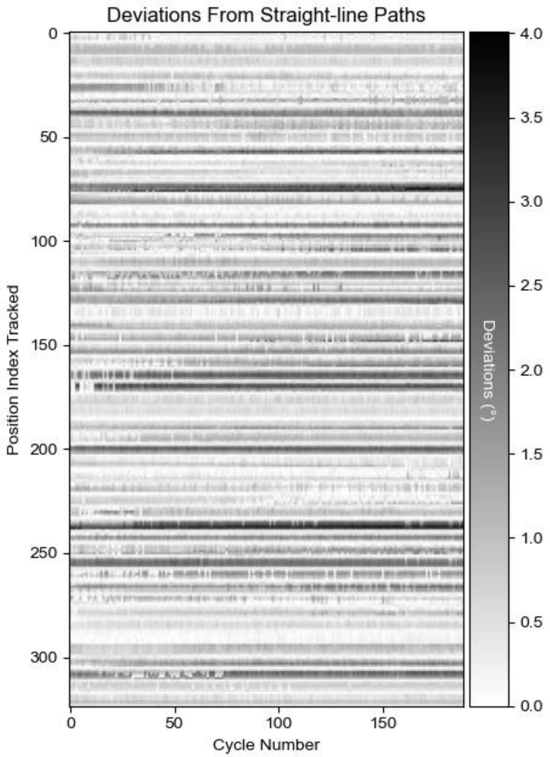
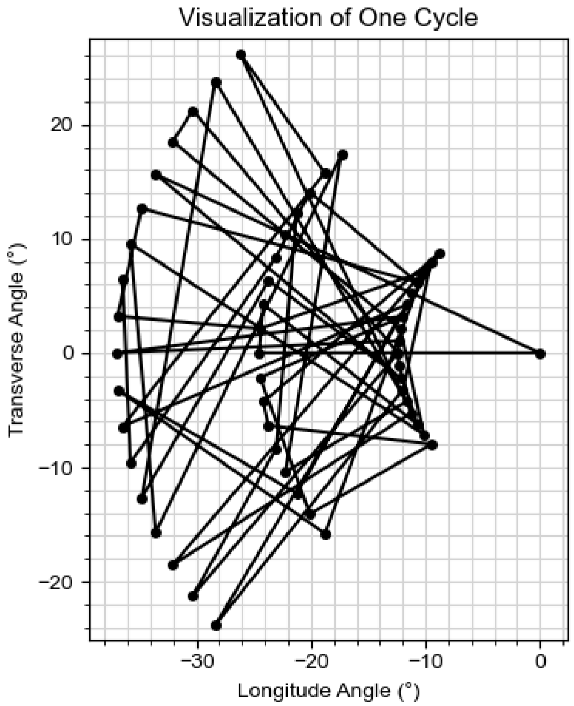
Lossless beam-width adjustment with low cost mechanics





Glint Photonics, Inc.
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DE-SC0021670

Project Summary

Objective and outcome

How light is used is becoming more important than how its generated. Solid-state lighting creates a unique opportunity to achieve revolutionary new features in lighting such as lossless beam width, shape, and steering adjustments. This program brings together experts in compliant mechanisms, illumination optics, and additive manufacturing to unlock the true potential of solid-state lighting.

Team and Partners

Glint Photonics, Inc.

Stats

Performance Period: 06/28/2021 – 08/21/2024

DOE budget: $1,350k, Cost Share: $0k

Milestone 1: Beam Shape Tuning Demonstration

Milestone 2: Cost reduction of compliant mechanism

Milestone 3: Optical performance of compliant mechanism

Problem

- Achieving continuing, substantive reductions in lighting energy use will require us to look beyond "lumens per watt" and consider "lumens per where, lumens per when, and lumens per why".
- How we use the light we generate has increasingly become more important than how we generate it.
- The problem is that traditional light sources are static, difficult to adjust, and provide a small selection of light distributions. These legacy fixtures can only provide the correct lighting a fraction of the time at best, sometimes not at all.
- DOE researchers estimate that tuning lighting to the environment can **increase light utilization efficiency by 2x to 3x**. [1] We estimate this opportunity at **a savings of up to 19.4 TWh of electricity use annually**.
- The solution will require an entirely new class of luminaires designed from the ground up to meet the complex and often dynamic lighting requirements of the real world, putting the right light, in the right place, at the right time, and at an affordable price.
- **Developing these highly capable next generation light fixtures and the enabling technologies behind them is Glint's core mission.**

[1] J. Y. Tsao, M. H. Crawford, M. E. Coltrin, A. J. Fischer, D. D. Koleske, G. S. Subramania, G. T. Wang, J. J. Wierer and R. F. Karlicek, "Toward Smart and Ultra-effi cient Solid-State Lighting," Advanced Optical Materials, vol. 2, pp. 809-836, 2014.

Alignment and Impact – Energy Benefits

Glint Photonics intends to dramatically reduce the cost and complexity of implementing well-designed lighting installations, with significant environmental benefits in reduced energy and materials consumption.

Energy savings benefits include:

- **Electricity savings in operation** - We estimate that 30% of the 216 TWh commercial/residential lighting market is addressable by directional LightShift products, and that a 30% reduction in lighting energy use is possible with improved light utilization. This corresponds to a savings of 19.4 TWh, 6.3 million metric tons of CO_2 emissions, and $2.5B per year.
- **Reduced number of installed luminaires**. Solid-state lighting systems reimagined to reduce the number of luminaires needed would directly reduce the cost of hardware, packaging, installation, and commissioning.
- **Reduced waste in manufacturing of luminaires.** An adjustable lighting system that can service a wide range of application needs and take advantage of short lead-time, low cost, and no NRE production enabled by 3D printing would greatly reduce the energy and materials intensity of luminaire manufacturing.

We define success as demonstrating three revolutionary technologies in market ready implementations.

Alignment and Impact - Human Benefits

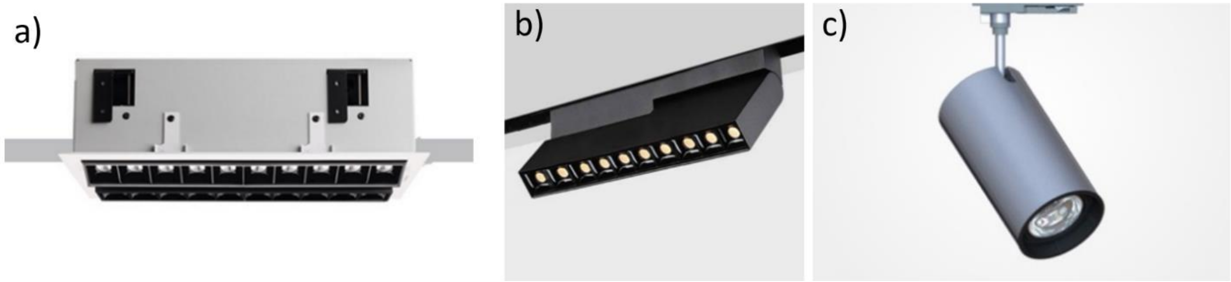
Humans are highly visual creatures, so lighting is a critical part of human experience with deep impacts on productivity, safety, and well-being. Expected societal benefits of the LightShift platform include:

- **Reduced glare.** Low glare directional fixtures can replace ambient lighting in many use cases, dramatically reducing unpleasant and dangerous glare that is now ubiquitous in most lit areas. Luminaires based on LightShift technology are inherently low-glare.
- **Improved lighting outcomes.** Directional fixtures with easily adjustable aiming and beam width will meet each application's unique requirements with more optimal lighting, which provides substantial benefits to productivity, safety, learning, and well-being. Lowering the cost of such fixtures will dramatically increase their penetration into the market.
- **More US manufacturing**. As much of the lighting industry moves to lowest-cost overseas manufacturing of standardized fixtures, the ability to quickly 3D print complex mechanisms as single parts provides a compelling opportunity for high-value and low-cost lighting manufacturing that is resistant to offshoring pressures with a more resilient supply chain.
- **Improved equity in access to good lighting.** By reducing the cost and complexity of obtaining well-designed lighting, these fixtures can help democratize its benefits. The cost of lighting design itself may be reduced by having fixtures that can be easily adapted to meet the needs of many spaces. Good lighting improves wellness and safety, which are critical to all communities.

Approach – Current Solutions and Drawbacks

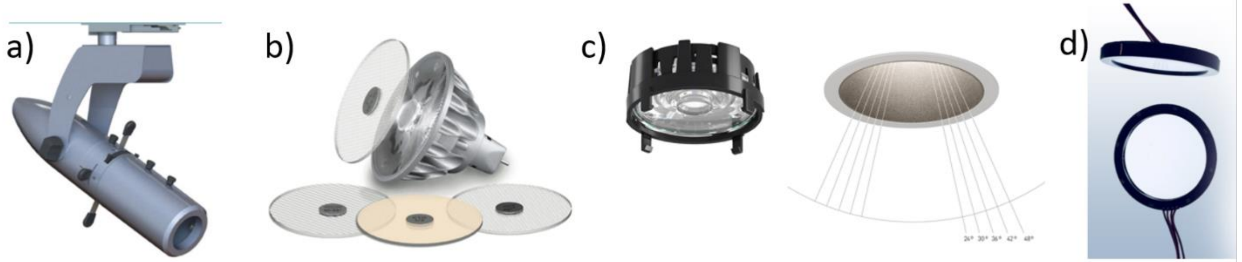
- Existing beam aiming techniques rely on one or two nested gimbals, and require the entire fixture to move to change the direction of the output beam
- Existing beam width/shape adjustments require either replacing the optics, multi-element projector lens systems, or complex LCD beam diffusers. All these systems suffer from some combination of high cost, poor efficiency, poor beam shape, and difficult operation.
- A small niche of motorized fixtures exist, but all rely on motorized gimbals, which must bear significant load and create distracting movement and noise when adjusted
- Glint's unique optical technology allows all these problems to be addressed to allow for a true next generation of lighting fixtures

Examples of beam aiming adjustment



iGuzzini LaserBlade recessed linear fixture (a), BOSCO ME600 tilting track light (b), LSI Lumilex 2044 track light (c)

Examples of beam shape/width adjustment



LSI BPM projector fixture (a), Soraa Snap System diffusers and color modifier accessories (b), Lucifer Atomos click-zoom optic (c), LensVector beam modifier (d)

Examples of remotely adjustable fixtures

Forma Lighting Motolux (a), Minibea Saliot (b), RCL track light (c), RCL recessed light (d)

Approach – Technology Intersection

LightShift Optics

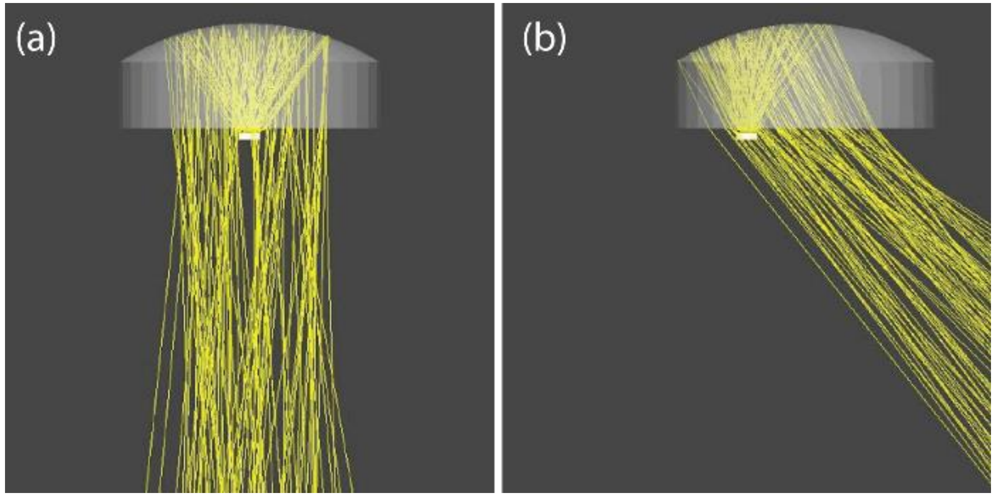
- Millimeter scale planar motions of lens/reflector relative to LED shifts light output angle
- Arrayed optics and emitters can create complex ensemble effects such as beam broadening and beam shaping
- **Requires precise control over position and alignment of LEDs and optics**

Compliant Mechanisms

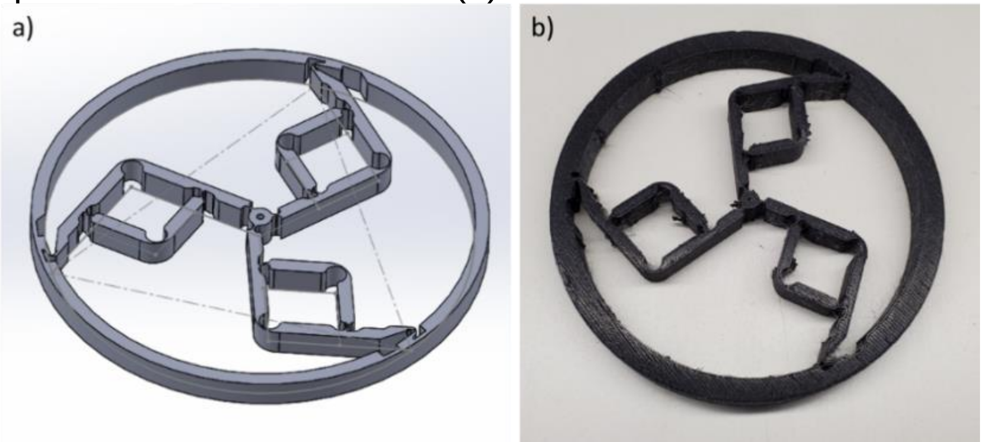
- Replace traditional rigid linkage and joint mechanics with flexible structures
- Can allow complex motion constraints with low cost and low part count
- **Requires complex iterative design process**

3D Printing

- Modern filament printers can print tight tolerance functional parts in a wide variety of materials
- **New printing materials and technologies have made rapid prototyping of compliant mechanisms possible**



Centered optic produces normal beamlet (a), offset optic produces steered beamlet (b).



Tri-pantograph design for in-plane translation with rotation constraint. Each element can be tuned to adjust the motion. Design (a) and 3D printed part (b).

Approach – Program Plan Overview

Achieving the highest efficiency and light utilization with directional lighting requires independent and remote control of not only beam direction and brightness, but also beam size and ideally beam shape. To achieve Glint's vision of a new generation of highly functional luminaires we have designed this research program to tackle the three biggest barriers to market adoption:

- **Functionality** – Compact and high brightness LEDs permit new levels of optical control thanks to their low etendue, and advances in optical design software and injection molding have enabled sophisticated optical forms to be produced at low cost. Adding beam width and shape adjustment to Glint's existing LightShift beam steering will add unprecedented functionality, allowing the light source to adapt to any lighting requirement.
- **Cost** – Glint's LightShift technology requires sub-100μm registry while being adjusted. Traditional precision kinematic mechanisms are high cost and complex to assemble. **What is needed are lab-grade kinematics for the cost of a toy.** Compliant mechanisms offer this opportunity by condensing an expensive multipart kinematic system into a single part with an ensemble of flexures that permit motion and apply constraints. Glint is developing novel compliant mechanism motion systems that allow new functionalities to be added while <u>reducing</u> cost.
- **Reliability** – The key challenges for adoption of motorized fixtures are cost and reliability. Glint has a unique advantage since instead of moving the entire mass of the luminaire, only the lightweight plastic optics package needs to be moved. Glint is developing and testing motorized fixtured to prove their reliability greatly exceeds traditional motorized fixtures, while also being lower cost.

Approach – Barriers, Challenges, and Risks

Barriers:

- Lighting market can be slow moving towards new technologies
  - Mitigated with customer engagement and in-depth market surveys
- Smart lighting ecosystem is fractured
  - Working with key industry players to keep them aware of our technology

Project Risks

- Optic injection mold fidelity
  - Mitigated by working with established supply chain
- Motor and electronics supply chain
  - Mitigated by moving designs to common source parts used across many industries

Technical challenges

- Optical design complexity
  - Mitigated by taking multiple simultaneous approaches to the problem
- Compliant mechanism design complexity
  - Mitigated by applying Freedom and Constraints Topological method for mechanism design
- Compliant mechanism prototyping
  - Mitigated by developing in-house 3D printing technology that allows high fidelity prototypes of compliant mechanisms
- Motorization requires 4 independent axes of control
  - Mitigated by development of static motor mounting linkage system
  - Mitigated by developing motor controllers based on commodity parts

Approach

Recommendation: 5-6 slides

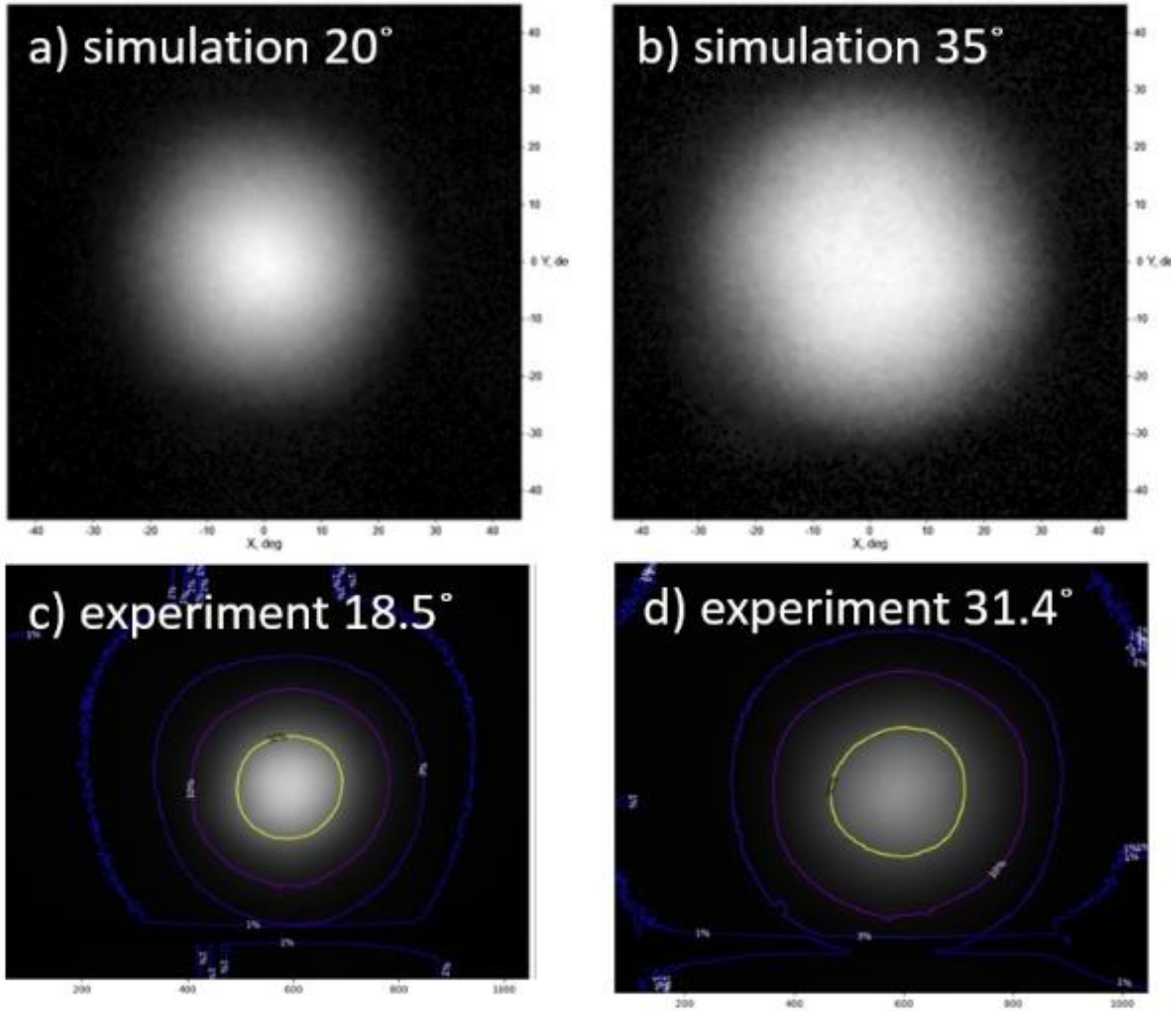
- Glint is planning to introduce the technologies developed in this program directly into its existing commercial sales channels, as well as licensing the technology to other lighting companies to allow broad industry impact.
- Glint’s award-winning Hero lighting fixture is a high-performance specification-grade adjustable spotlight. The fixture uses novel LightShift optics to enable adjustable beam pointing from a stationary luminaire, a first in the industry. Hero has won a wide array of industry awards for design and technology
- Glint has a nationwide network of sales agencies that represent it’s products, and plans to introduce these new technologies for market feedback this calendar year
- We plan to work with lighting design firms to explore the benefits that these new functionalities will provide

Design and lighting awards won by the Hero luminaire incorporating LightShift technology.

Map of contracted sales agents for Glint Lighting products.

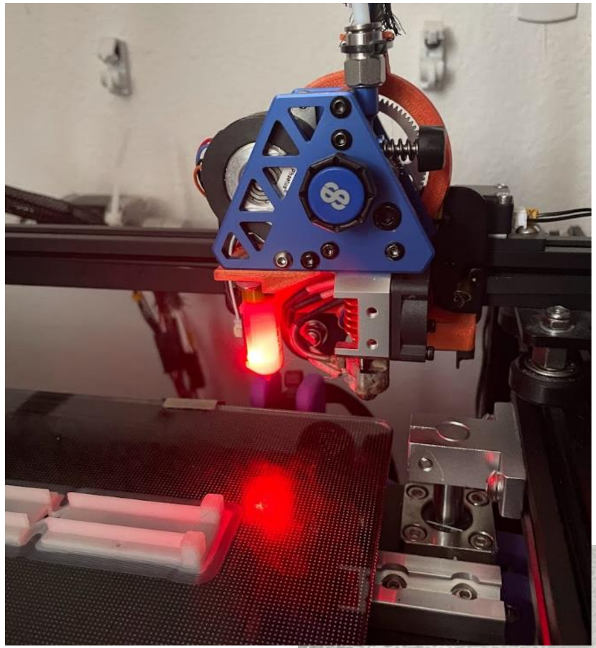
Progress and Future Work –Beam Width Adjustment

- During this program Glint developed a novel beam width adjustment technique.
- This technique was refined with optical simulations and could provide a beam adjustment from FWHM of 20° to 35°
- Injection molded lenses based on this design were manufactured and tested at Glint's in-house photometry lab
- Experimental results match simulation well, but some discrepancy was present, and Glint performed a detailed investigation
- It was found that specific details of the injection mold tooling process were interfering with the desired optical effect
- Glint re-designed the optic to account for these factors and is in the process of generating new parts



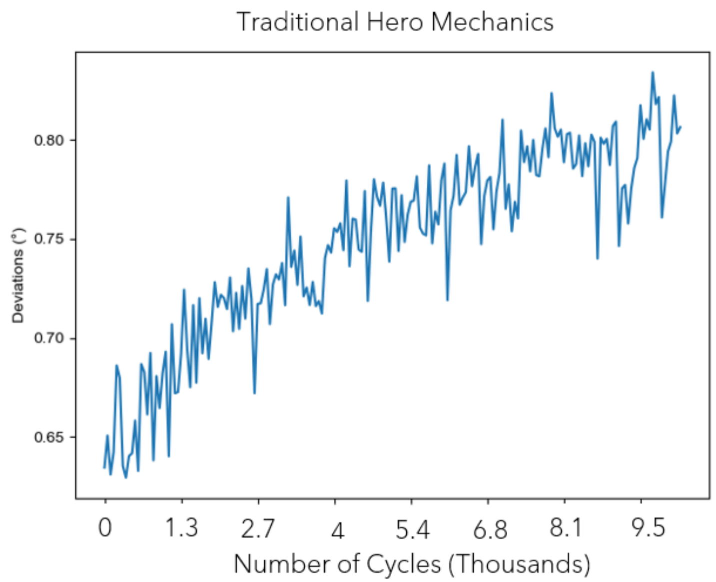
Progress and Future Work – In-House 3D Printing

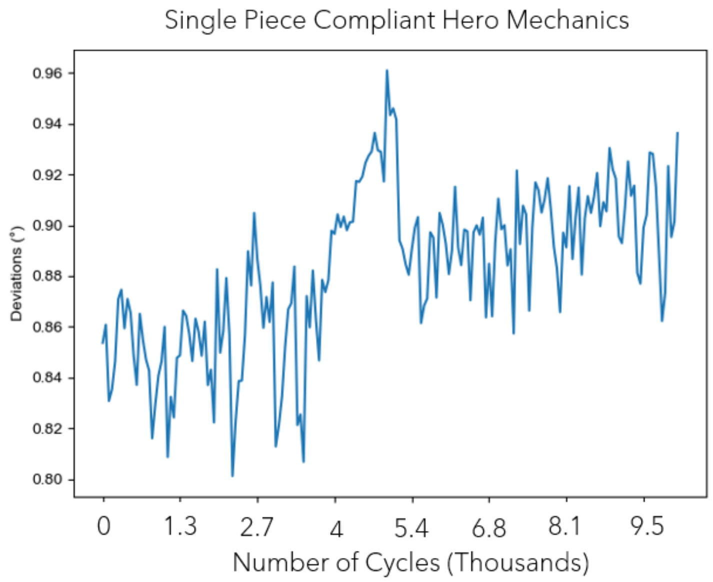
- The development of compliant mechanisms requires significant investment in prototyping
- Glint pursued several 3D printing technologies from available services
- We found that these services do not have the fidelity, consistency, or lead time to make development efficient
- In-house printing has proven to be a critical resource in development of compliant mechanisms
- Control over how solid files are prepared to print is key to achieving good performance
- The precision and low cost of FDM printed parts creates an opportunity to use 3D printing in production
- Glint has developed expertise in printing with Polypropylene filament to allow for fully functional prototypes to be printed in a few hours



Progress and Future Work - Accomplishments

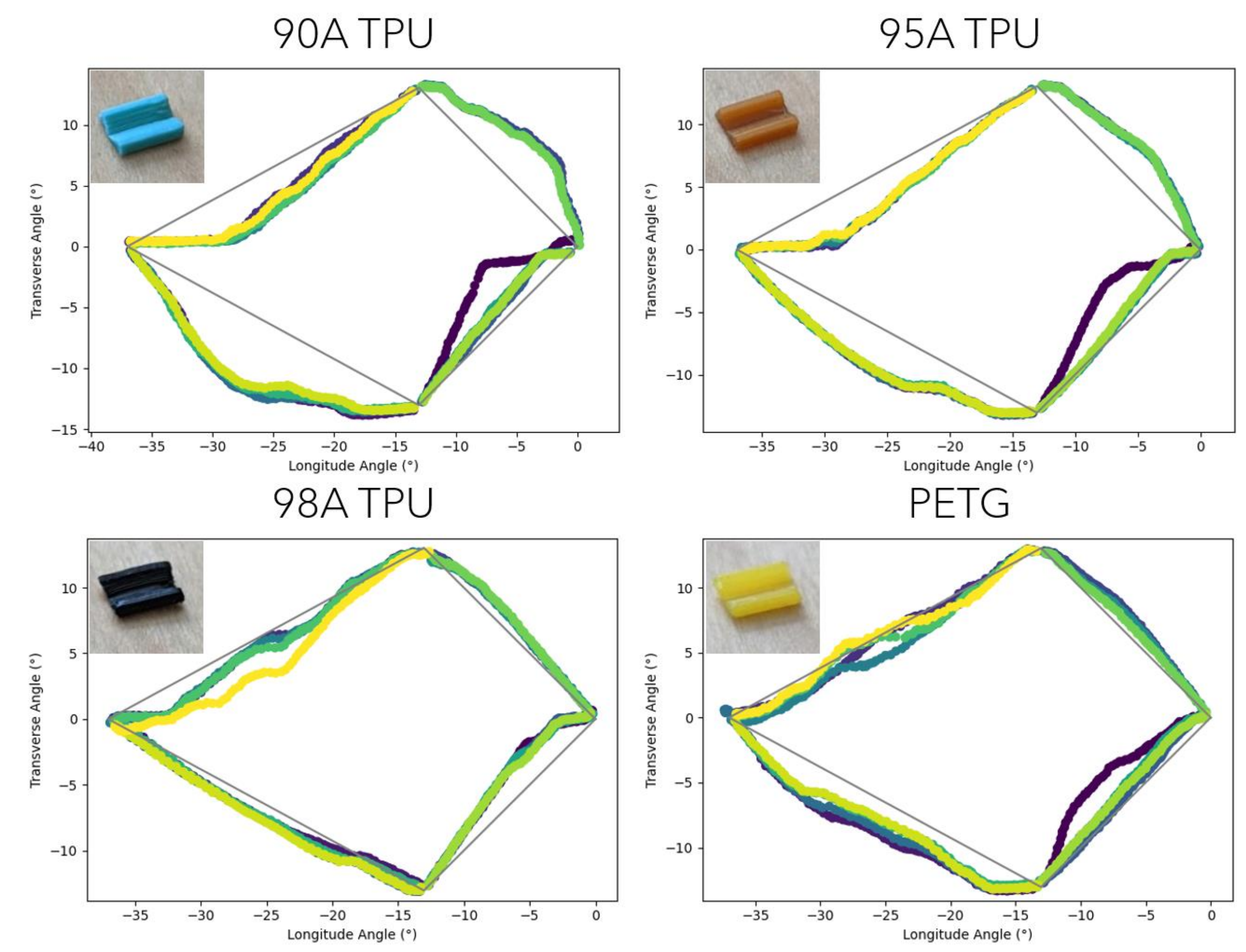
- Original Hero fixture uses traditional linkage with 10 parts and significant assembly time
- Compliant Hero Mechanics replaces all 10 parts with a single part
- 20X BOM cost reduction Vs. previous design
- 20X Assembly time reduction Vs. previous design
- Parts were printed in-house with Glint's polypropylene printing technology
- Performance testing indicated no loss of performance in new design
- Durability testing performed on side-by-side motorized luminaires for 50k cycles with no loss of performance or function
- Currently working to incorporate this technology into current and future products





Progress and Future Work - Accomplishments

- Glint developed a motorized luminaire platform based on a compliant mechanism with interchangeable elastomeric flexures
- To assess what materials were best suited to the performance requirements of light fixtures the different materials were subjected to a positioning stress test with closed loop feedback provided by a two-axis position sensor
- Tested 4 different materials to determine performance impact
- Shore 98A hardness TPU had best balance of stiffness and accuracy
- Additional materials under evaluation
- Long term cycling up to 10K cycles shows excellent durability



Progress and Future Work – Remaining Work

Task 1 – Lossless Beam Width & Shape Adjustment Optics

- Build demonstration of adjustable beam shape luminaire
- Design multi-modal adjustment system to allow beam shape and width adjustment in conjunction with steering

Task 2 – Compliant Mechanisms for Volume Manufacturing

- Expand and refine the compliant mechanics within platform, demonstration of 3 additional systems
- Rigorous testing to ensure proper performance over high cycle counts and environmental conditions
- Direct comparison in supply chain, product performance, and overall cost between 3D printing and injection molding

Task 3 – Low-Cost High-Reliability Motorized Luminaires

- Optimize motorization module for cost and reliability
- Stress test motorized luminaires to ensure high quality and long lifetime
- Integration of motorization platform and beam width/shape/steering adjustment

Task 4 – Commercialization Preparation

- Cost/benefit/impact study on beam adjustment technology
- Market study on motorized fixture cost and performance targets

Thank You

Performing Organization(s)

PI Name and Title

PI Tel and/or Email

WBS #, FOA Project # and/or any other Project #

REFERENCE SLIDES

Project Execution - Gantt

		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
Task 1	**Lossless Beam Width & Shape Adjustment Optics**								
1.1	Beam adjustment optics optimization software development								
1.2	Lenticular rotation beam width adjustment optimization								
1.3	Lenticular rotation beam shape adjustment design								
M1.1	Milestone 1.1 - Demonstration of beam shape adjustment								
1.4	Compound beam width & shape adjustment design								
M1.2	Milestone 1.2 - Demonstration of beam width & shape adjustment								
Task 2	**Compliant Mechanisms for Volume Manufacturing**								
2.1	Compliant mechanism design for cost/performance/manufacturing								
2.2	Compliant mechanism production qualification study								
M2.1	Milestone 2.1 - Demonstration of mass-producible mechanism								
2.3	3D printing vs. injection molding manufacturing comparison study								
Task 3	**Low-Cost High-Reliability Motorized Luminaires**								
3.1	Motorization module optimization for cost and reliability								
3.2	Motorized luminaire stress testing								
3.3	Beam width/shape/steering motorized prototype development								
M3.1	Milestone 3.1 - Beam width/shape/steering motorized prototype demonstration								
Task 4	**Commercialization Preparation**								
4.1	Cost/benefit/impact study on beam adjustment technology								
4.2	Market study on motorized fixture cost and performance targets								

Project Execution – Go/No-Go Milestones

Go/No Go Milestone or Technical Metric Number	Anticipated Month of completion	Performance Metric	Success Value	Assessment Tool / Method of Measuring Success Value	Verification Process	Metric Justification, Additional Notes
1	9	Beam Shape Adjustment Range	Continuous tuning from 1:1 to 1.5:1 aspect ratio	Measured by 2-axis FWHM assesed by photogoniometer measurement and confirmed with beam imaging	Photometric data reported to DOE	FWHM is industry standard for beam width mearurement. Beam cross sections will be taken with orthogonal slices and compared to assess aspect ratio.
2	9	Cost reduction of mass-producible compliant mechanism	Cost reduction of 10x relative to current system.	Cost will be analyized by quoted production cost from injection molding suppliers. Assembly cost reduction will be assessed by comparative build time.	Certified quotes and BOM comparison will be reported to DOE	Existing cost of mechanical system is established through cost BOM, new component can be compared based on amortized production costs and assembly cost impact
3	9	Optical performance of mass-producible compliant mechanism	Less than 1.1 native aspect ratio, Less than 5% dynamic beam skew	Measured by FWHM assessed by photogoniometer and beam imaging	Photometric data reported to DOE	The compliant mechanism must maintain proper array alignment in the static case (which is measured as aspect ratio) and the dynamic case (which is measured as beam skew). The targets are based on what our current non-compliant mechanical system is able to achieve

Team

- Glint Photonics Inc.
    - **Dr. Chris Gladden (PI)** is the Director of Engineering and has been with Glint for over 8 years. He has a PhD in Mechanical Engineering from UC Berkeley and has led all aspects of engineering work at Glint, including the development of the LightShift platform and Hero product. Chris will oversee the program and lead the technical work.
    - **Dr. Peter Kozodoy** is the founder and CEO of Glint Photonics, Inc. He has wide-ranging experience in technology research, program management, and product development, including 20 years in R&D and successful product commercialization at two previous startup companies. Peter will manage project resources and team.
    - **Dr. Andrew Kim** is VP of Product and has led product development, business development, and manufacturing at Glint for over 4 years. He has 25 years of experience in solid-state lighting, with deep industry leadership experience at Lumileds that ranged from R&D through manufacturing. Andrew will work on commercialization efforts.
    - **Michael Pan** is a Mechanical Engineer at Glint and has brought multiple LED products from the initial design stages to mass production in his time at Architectural Lighting Works and DiCon. Michael will lead mechanical design efforts.
- Consultants:
    - **Dr. John Lloyd** is the Optical Design Lead for Glint's lighting projects, and former Glint employee. He holds a PhD from CalTech in Materials Science and has over 8 years of experience in advanced optical systems. John will continue to lead optical design efforts.
    - **Jay Matsueda** is a veteran of lighting sales and marketing. He has worked with Glint for the past 3 years to help build out our sales network and provide critical market feedback for Glint's product and technology development .