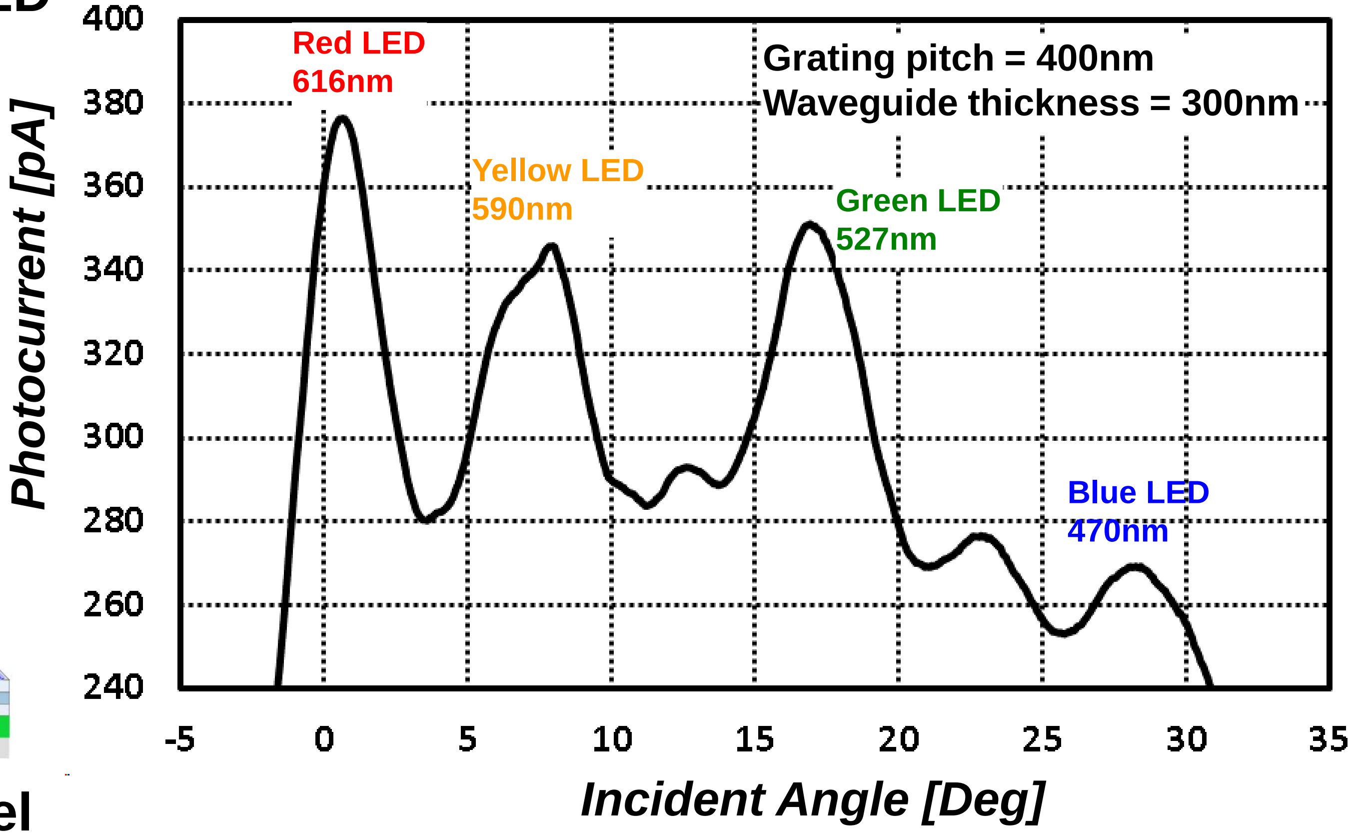
Plenoptic Sensor: Example 2



Latest Experimental Results with LED

“RGBY” LED

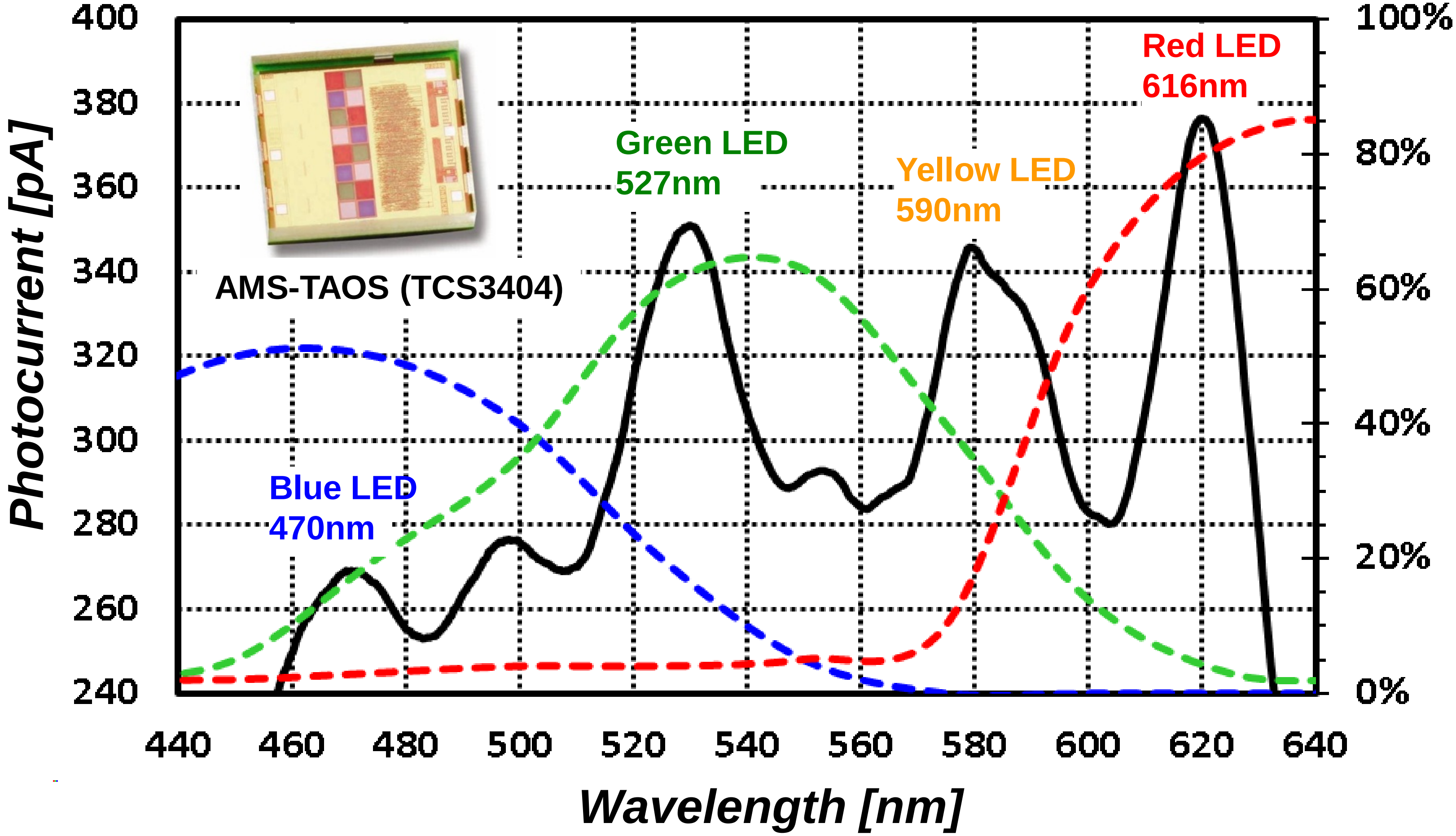




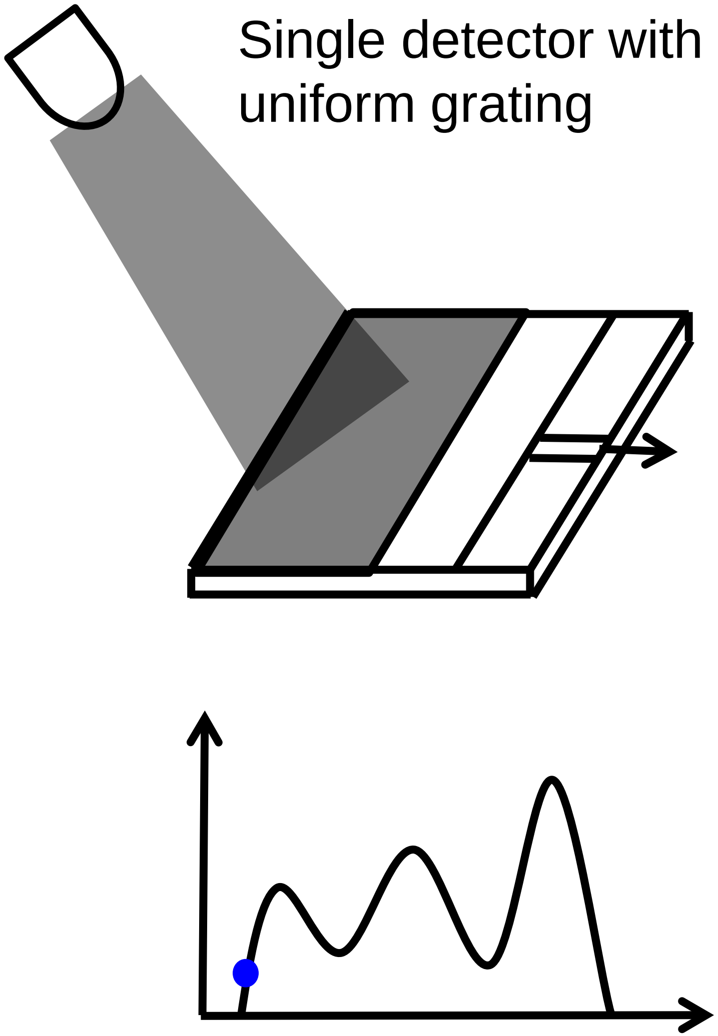
Single Pixel
Pleoptic Sensor

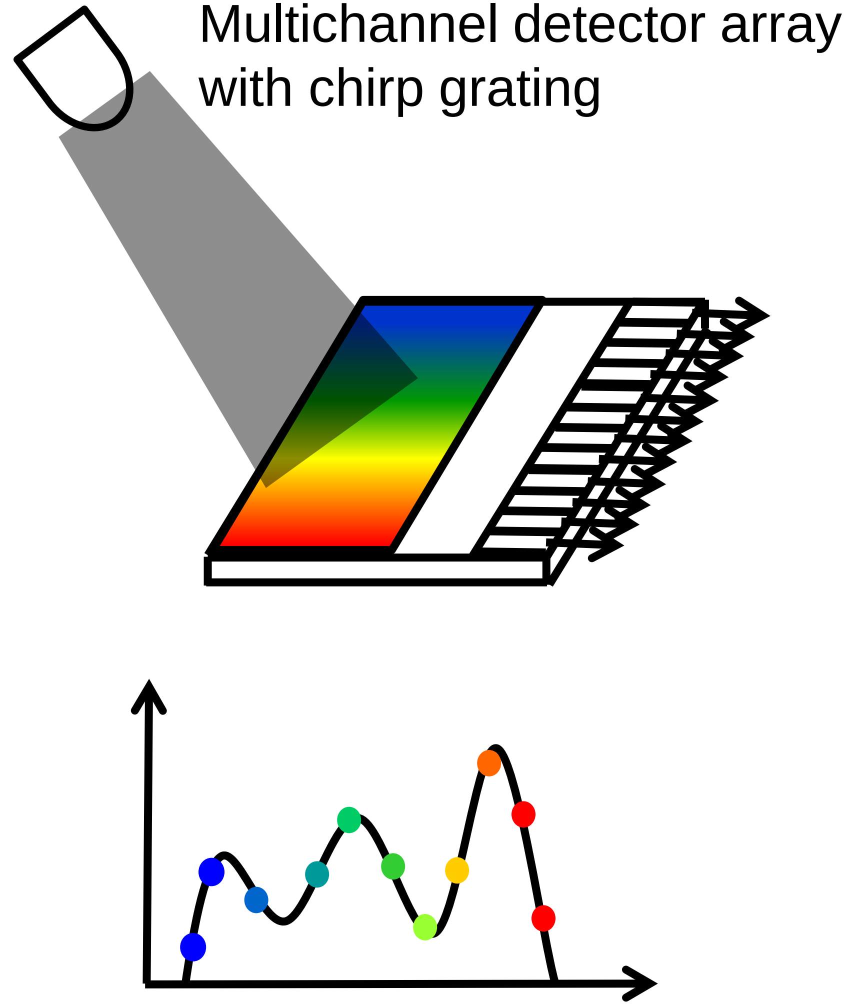
Conversion to Wavelength (Spectrometer)

$$\sin\theta_C \pm \frac{\lambda}{d} = \pm n_{Guide}$$

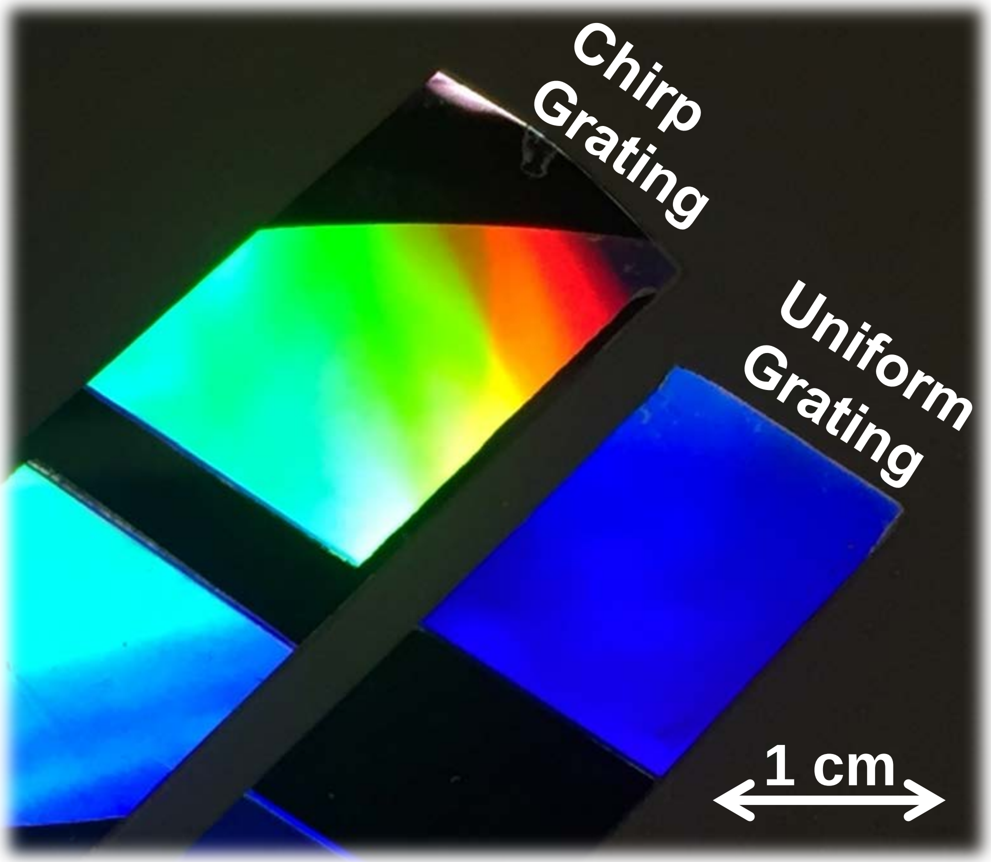


Next Step: Arrays of Plenoptic Sensors

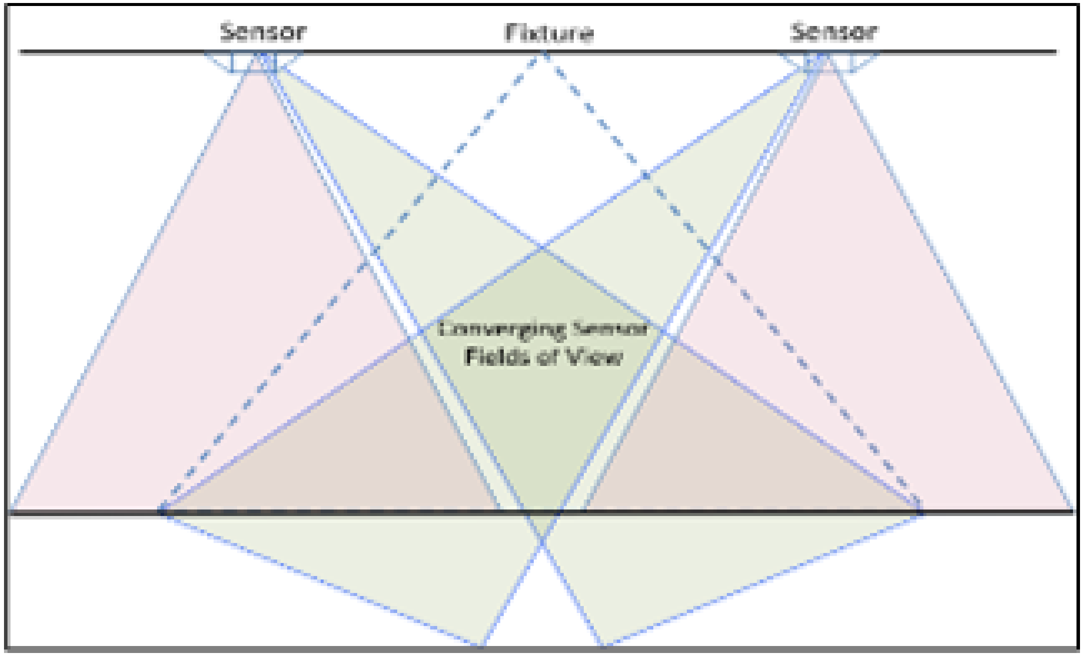




Successful Fabrication of Chirp Gratin



More Applications for Plenoptic Sensor

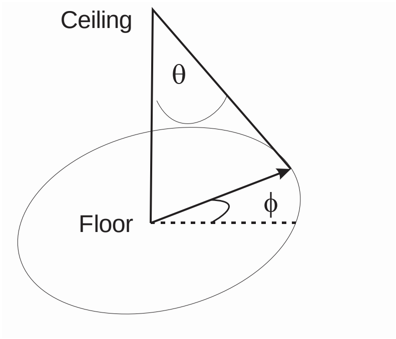


- ❑ **Use angular selectivity of plenoptic sensor instead of wavelength selectivity.**
- ❑ **Combine with ToF system to determine the angle of the reflected light.**
- ❑ **Can be used for occupant counting and tracking.**

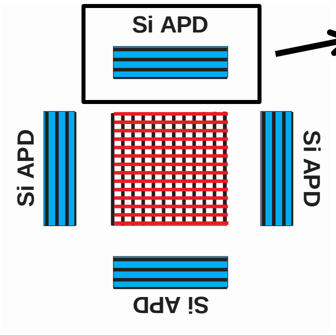
People Counting with Plenoptic ToF Sensor

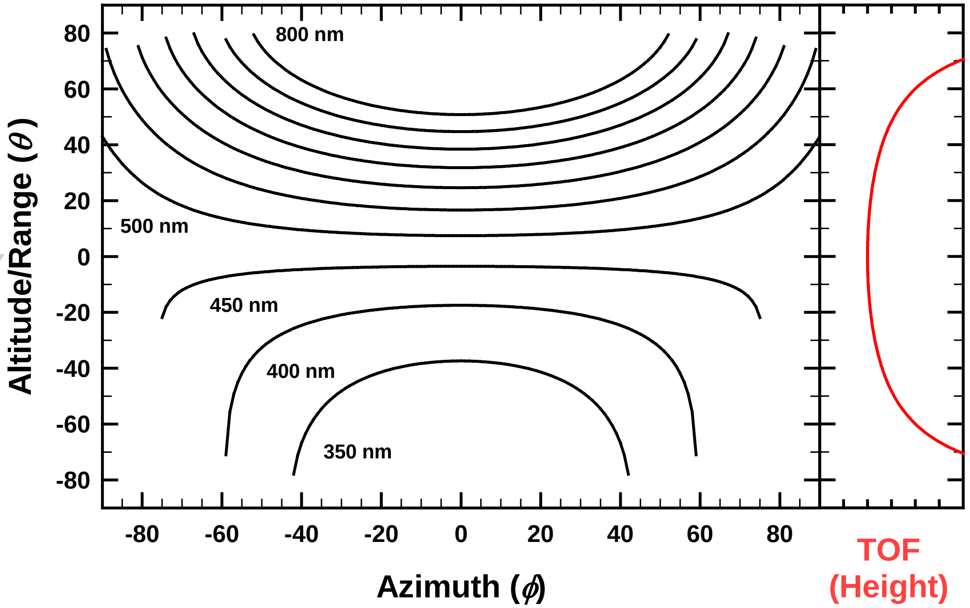
- Fixed wavelength (IR) varying angle of reflected light.
- High resolution in altitude (θ).
- Lower resolution in azimuth (ϕ).
- Use multiple gratings and detectors to define (θ, ϕ).
- Add TOF information to uniquely define position in 3D space.

Coordinate System



Sensor Layout





Conclusions

- Sensors are essential components in future LED systems that require feedback control.
- Existing off-the-shelf color sensors are not suitable for advanced multi-color LED lighting systems.
- Plenoptic sensor can deliver light-field information (angle and wavelength) with high resolution needed for high quality LED lighting.
- Fixed angle – spectral sensor (no moving parts spectrometer).
- Fixed wavelength – Multiplexed TOF sensor for people counting.