Wide-angle, Nonmechanical Beam-Steering Utilizing Liquid Crystal Polarization Grating

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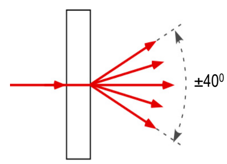
Summary & Motivation

❑ Wide-angle, Nonmechanical Beam-Steering

- light, compact and cost effective
- low loss, high-efficiency and large steered angle (±40°)

❑ Liquid Crystal Polarization Grating (LCPG)

- Electrically controlled, polarizing beam-splitter or optical switch
- Direct with ~100% diffraction efficiency into single order
- Implemented using switchable(active PG) or polymerizable(passive PG) nematic Liquid Crystal



Properties of LCPG

❑ LCPG Structure

The polarization grating (PG) with a periodically varying, in-plane uniaxial birefringence has been modeled and compared to analytic expressions

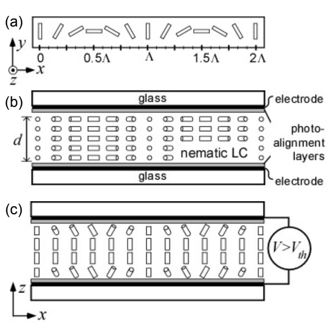
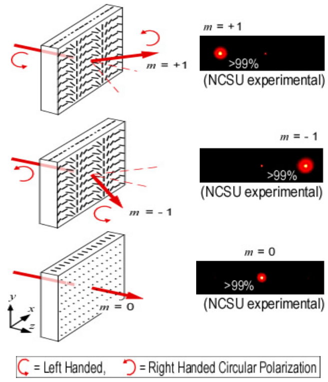


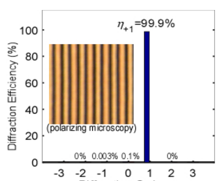
Fig: The director profile of LCPGs: (a) top-view, (b)side-view with 0V (c) side-view with V_{th}

$$\eta_0 = \cos^2\left(\frac{\pi\Delta n d}{\lambda}\right) \quad \eta_{\pm1} = \frac{1}{2}(1 \mp S_3')\sin^2\left(\frac{\pi\Delta n d}{\lambda}\right)$$

- only three (0 and ±1) orders
- ~100% efficiency possible by a thin grating
- polarization selectivity of the first orders

❑ Diffraction Efficiency





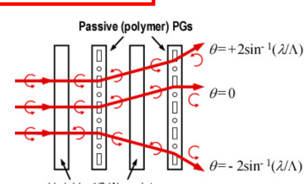
Recent experimental results of diffraction efficiency for the first order @ 1550nm

$$\eta_m = \frac{I_m}{\sum I}$$

Configuration of Single Steering Stage

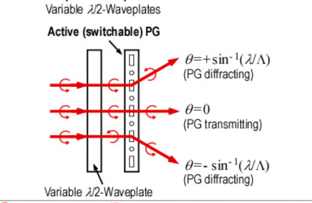
❑ Passive PG single steering stage

- Two passive PGs + two LC half-wave waveplates
- LC half-wave waveplates change the handedness of the beam (on/off states)
- Direction of beam (+θ,0,-θ) is controlled by changing the handedness of beam on passive PGs



❑ Active PG single steering stage

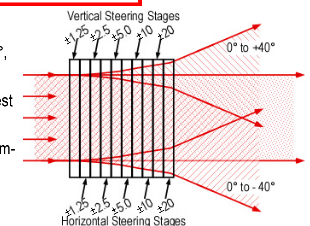
- One Active PG + one LC half-wave waveplate
- Direction of beam (+θ,-θ) depends on the handedness of the input beam on active PGs
- When voltage is applied, PG passes the light without changing angle (θ=0)



Multi-Stage Beam Steering Approach

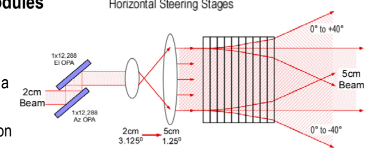
❑ Coarse steering module

- 5 azimuth and 5 elevation steering stages with 1.25°, 2.5°, 5°, 10°, 20° deflection angles
- azimuth and elevation components are interleaved with largest deflection angles at the end of the stack to reduce walk-off
- cover an 80° x 80° field of regard in 1.25° steps with a random-access rate of <10ms



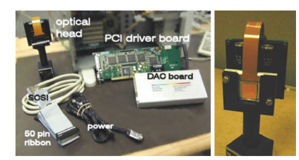
❑ Integration of coarse and fine steering modules

- fine angle module steers over a ±3.125° range in azimuth & elevation
- steering angle is reduced as expanding the beam by a factor of 2.5
- Total system can steer ±40° with fine angle resolution



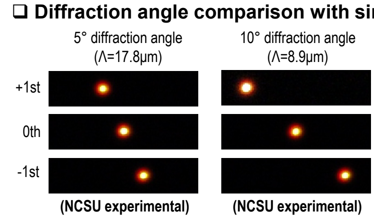
❑ Fine steering module

- 1 x 12,228 OPA system having a 2cm x 2cm aperture
- Two liquid crystal on silicon OPAs are integrated to operate as a 2D fine angle scanner
- ~80% steering efficiency (90% efficiency is possible)



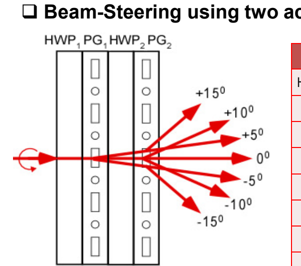
Beam Steering Experiments

❑ Diffraction angle comparison with single PG



- Diffraction patterns for different grating period of PGs with maximum applied voltage of 10V
- Diffraction angle: $\theta_m = \sin^{-1}(m\lambda / \Lambda)$
  λ: applied beam wavelength (1550nm)
  Λ: grating period of PGs
- **Throughput from single PG: >90%**

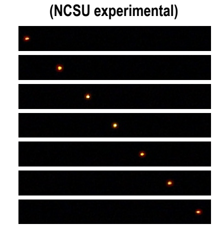
❑ Beam-Steering using two active PG stages



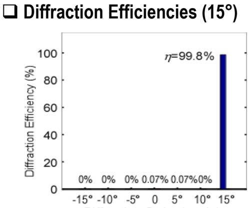
HWP: Variable half-Waveplate
PG: Polarization Grating(switchable)

Applied voltage (10V)				Diff. angle
HWP_1	PG_1	HWP_2	PG_2	
on	off	off	off	+15°
on	on	on	off	+10°
on	off	on	on	+5°
on	on	on	on	0°
off	off	on	on	-5°
on	on	off	off	-10°
off	off	off	off	- 15°

Diffraction Patterns (NCSU experimental)



❑ Diffraction Efficiencies (15°)



Expected throughput (2D 80° x 80° Beam-Steering in 1.25° steps)

	Passive module (20 PG + 20 HWP)	Active module (10 PG + 20 HWP)
Steering loss	10 stages@1%per=10%	10 stages@1%per=10%
Fresnel loss	40 components@0.1%per=4%	20 components@0.1%per=2%
Absorption (ITO)	40 layers@<1%per=24%	40 layers@<1%per=24%
Scattering	10 stages@0.5%per=5%	10 stages@0.5%per=5%
Overall throughput	~ 62%	~ 64%

Conclusions and Further Works

- We experimentally demonstrated multi-stage beam steerer based on polarization gratings with very high diffraction efficiencies (>99%) over the communication range (1500nm)
- Our approach can cover 80°x80° beam steering in 1.25° steps with >60% overall throughput
- Using the optimized glasses (index matched and low ITO absorption <0.1%) are used, the total throughput will increases to >80%
- Hybrid (HWP+APG) grating approach will be implemented to reduce the number of layers

❑ References

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