Waveguide-based Spatial Light Modulators for Use in Holographic Video Displays

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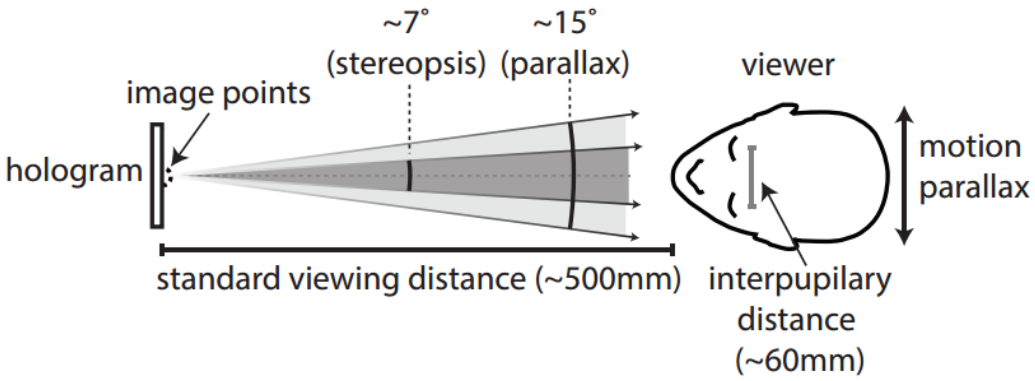
Outline:

- Published Work
  - ❑ Leaky-mode waveguide modulators with high deflection angle for use in holographic video displays
    - ✓ Background
    - ✓ Theory of Leaky-mode waveguide modulators
    - ✓ Design, fabrication, and tests
- Current and Future Projects
  - ❑ Doubling deflection angle using a new design
  - ❑ Holography through surface Plasmon Polariton (SPP)
  - ❑ Diffraction efficiency of waveguide light modulators with different methods of proton exchange
- Publications
- Contributions

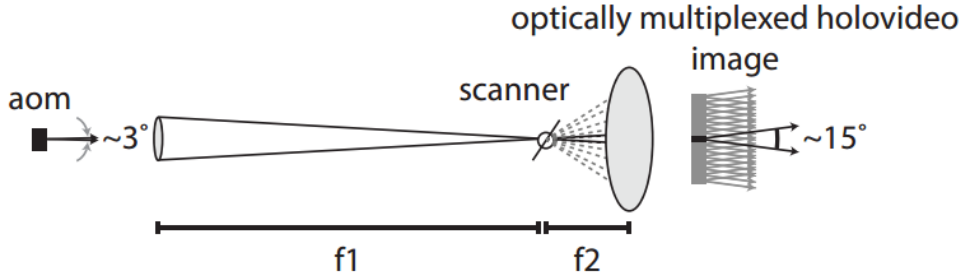
Leaky-mode Waveguide Modulators with High Deflection Angle

Holograms can be viewed directly.



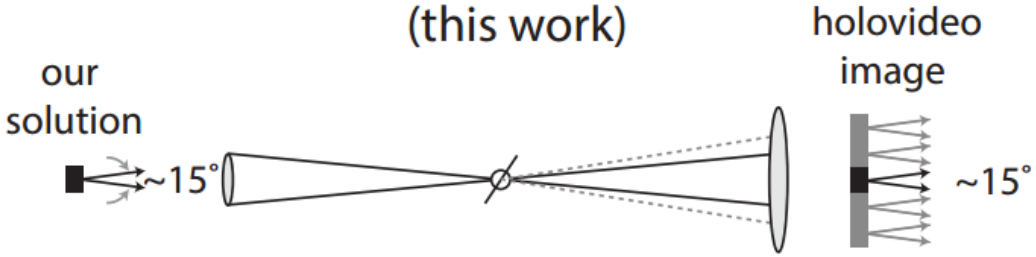
a.

Holovideo requires demagnification and derotation.



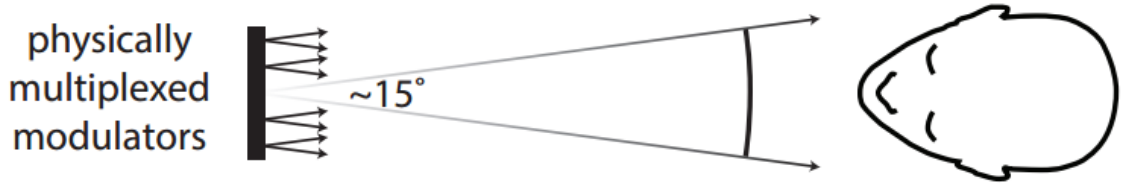
b.

Holovideo with no Demagnification
(this work)



c.

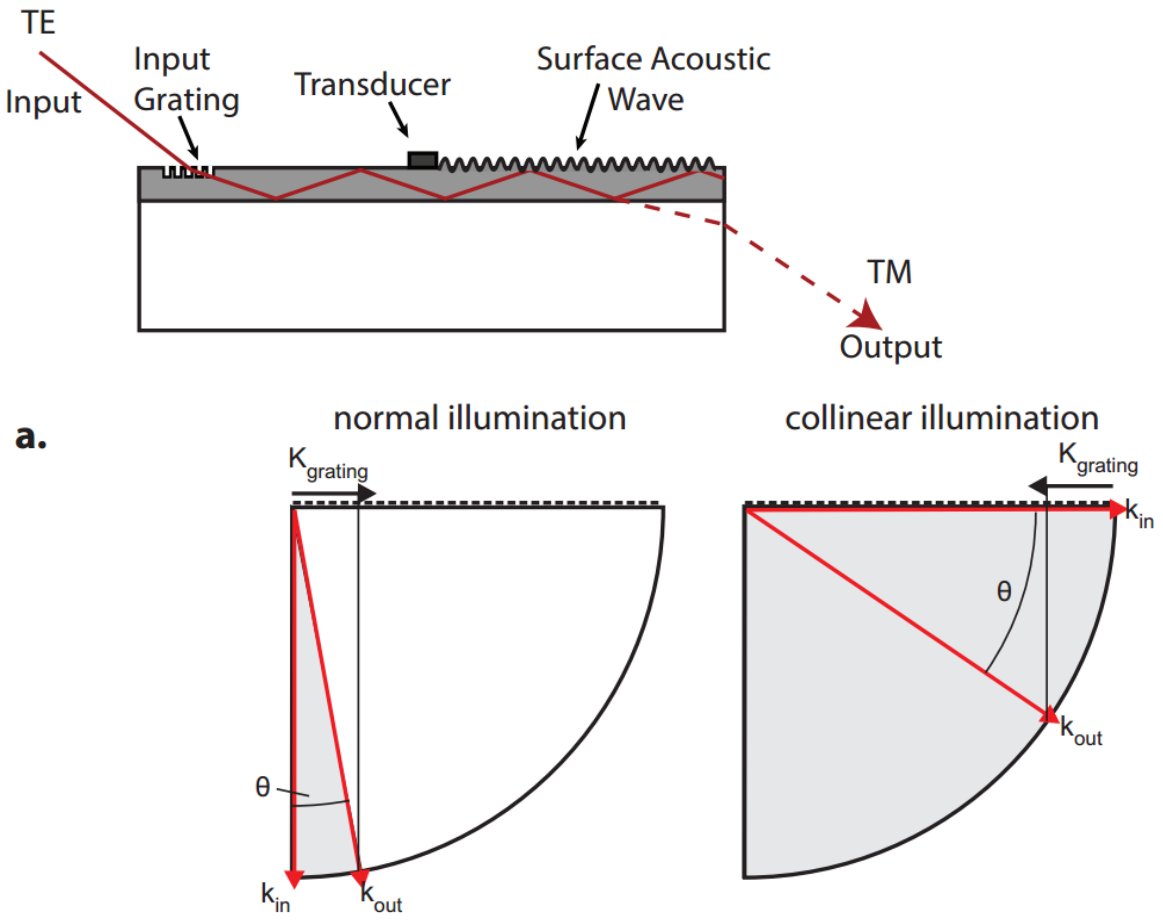
No Demagnification and No Derotation
(possible for the first time)

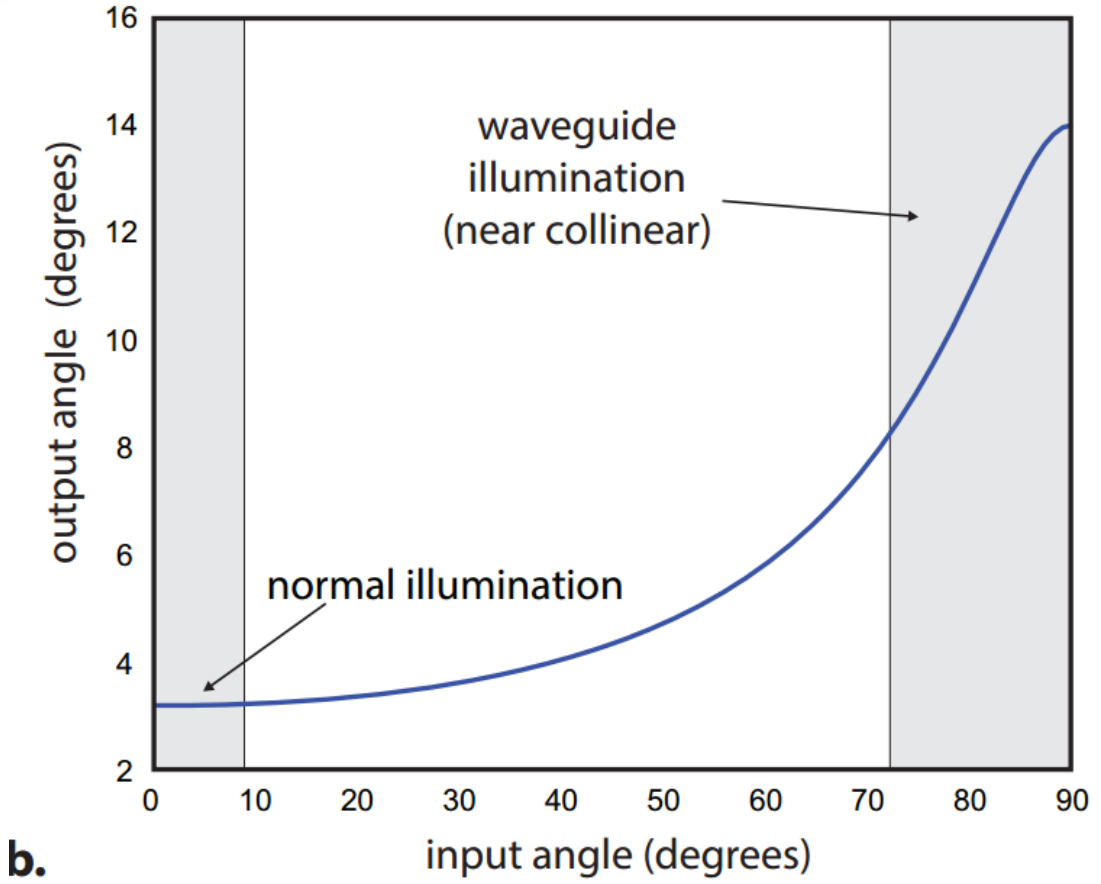


d.

Qaderi, K., et al. Optics Express (2016)

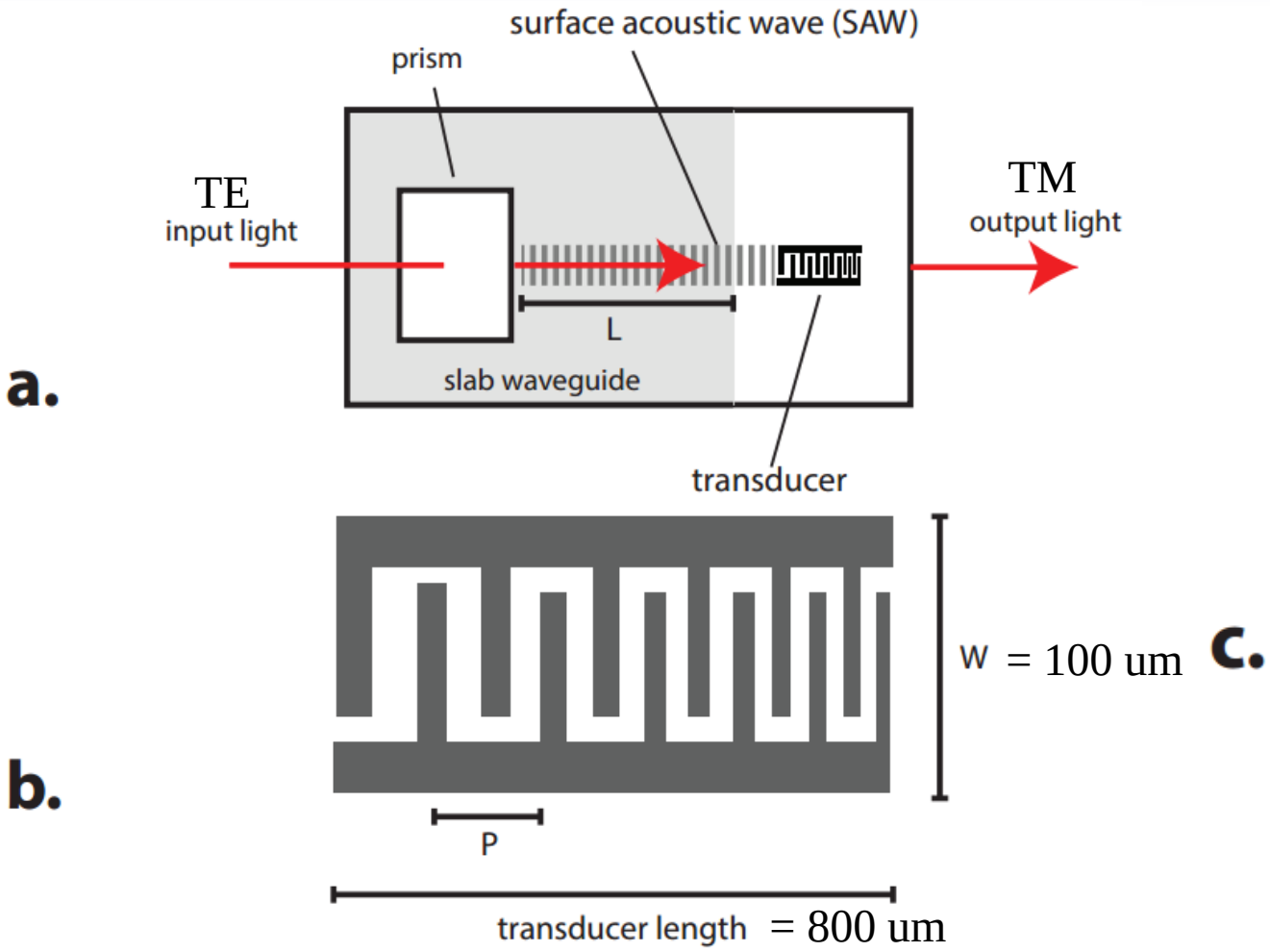
Theory behind the Waveguide Modulators





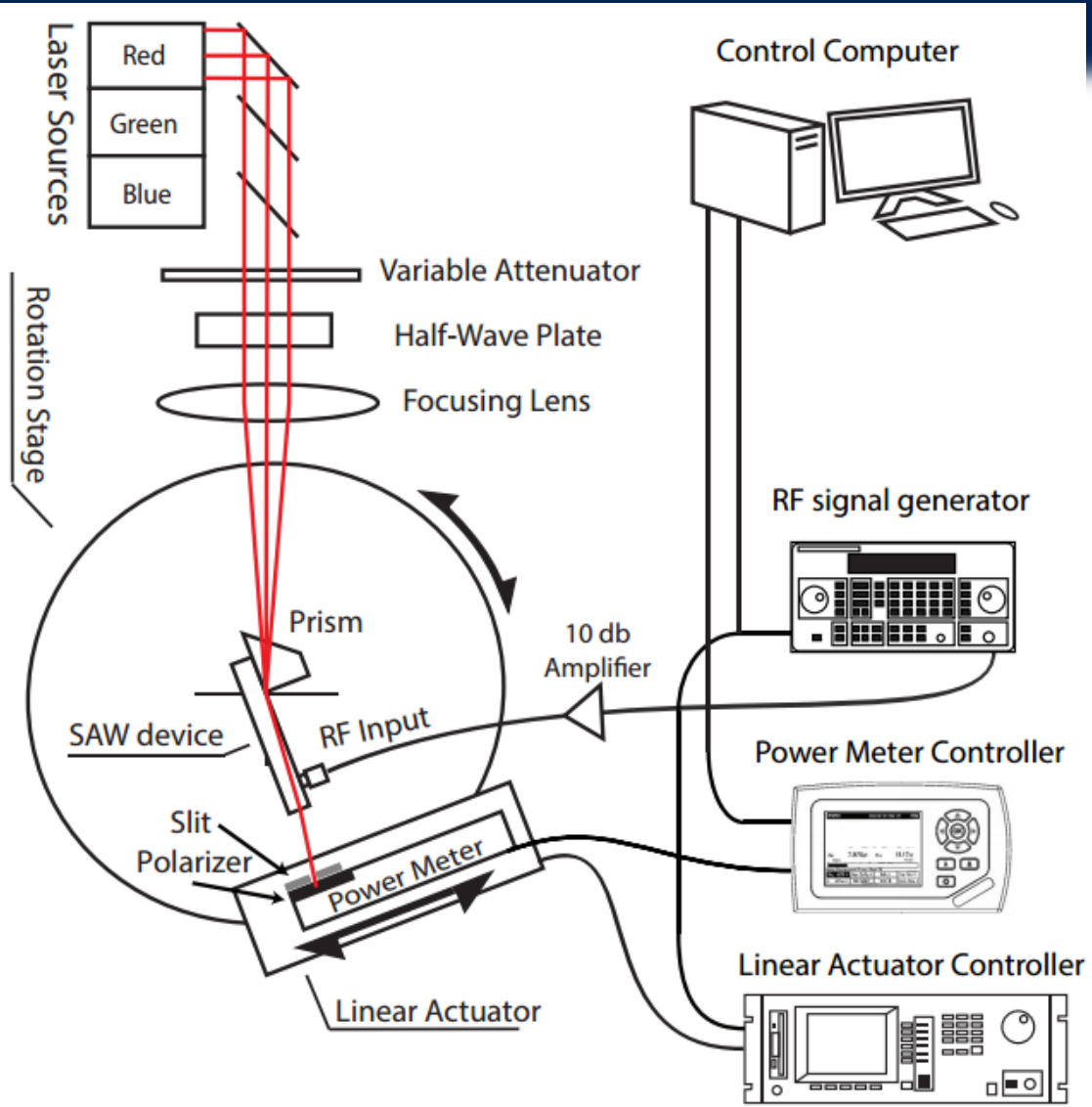
Qaderi, K., et al. Optics Express (2016)

Design and Fabrication



Qaderi, K., et al. Optics Express (2016)

Apparatus Used for Data Acquisition



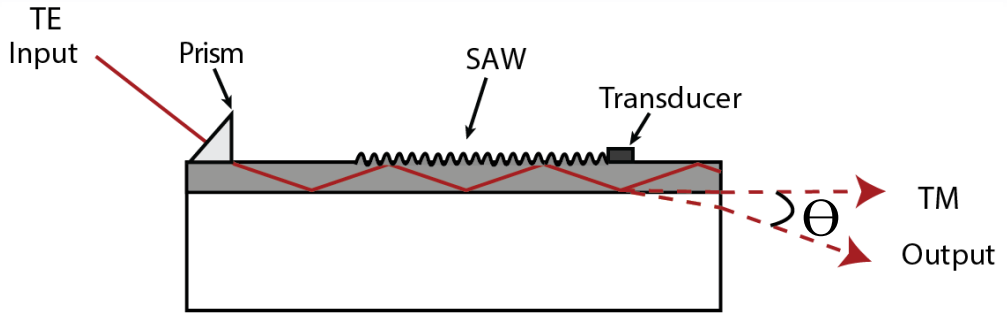
- Mount each sample in a custom, semiautomatic characterization apparatus
- Sweep the RF input
- Sample the optical output and record it
- Data analysis in Matlab
- Determine angular bandwidth

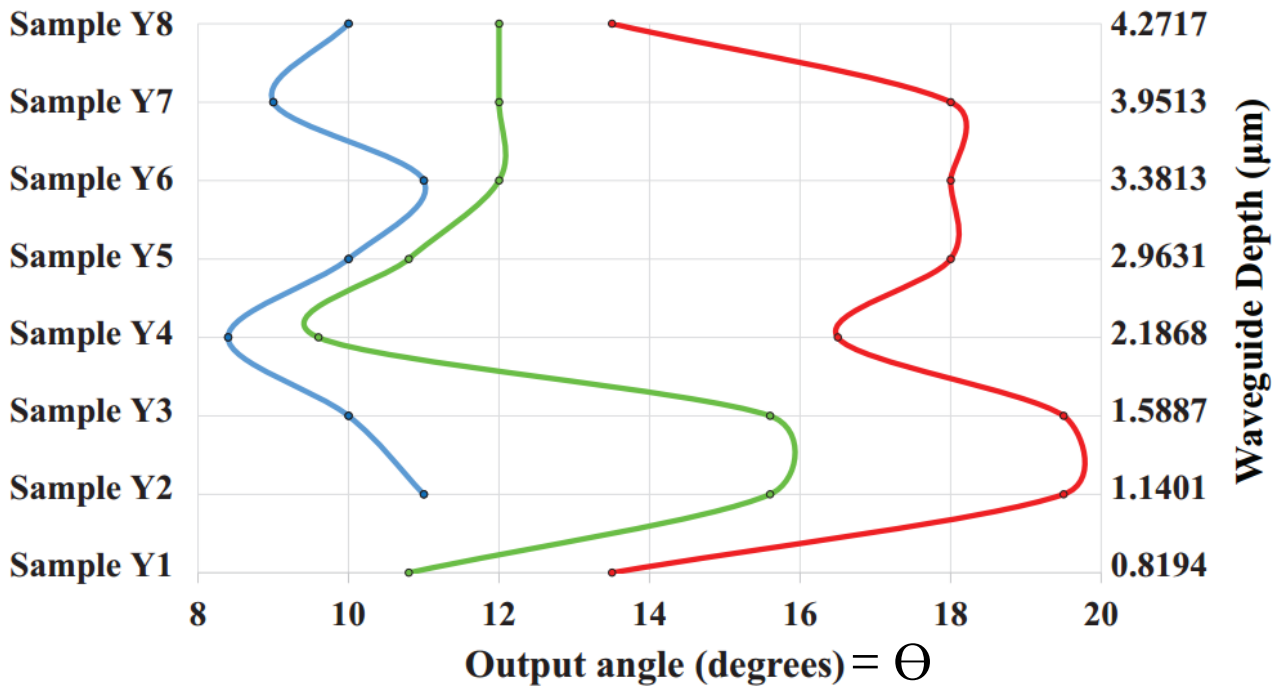
Qaderi, K., et al. Optics Express (2016)

Results

Device	Proton-Exchange Time (minutes)	Waveguide Depth (μm)	Number of TE Modes	Highest Transition from TE-Guided to TM-Leaky for Red and Green	Highest Transition from TE-Guided to TM-Leaky for Blue
Y1	12	0.8194	2	TE1	-
Y2	20	1.1401	3	TE2	TE1
Y3	45	1.5887	4	TE3	TE2
Y4	80	2.1868	5	TE4	TE3
Y5	140	2.9631	6	TE5	TE4
Y6	190	3.3813	7	TE6	TE5
Y7	260	3.9513	8	TE7	TE6
Y8	330	4.2717	9	TE8	TE7

Pure proton exchange



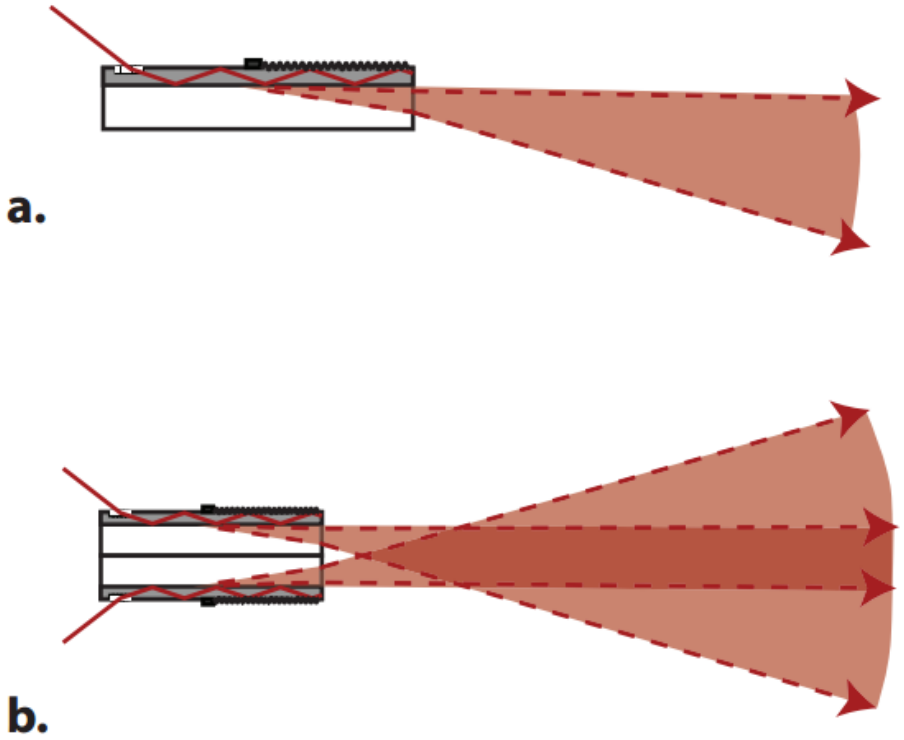


Qaderi, K., et al. Optics Express (2016)

Current and Future Projects

- ❑ Doubling deflection angle of the Waveguide Light Modulator (Sandwich device)
- ❑ Surface Plasmon Polariton (SPP)
- ❑ Reverse Proton Exchange (RPE)

Doubling Deflection Angle of Waveguide Modulators (Sandwich Device)



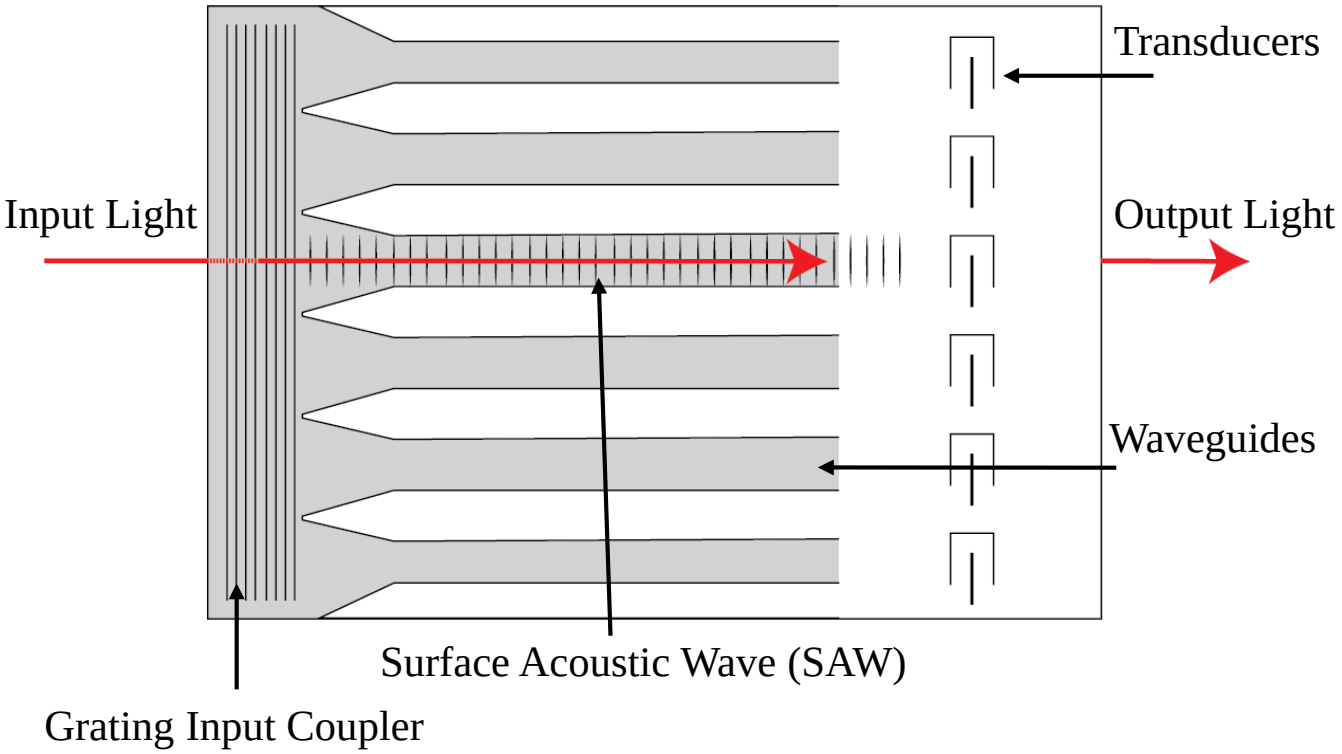
Improvements with respect to my published paper:

A. Grating Input Couplers
B. Dilute Proton Exchange
C. Doubled deflection Angle

a. Easier-to-test and cheaper devices
b. Low-loss waveguides
c. No demagnification and derotation for RGB

Qaderi, K., et al. Optics Express (2016)

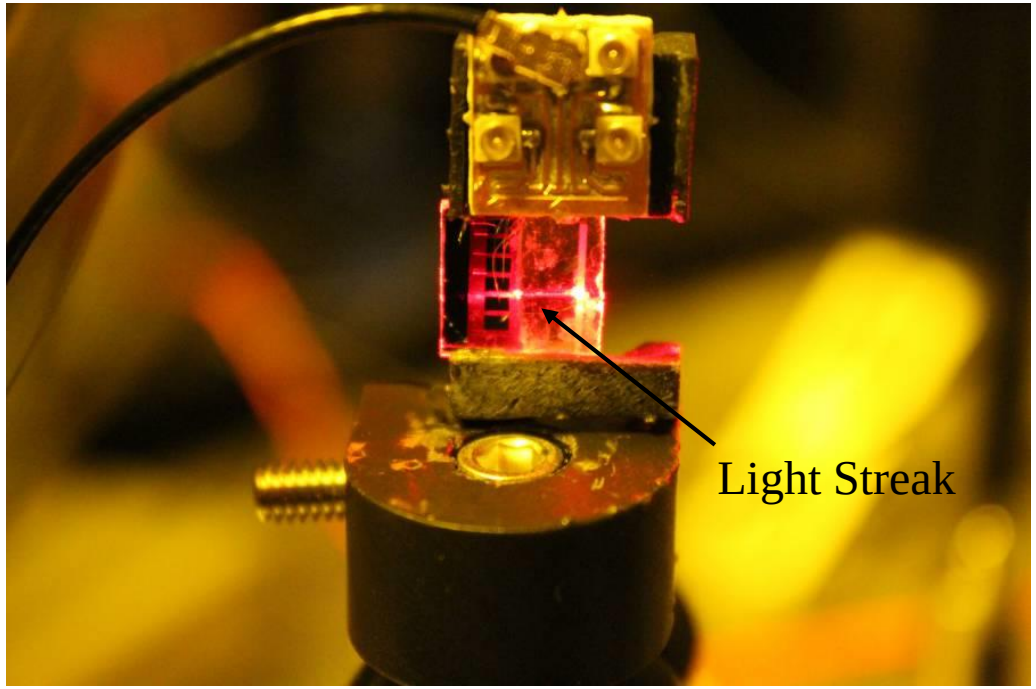
Design and Fabrication

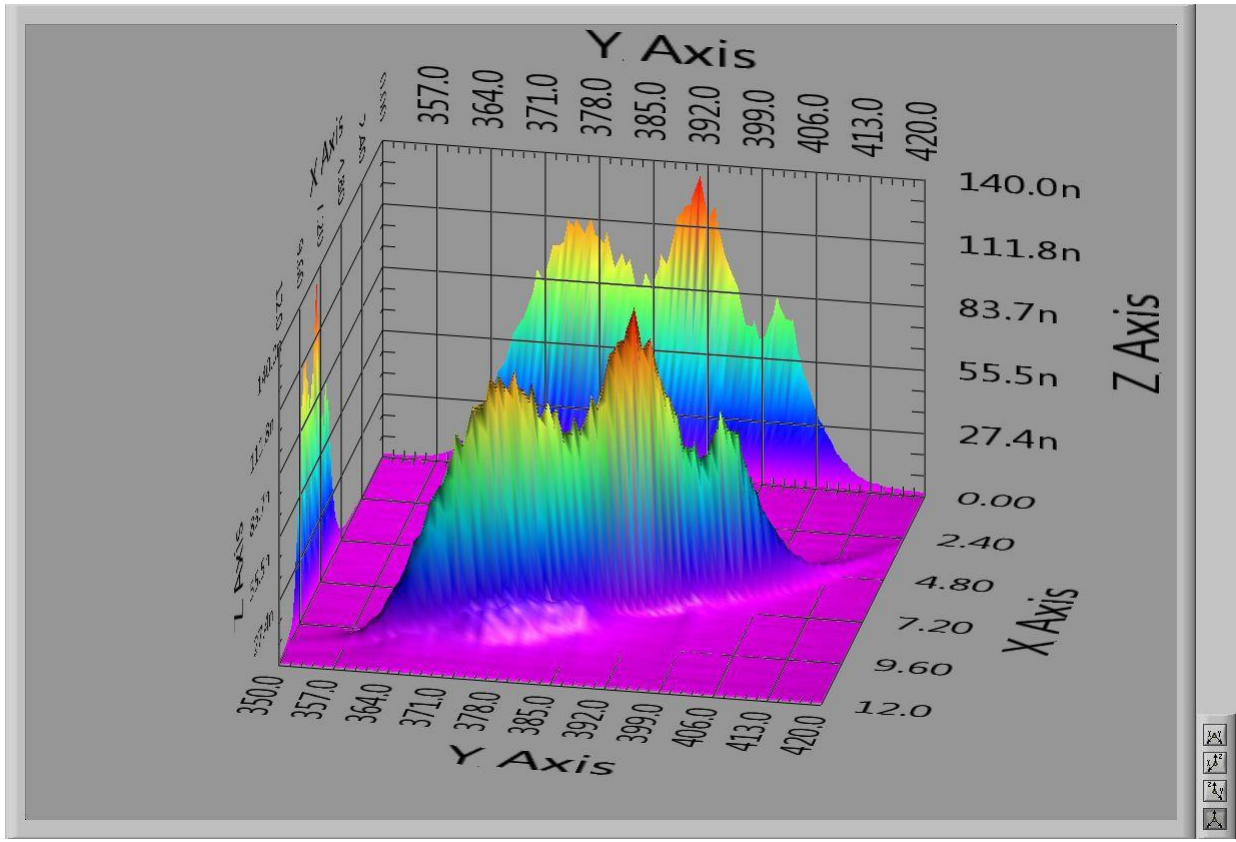


Fabrication steps:
RIE grating input couplers
Waveguides
Proton exchange
Transducers
Polish

Tests and Results

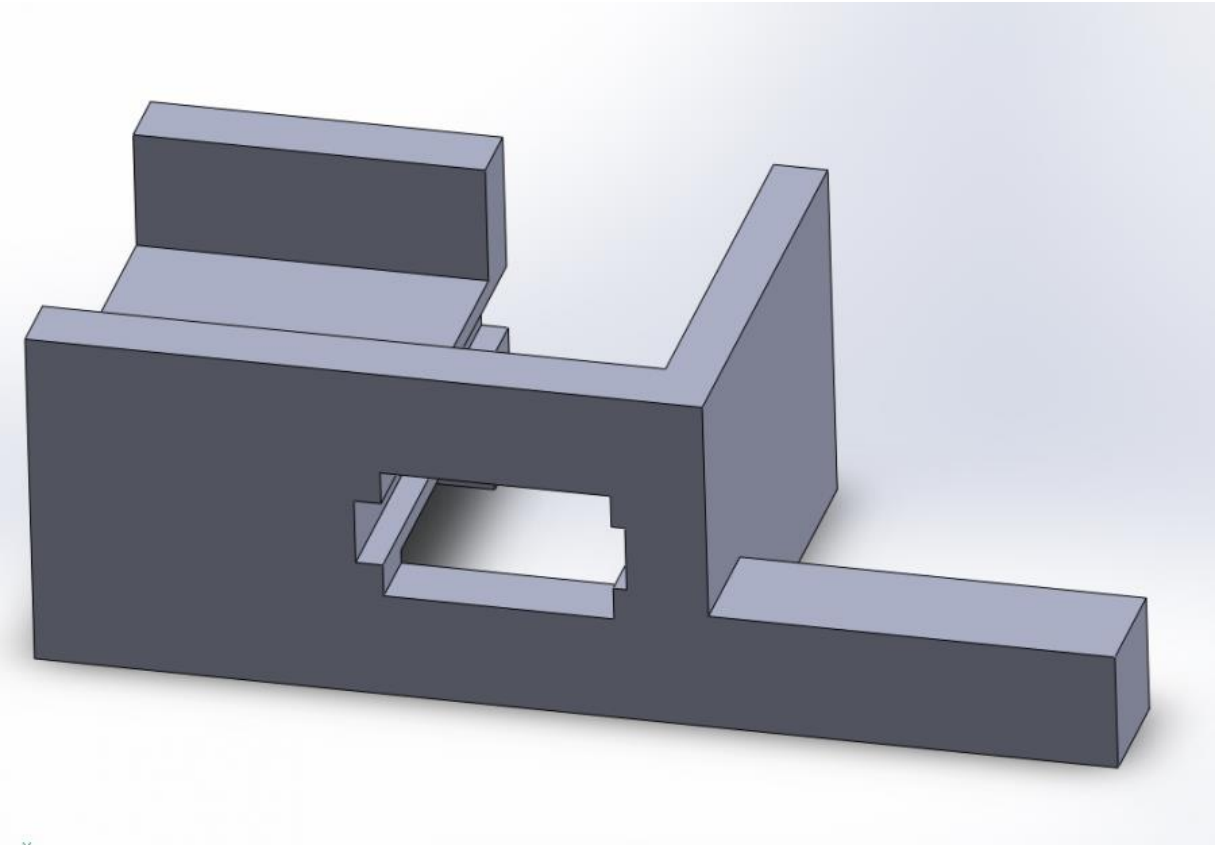
- Same apparatus used in last project
- Waveguide 2nd mode at ~40 degrees
- RF voltage applied to the IDT

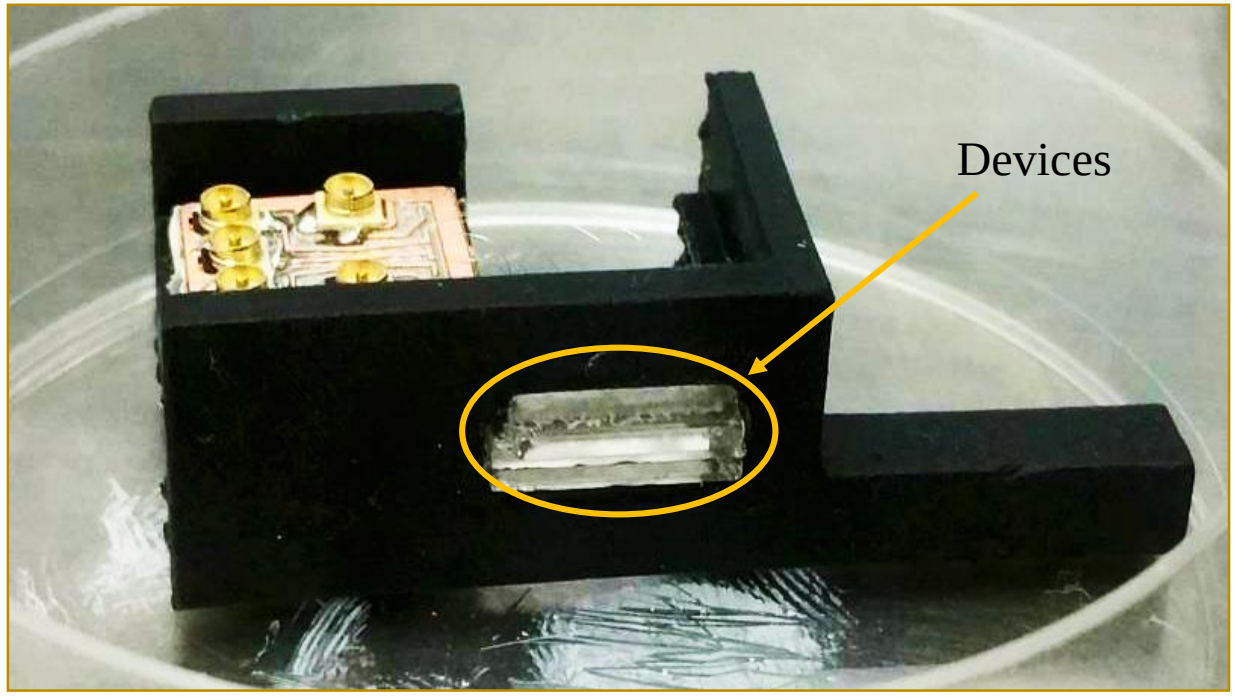




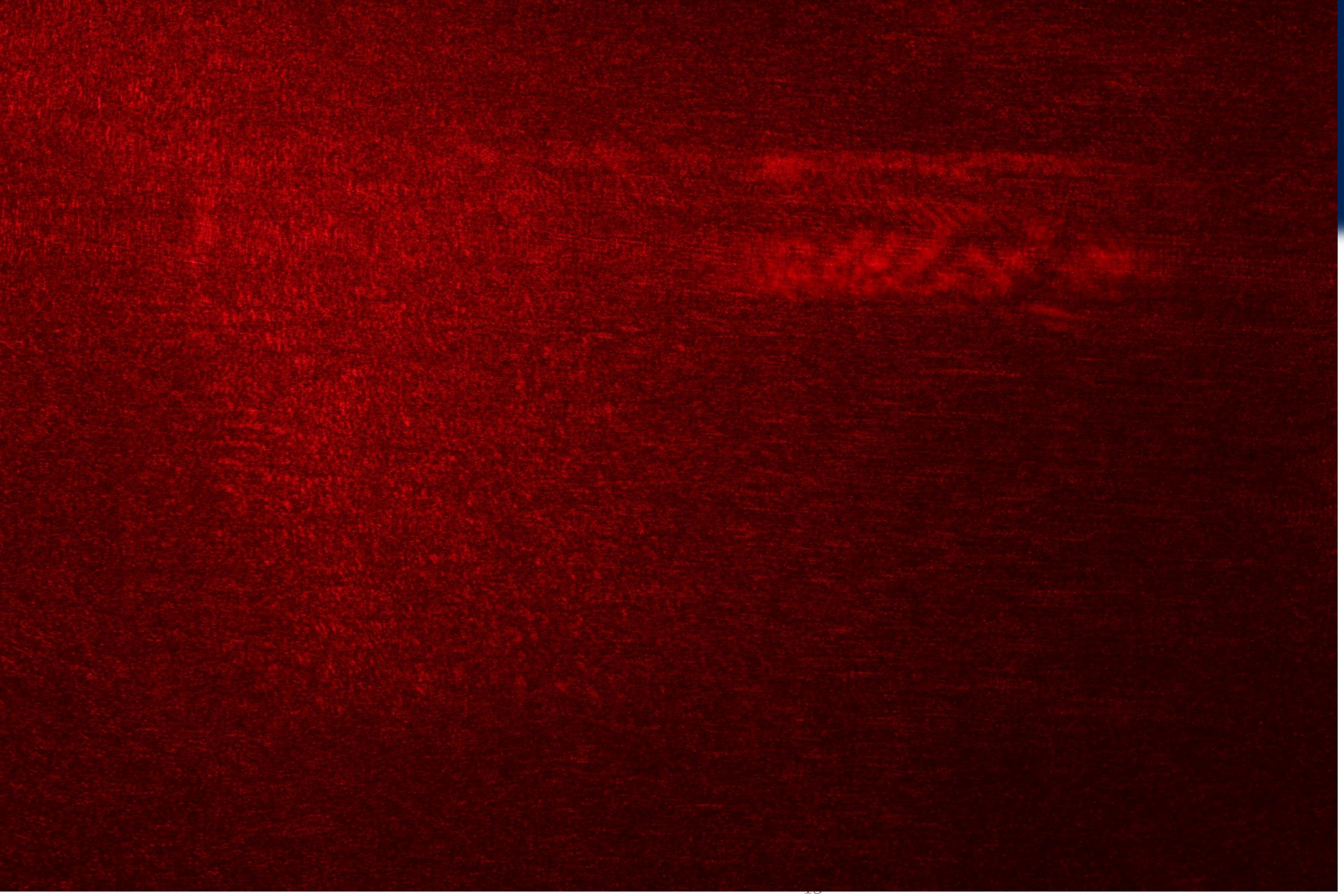
Mount and Wirebond

- Sample holder designed in SolidWorks
- 3D printed using “Formlab 1+” 3D printer



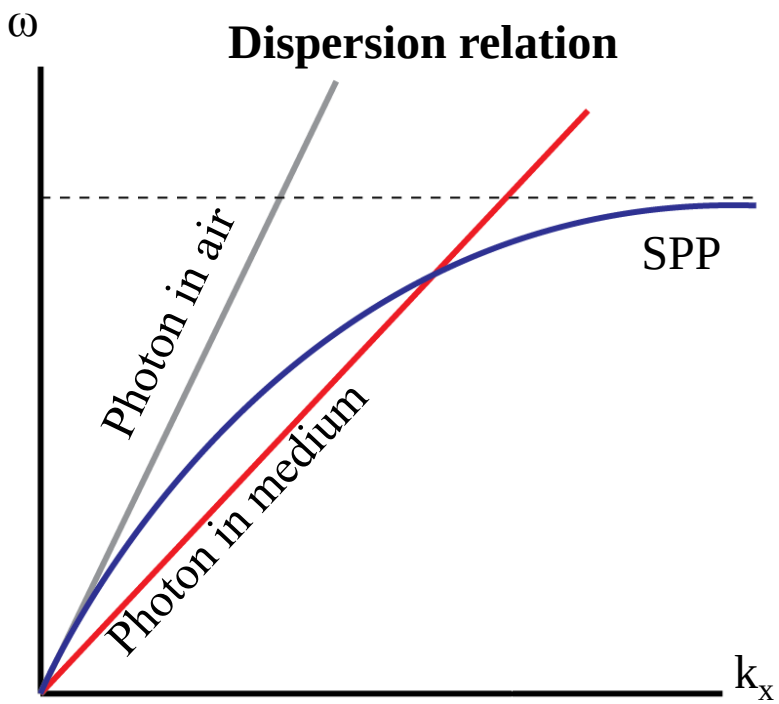


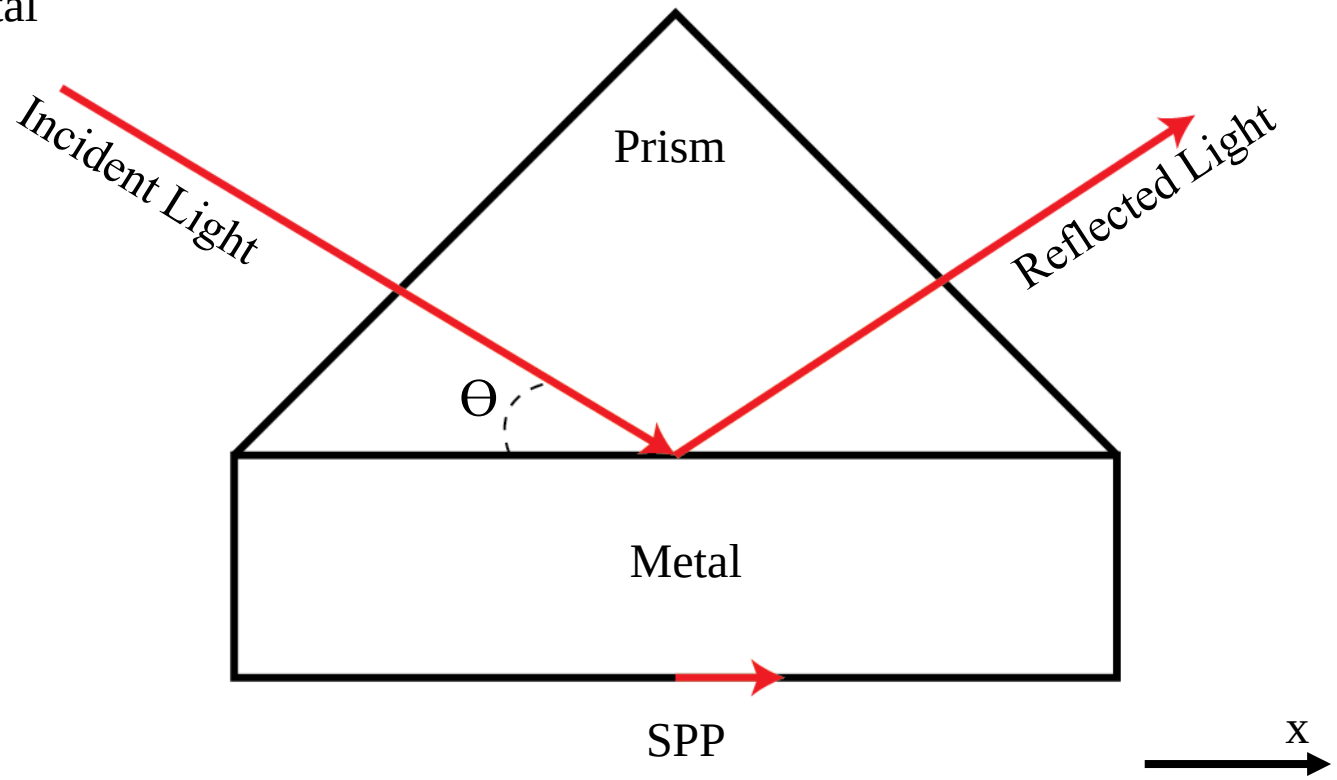
- Super-glued
- Mounted
- Wirebonded



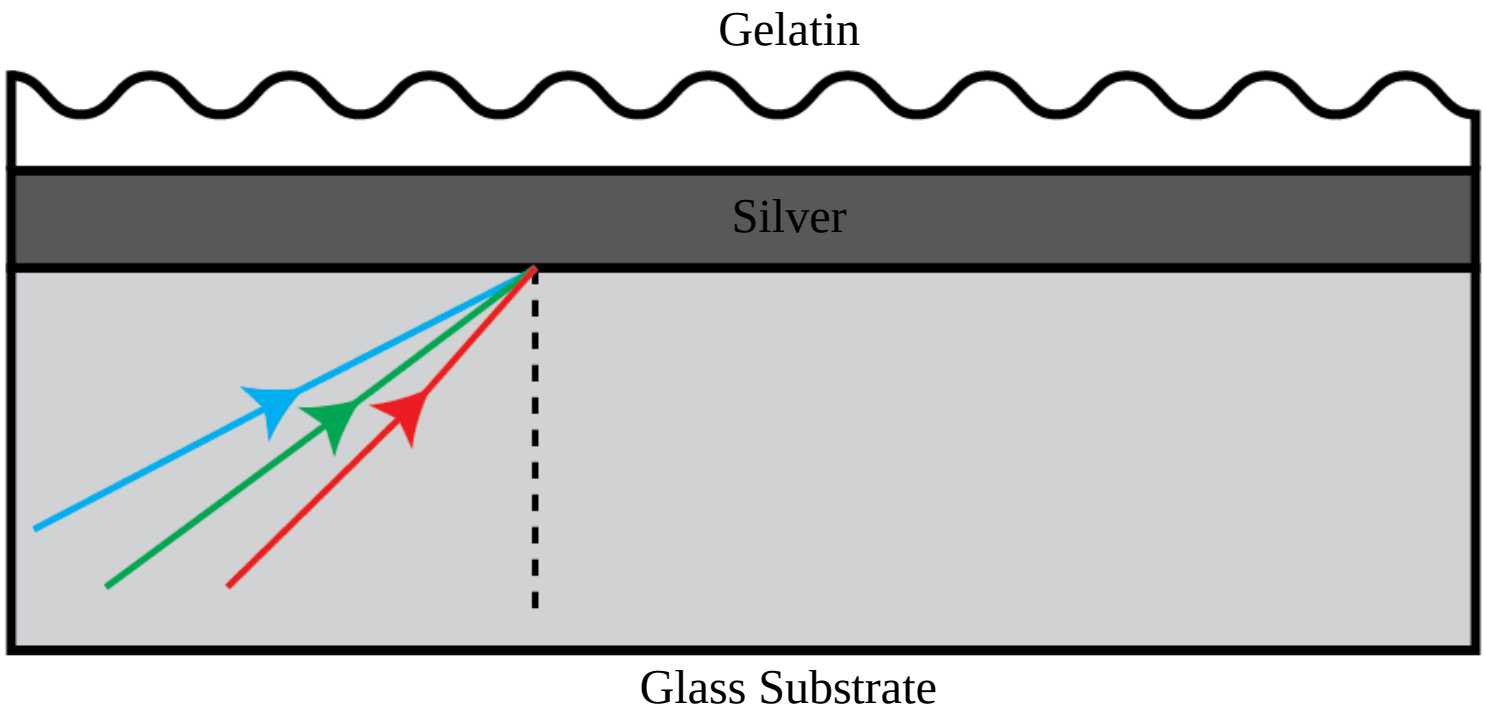
Surface Plasmon Polariton (SPP)

- Infrared or visible-frequency electromagnetic waves
- On metal-dielectric or metal-air interface
- Surface Plasmon → Charge motion in metal
- Polariton → Electromagnetic waves





White Light Illumination holograms using SPP principle

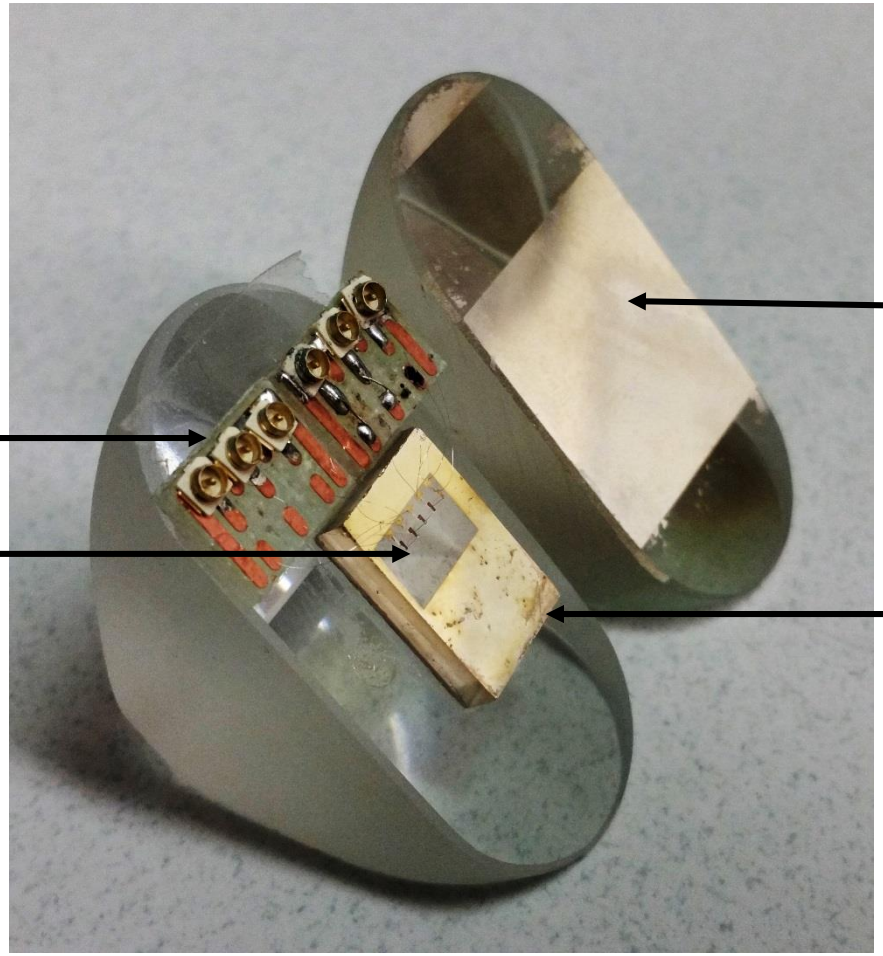


- Discovered by Satoshi Kawata group in Japan
- Different incident angles for different colors
- White light illumination
- No higher orders of diffraction

Downsides:

- Static holograms
- No video holography

My work on SPP



Silver on Prism

Breakout boards

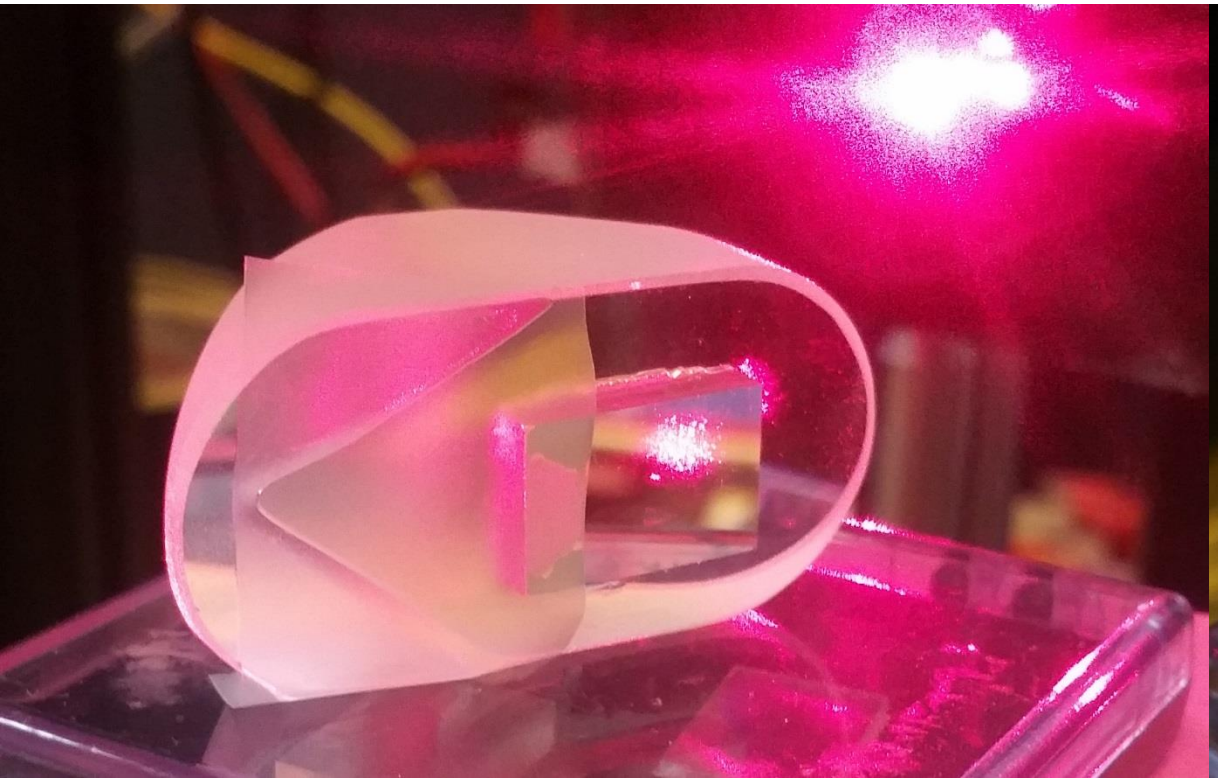
Interdigital transducers designed for 350-450 MHz

Silver on Thick lithium niobate sample

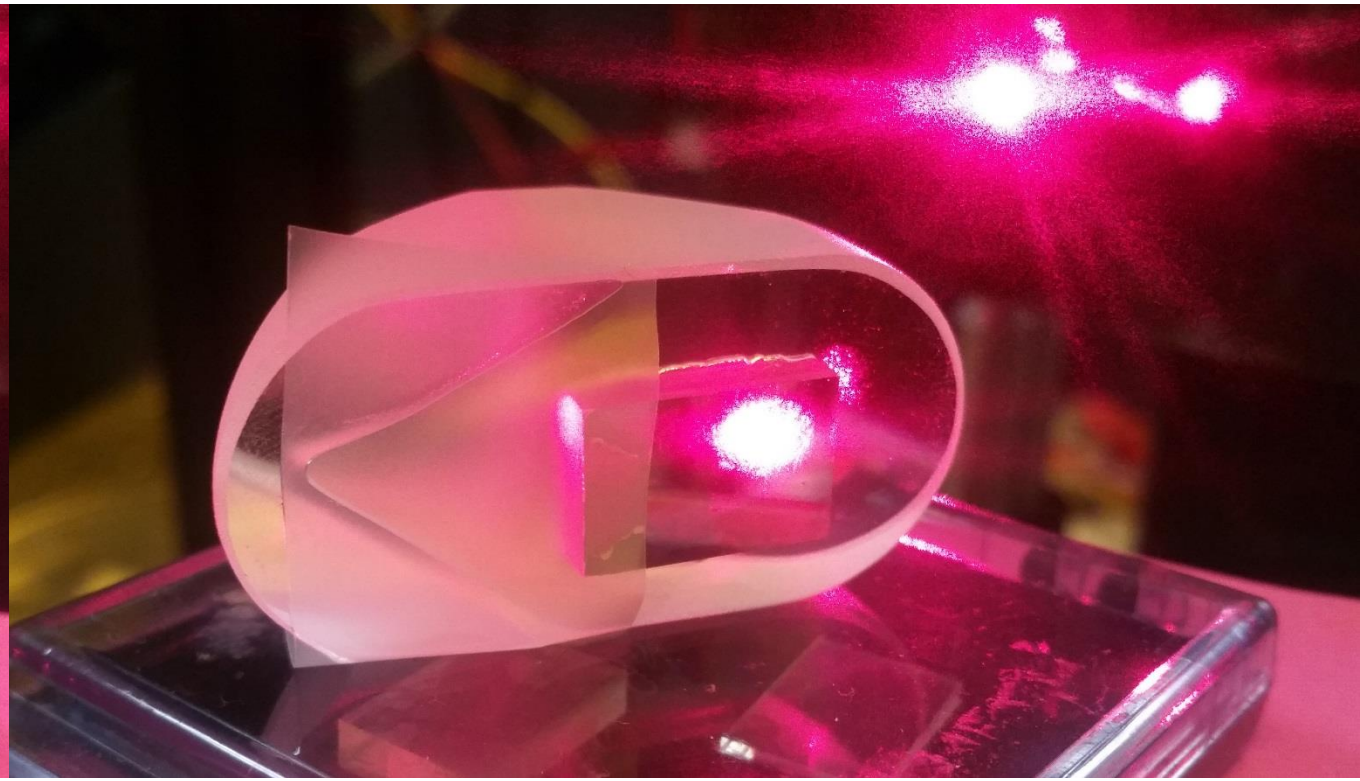
Tests and Results

- Efficient SPP up to %95 with 55 nm Silver

SPP not excited



SPP excited at ~45 degrees



Short Video of observed SPP

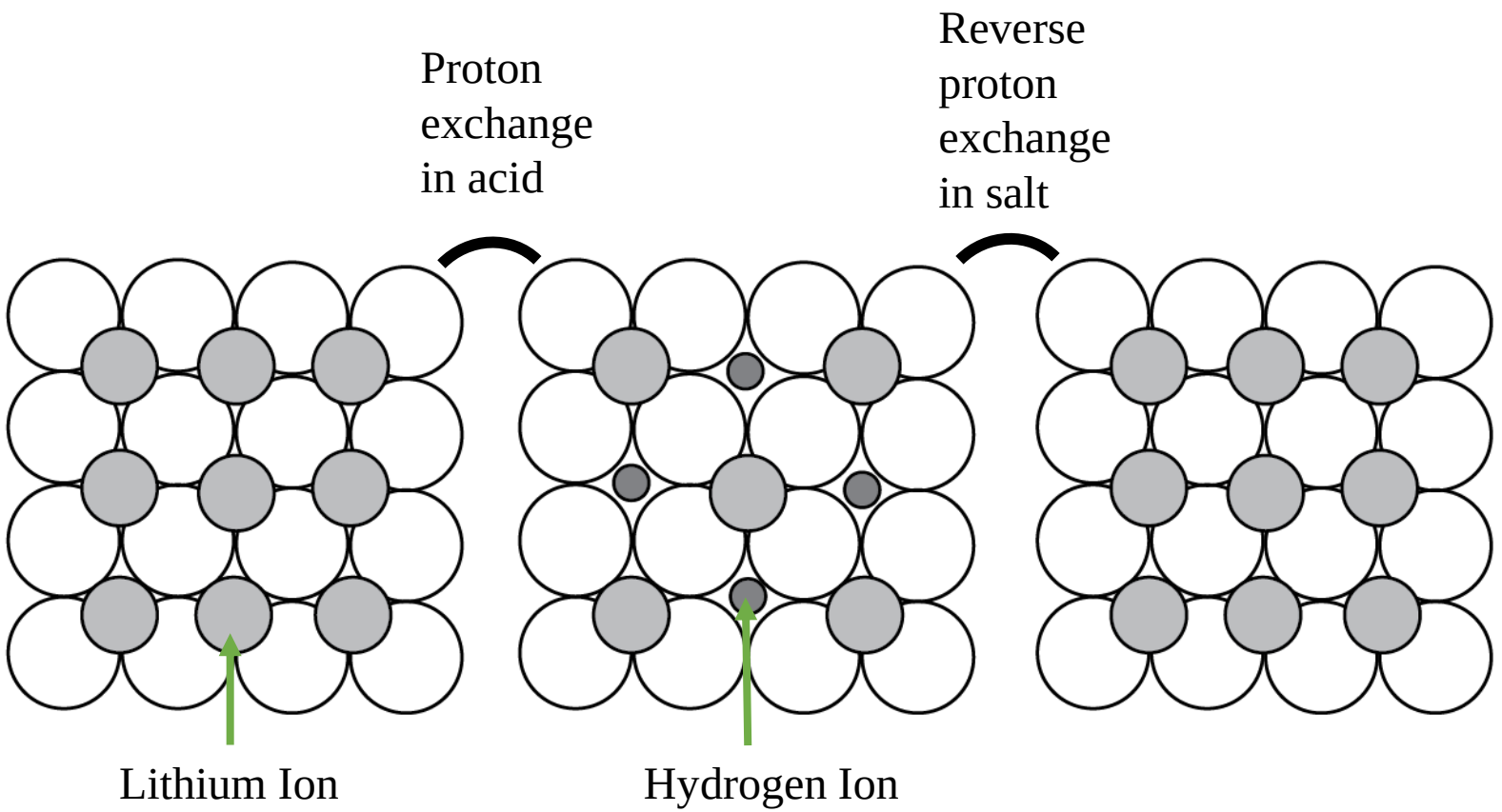
Tests and Results

- Applied RF voltage
- No diffraction observed from the SPP light
- Calculated the frequency range of the SAW using the K-diagram
- Light exits the top of the sample if the frequency range is 3-9 GHz meaning 100-300 nm resolution

Possible solutions:

- Use higher order harmonics
- Fabricate the transducers in ESEM

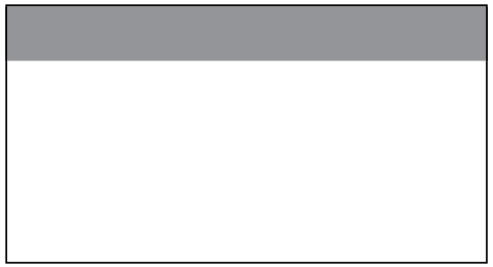
Reverse Proton Exchange (RPE)



- Surface diffusion process
- Molten acid such as benzoic acid
- $H^+ \rightarrow Li^+$
- Formation of waveguide

Work of Fedorov's Group on Second harmonic Generations

DPE



APE

RPE

Dilute proton exchange (DPE):

- Step-index profile
- Relatively lossy
- Elimination of nonlinearity effect

Annealed proton exchange (APE):

- Annealed at 375 ^{o} C
- Diffusion of protons deeper into the substrate
- Graded-index profile with maximum at the surface
- Asymmetric waveguide
- Low loss compared to DPE
- Partial recovery of the nonlinear coefficient

Reverse proton exchange (RPE):

- Removal of protons from surface
- Symmetric
- Preserved nonlinearity

Second harmonic generation by using RPE

Efficient modulators by RPEing our devices

- Better acousto-optic effect
- Better piezo-electric effect

Leading to: →

Higher diffraction efficiency than DPE and APE devices

Publications

1. Qaderi, K., & Smalley, D. E. (2016). Leaky-mode waveguide modulators with high deflection angle for use in holographic video displays. *Optics Express*, *24*(18), 20831-20841.

2. S. Gneiting, D. E. Smalley, K. Qaderi, A. Henrie, B. Haymore, S. McLaughlin, J. Kimball, C. Leach, and T. DeGraw., ”Optimizations for Robust, High-Efficiency, Waveguide-Based Holographic Video,” 14th IEEE International Conference on Industrial Informatics (Futuroscope-Poitiers, France, 2016) (in press).

3. “Levitated optomechanics for full-color, free-space volumetric display with the potential for occlusion,” 2016 (in submission)

4. “Doubling deflection angle of acousto-optics modulators using a sandwich design,” 2016 (in preparation **as first author**)

Future possible publications:

1. “Building holographic video displays using SPP light modulators,” (**as first author**)

2. “Comparison of diffraction efficiency of revers proton exchange with pure and dilute proton exchange,” (**as first author**)

Contributions

- Design and fabrication of a new AOM capable of ~20 degrees deflection. It is now being used in our new holographic displays.
- Fabricating functional SPP devices with the correct parameters.
- Observation of SPP for the first time in Dr. Smalley's group
- Mentoring Multiple Undergraduate Students