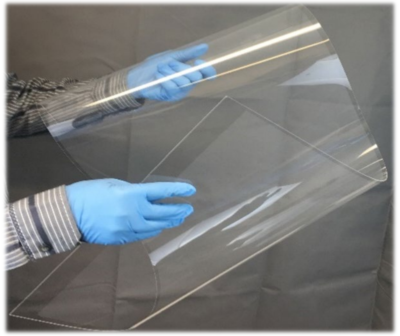
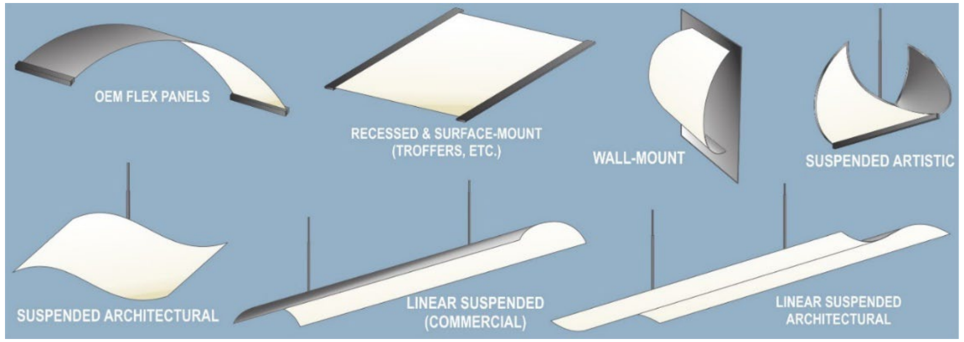
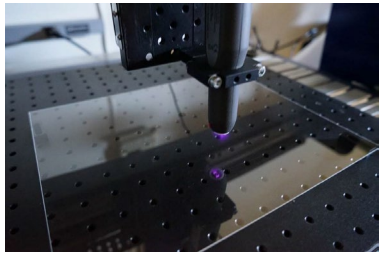
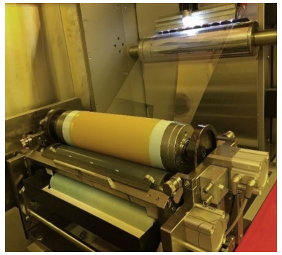
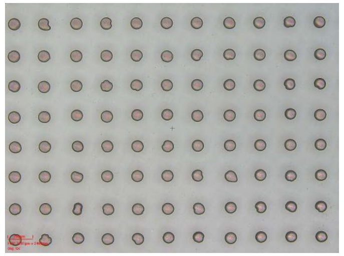
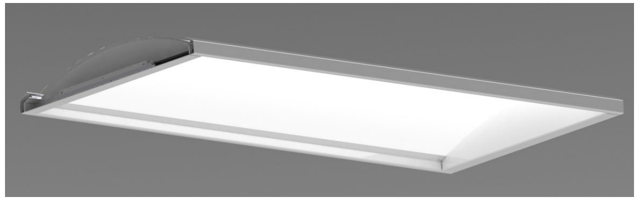
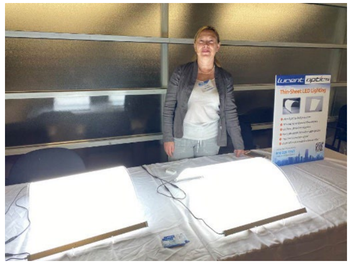
Microprinting Waveguides for Ultra-thin and Flexible LED Lighting Panels





Performing Organization(s): S.V.V. Technology Innovations, Inc. (Lucent Optics)
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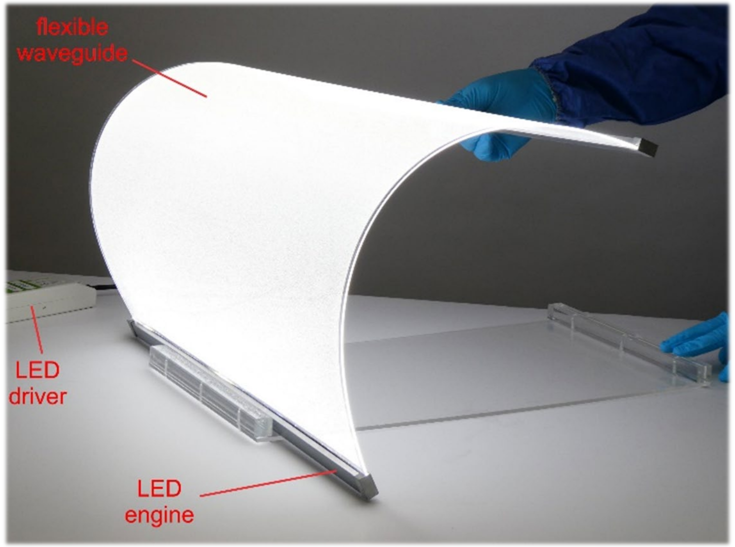
DOE SBIR Phase II, Award #DE-SC0020780

Project Summary

Objective and outcome

This SBIR Phase II project will develop a novel additive manufacturing technology “microprinting” that enables making large-area, low-cost LED panels with thin and flexible forms and highly customizable appearance.

The microprinting technology will make viable the large-scale replacement of linear fluorescent fixtures with energy-efficient LED technology, leading to significant energy savings in commercial buildings.



Team and Partners

Sergiy Vasylyev (PI): Ph.D. in Physics, inventor, >25 yrs. in optics R&D, entrepreneur, >20 yrs. in tech startups

Nick Masalitin (Sr. Engineer): M.S. in Phys. Optics, co-inventor, 20 yrs. in engineering & product development

WCET: manufacturing (roll-to-roll substrate patterning)

LBNL: optical testing

Phosphor Tech: LED phosphors

Stats

Performance Period: Aug. 22, 2022 - Aug. 21, 2024

DOE SBIR Phase II budget: $1,100k Cost Share: $0

Milestone 1: Variable intensity distribution

Milestone 2: 24"x48" size of the panel

Milestone 3: Color-tunable panel

Milestone 4: 12"x12" panel with embedded phosphors

Milestone 5: R2R waveguide production

Problem

- Commercial buildings hold ~1 billion linear fluorescent light fixtures which represent 31% of all lighting energy consumption across all sectors
- Replacing these fixtures with LED technology has the largest energy saving potential across all lighting submarkets and could save more than 2,500 tBTU annually in the commercial sector alone*
- However, the adoption of LEDs in linear fixtures is relatively low (only 20% of the installations)
- Main barriers: high cost of LED products ($30-$160/klm), lack of sufficiently compelling visual differentiation from the incumbent fluorescent fixtures
- The problem is further compounded by the influx of subpar-quality, commoditized light fixtures from overseas manufacturers, which suppresses domestic SSL manufacturing and further elevates the need of product differentiation
- Large-area LED light sources with thin and flexible forms, reduced raw material intake, and enhanced customizability can help overcome these barriers and speed the adoption of energy-efficient lighting
- Developing a low-cost, domestic manufacturing technology for making such light sources can contribute significantly to BTO's goals of energy efficiency, cost savings, environmental impact reduction, market transformation, job creation, grid resilience, and global competitiveness of the U.S. industry

**Source: U.S. DOE, “Energy Savings Forecast of Solid-State Lighting in General Illumination Applications”, Dec. 2019*

Alignment and Impact

- New LED technology for replacing linear fluorescent fixtures would encourage more widespread adoption of energy-efficient lighting, resulting in reduced energy consumption and environmental impact for commercial buildings, improved grid resilience, and contributing to global decarbonization and net-zero emissions economy
- Lowering the raw material intensity by >50% will lower the upfront cost of upgrading or installing energy-efficient lighting by 30%, resulting in long-term cost savings for building operators due to reduced energy bills
- The introduction of thin and flexible forms for large-area LED panels, with advanced customization, will create virtually unlimited new opportunities for lighting design and further incentivize the adoption of energy-efficient lighting
- Ideally, this effort would result in the completion of an integrated technology platform for making ultra-thin, flexible LED lighting panels up to the sizes of most prevalent linear fluorescent lights such as 1’x4’, 2’x2’, and 2’x4’ troffers and suspended architectural fixtures
- A further measure of success would be demonstrating additional ways for improving energy efficiency and light quality for general illumination, as well as expanding the customization of LED lighting fixtures to improve their aesthetics and desirability (e.g., curved forms, transparency, custom emission patterns, and overall appearance)

Approach

CURRENT APPROACHES

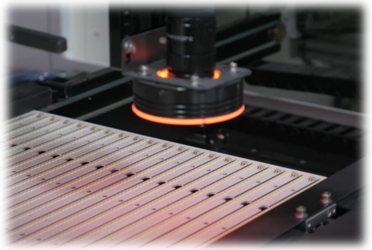
Solution	Benefits	Disadvantages
Fluorescent fixtures and tubes (most prevalent)	Lowest system cost	Low energy efficiency Low quality of light, choppy spectrum, flickering, glare The need of periodic tube replacement and proper disposal Hazardous materials (mercury)
LED tubes (TLEDs)	Lower cost than replacing the entire fixture Simplified installation	Limited energy efficiency improvement due to 25-30% light loss in the fixture Keeps the appearance of the old fixture Emission uniformity and glare issues
LED retrofits	Lower cost than replacing the entire fixture	Same as above
Replacement fixtures (LED)	Maximum energy efficiency can be realized (depending on the design)	High cost Relatively high intake of raw material Lack of sufficient design differentiation from fluorescents Glare can still be an issue
Replacement fixtures (OLED)	Innovative designs/appearance Better color rendering Reduced glare	Extremely high cost (>10x the LED fixtures) Low energy efficiency (<0.5x that of LEDs)

Approach

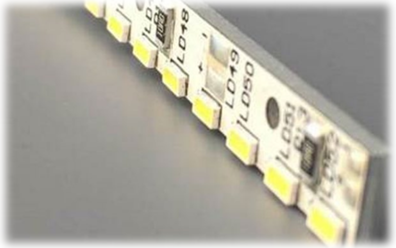
COREGLO™ TECHNOLOGY PLATFORM

LEDs

high-efficacy packages



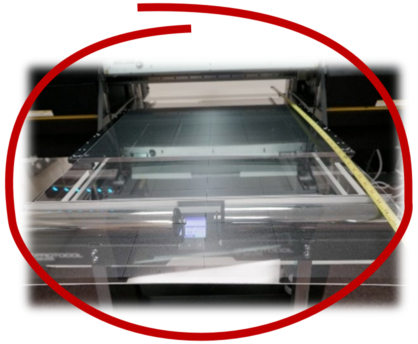
automated assembly



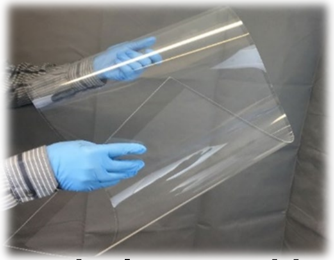
low-profile LED engine

Plastic sheeting

raw sheets



Microprinting: *additive manufacturing process*



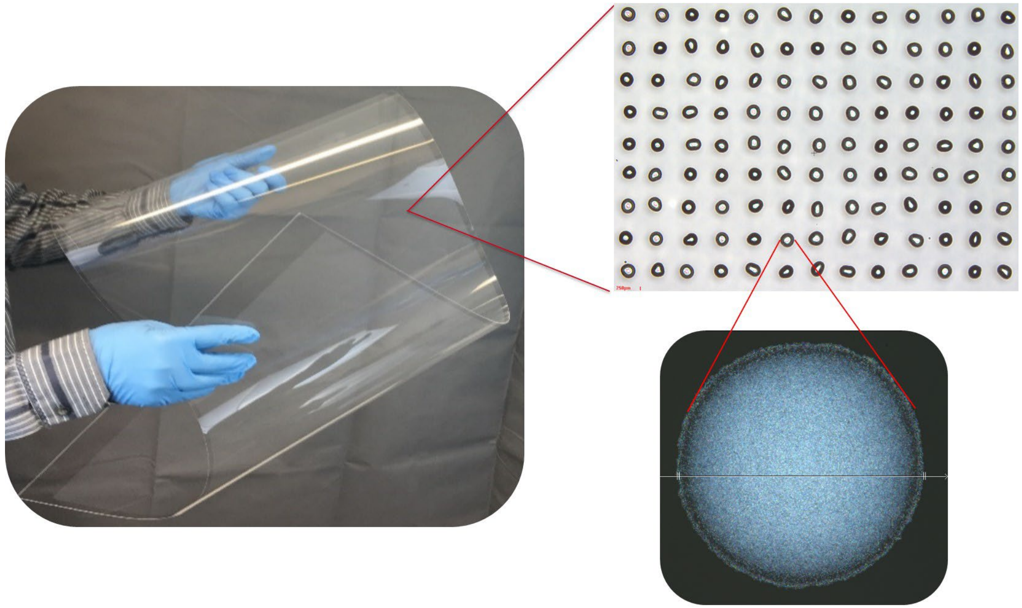
optical waveguide

Ultra-thin, large-area LED source

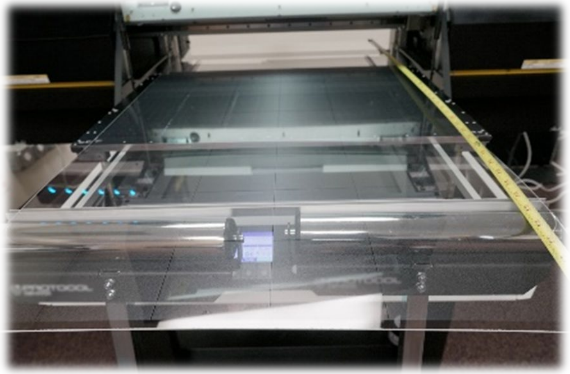
Approach

MICROPRINTING TECHNOLOGY

- Additive surface patterning with minimum use of consumables
- Serial high-throughput process with low capital costs
- Sustainable production, no hazardous materials, minimum water and energy use
- High repeatability with precise control over substrate patterning process
- Ability to control surface luminance distribution by the density of light extraction pattern



~ 100 µm



Approach

Challenge	How this challenge is addressed in this project
Scaling the microprinting process to full-size luminaires while maintaining high optical efficiency and uniformity	Enhancing the light extraction pattern generation process Improving the fidelity and repeatability of the microprinting process Demonstrating microprinted waveguides in 24”x48” sizes.
Compatibility with a wide variety of LED parameters (e.g., different CCTs and CRIs)	Tune-up the composition of materials used in microprinting to operate in a wide range of CCTs (2,700K-5,000K) without introducing color shift. Prototype a color-tunable CoreGLO panel.
Customization of CoreGLO panels	Further improve optical models and light extraction pattern generation algorithms to control emission distribution patterns and overall appearance of the lighting panel. Demonstrate panels with variable intensity distribution.
Further improving luminaire-level efficacy and enhancing light quality	Develop color-converting waveguides using advanced phosphor materials in the microprinting process. Demonstrate 12"x12" lighting panel with embedded phosphors.
Further reducing the production cost and increasing production throughput	Adapt microprinting for roll-to-roll (R2R) processing and demonstrate a sample R2R production run.

Approach

VALIDATION & COMMERCIALIZATION

- Performance validation by independent 3rd party optical/electric/photometric testing
- Phased-in pilot manufacturing
- Refining product parameters and manufacturing process through customer feedback loop
- Addressing multiple markets
- Combination of direct sales with licensing
- Building a comprehensive patent portfolio
- Engaging industry stakeholders

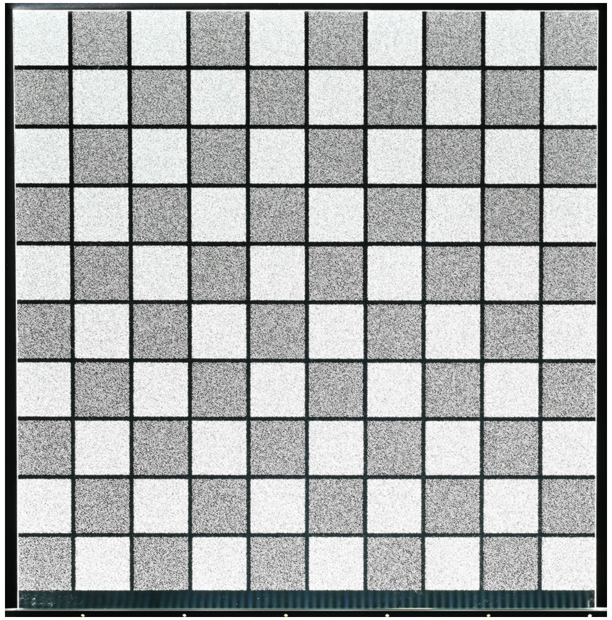
RISK MITIGATION

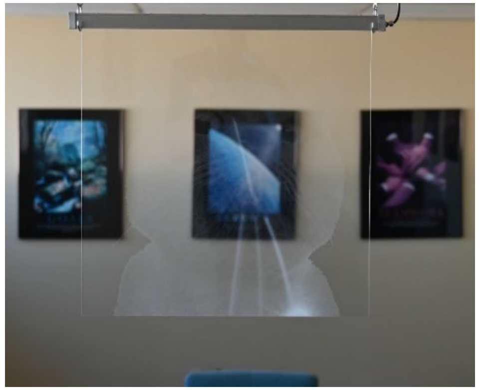
- Internal critical review meetings upon reaching each milestone or identifying a major technical issue, taking corrective actions if necessary.
- Time contingency
- Relying on mature technologies whenever possible
- Contingency plans for each high-risk task (e.g., color-converting waveguide development or R2R patterning)

Progress and Future Work

ADVANCED LIGHTING PRODUCT CUSTOMIZATION

- First milestone reached: Enabling custom variable-intensity emission distributions while maximizing the total light output.
- Unlocking advanced lighting design opportunities (unique visual effects, enhanced aesthetic appearance) without changing the panel design, increasing the cost, or impacting lighting performance.
- Work in progress: Encoding complex images/pattens into emission patterns
- Prototyping of end-products using such new capabilities

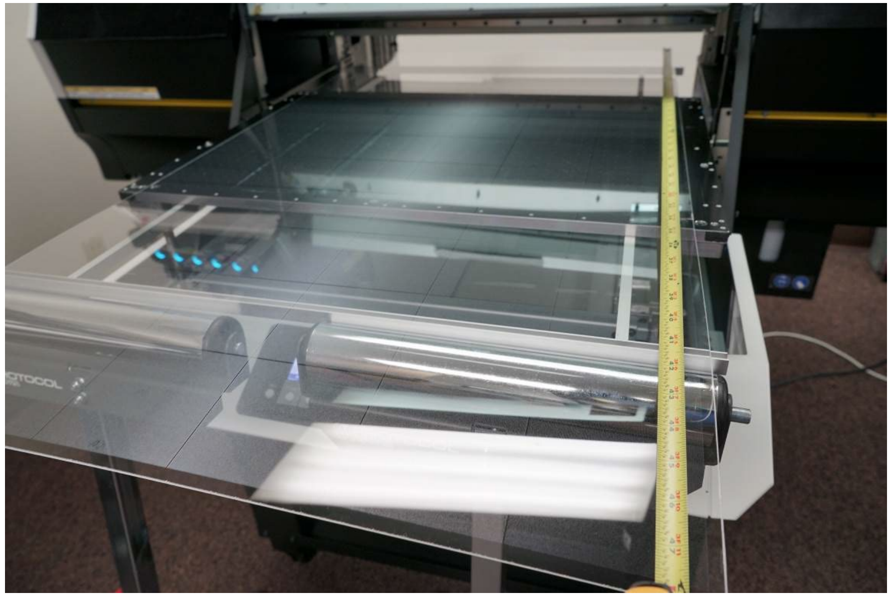


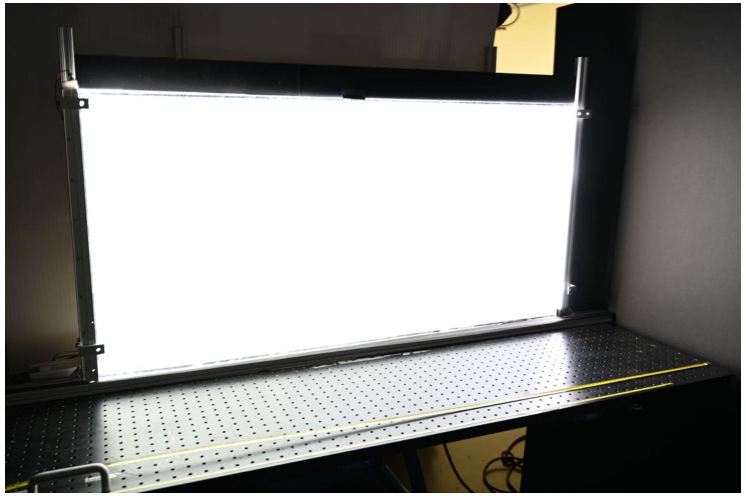


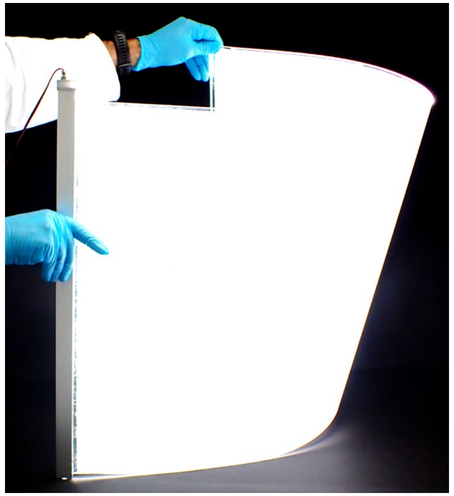
Progress and Future Work

SCALE-UP OF MICROPRINTING PROCESS

- New maximum panel size: 24” x 48” (~50% increase of the baseline, 2nd milestone achieved)
- Targeting the most popular form factor of linear fluorescent fixtures (2’x4’ troffers)
- Supporting custom panel dimensions up to the maximum size
- Design/production turnaround times for custom-size waveguides reduced from weeks to days/hours



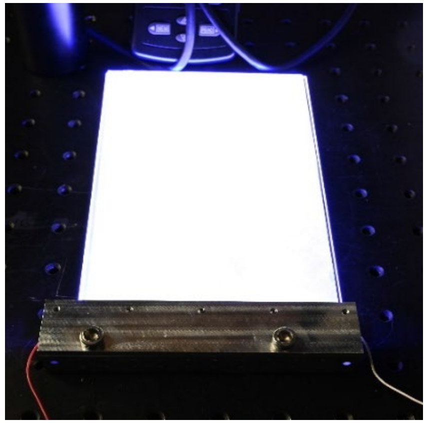




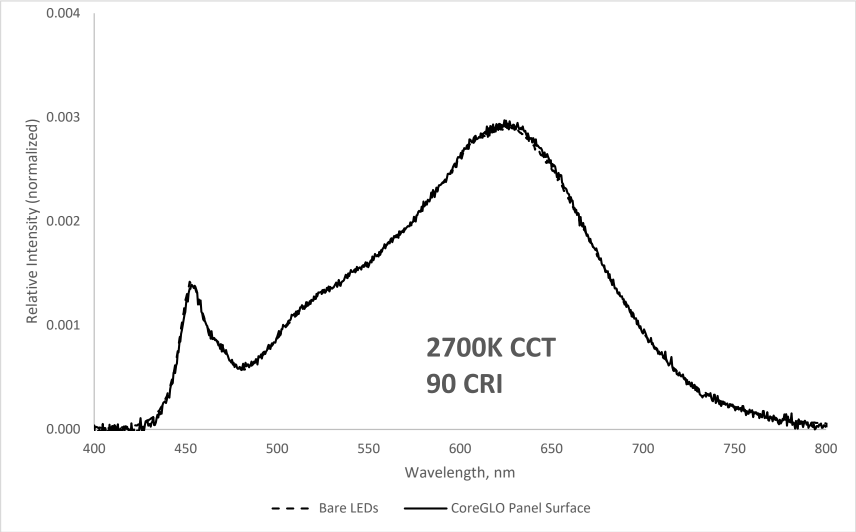
Progress and Future Work

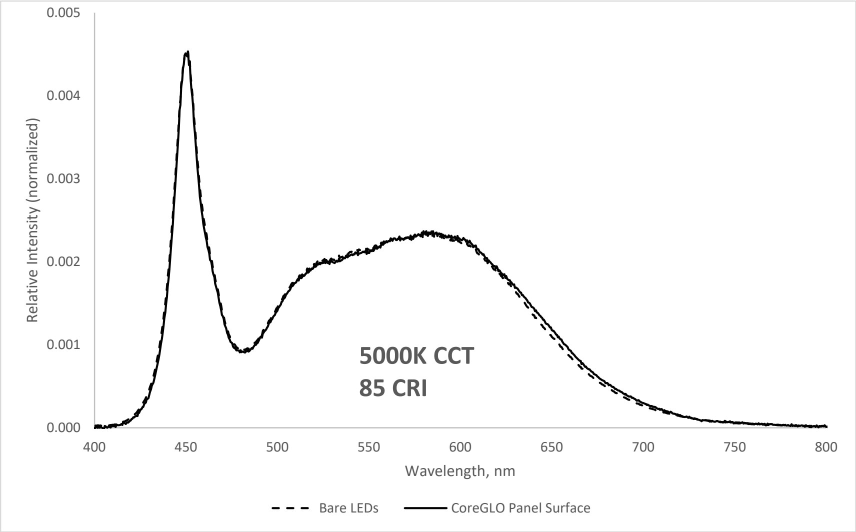
ENHANCING LIGHT QUALITY AND LUMINAIRE-LEVEL EFFICACY

- Operability of microprinted waveguides without color shift (e.g., yellowing) demonstrated at both ends of the target CCT range (2,700K and 5,000K)
- Implementation of microprinted waveguides for color-tunable CoreGLO panel has started
- Small-size prototype of first-ever thin/flexible LED light source with waveguide-embedded phosphors demonstrated



- Scale up of the panel with waveguide-embedded phosphors to 12”x12” is planned for the subsequent tasks

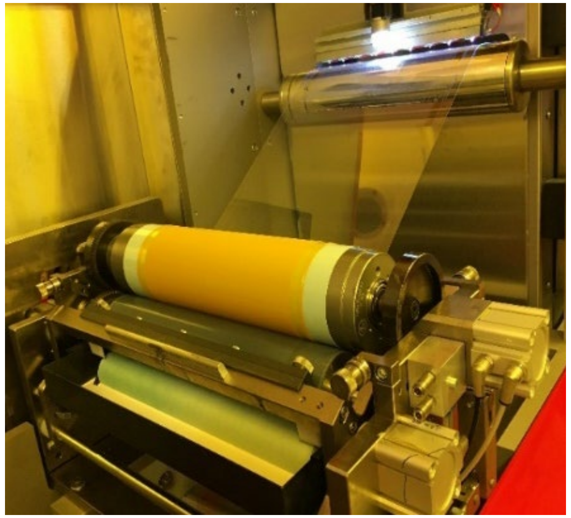


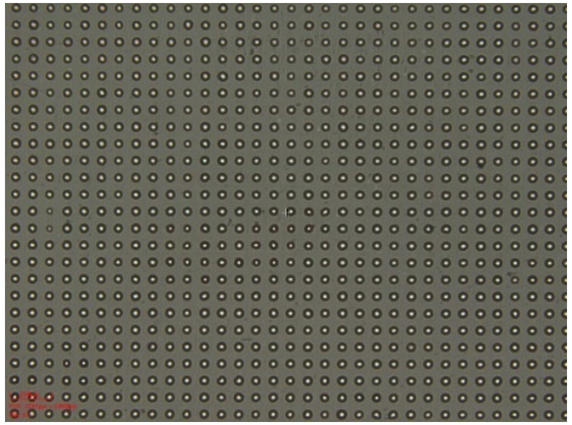


Progress and Future Work

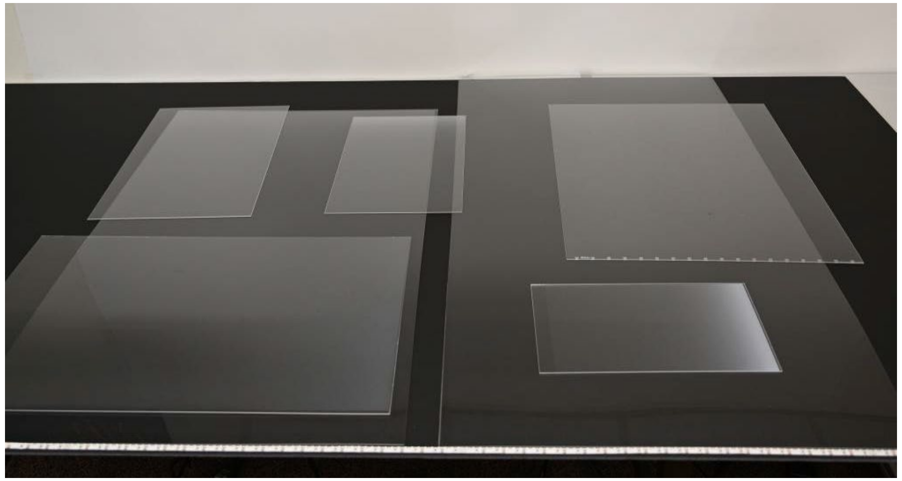
DEVELOPING R2R IMPLEMENTATION OF MICROPRINTING

- Principal manufacturability of microprinted waveguides using R2R process demonstrated by patterning small areas on a roll-fed film using high-resolution flexography.
- High-fidelity light extraction structures that are comparable in size, shape, and repeatability to the standard microprinting process have been obtained.
- Full production cycle tested on equipment with a potential 100x further increase in the production speed.
- Future plans for the subsequent tasks include producing a functional microprinted waveguide of at least 12”x12” in size using the R2R process and demonstrating a uniform emission from this waveguide within an actual CoreGLO panel.



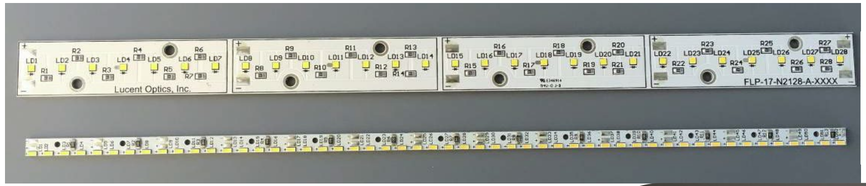


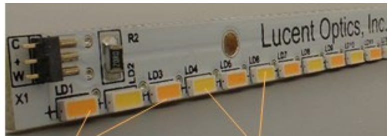
Progress and Future Work



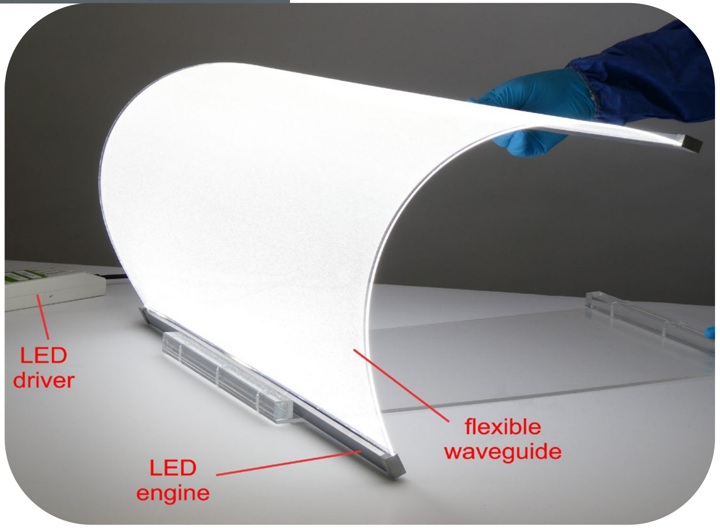
COMMERCIALIZATION & MARKET TRANSFORMATION

- Pilot production of microprinted waveguides.
  - Standard sizes: 12”x12”, 12”x18”, 12”x24”, 16”x24”, 24”x48”
  - Custom sizes from 8” to 48” in the largest dimension
  - Uniform & user-specified emission profiles, segmented emission
  - Appearance: Transparent/translucent
- Pilot manufacturing of waveguide-compatible LED strip engines





  - 24” nominal length (cuttable at 3” increments)
  - ~140 lm/W wall-plug efficacy
  - CRI options: 80+, 90
  - CCT options: 2,700 K; 5,000 K; color-tunable 2,700 K – 5,000 K
- Integrated lighting products
  - 2’x2’ OEM thin/flexible LED lighting panel with 120 lm/W efficacy
  - Included in 2021 IES Progress Report.
  - >1,000 lm/ft^2 light output; ~4,000 cd/m^2 surface luminance;
  - highly diffuse, >85% luminance uniformity, <1 lbs/ft^2 weight, <1.5mm thickness
- >20 issued patents



Thank You

S.V.V. Technology Innovations, Inc. (Lucent Optics)
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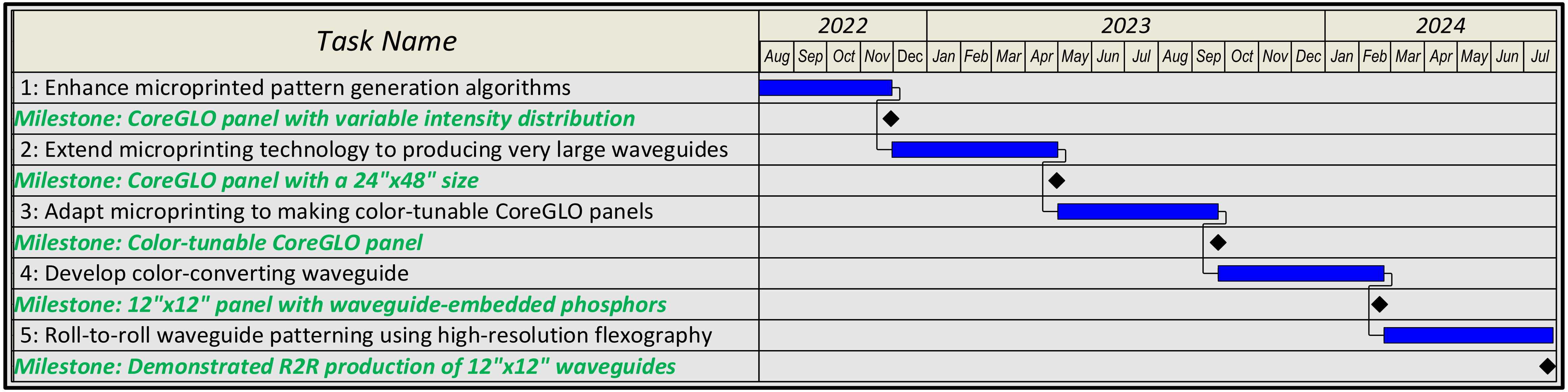
DOE SBIR Phase II, Award #DE-SC0020780

REFERENCE SLIDES

Project Execution



GO/NO-GO DECISION POINTS

1. Panel Size: >42” in the largest dimension (met ahead of schedule)
2. Color Tunability: Correlated color temperature (CCT) tunable from 2,700K to >5,000K (work in progress, on-time)
3. Emission Uniformity: >85% at the maximum size (work in progress, on-time)

Team & Partners

- Sergiy Vasylyev (PI): Ph.D. in Physics, inventor, >25 yrs. in optics R&D, entrepreneur, >20 yrs. in tech startups
- Nick Masalitin (Sr. Engineer): M.S. in Phys. Optics, co-inventor, 20 yrs. in engineering & product development

UNIVERSITY of WASHINGTON

WASHINGTON Clean Energy Testbeds

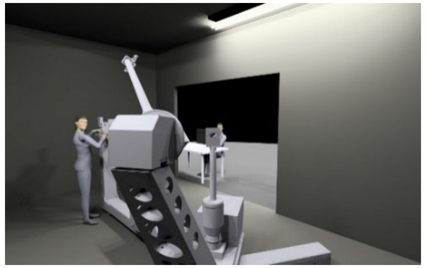
University of Washington Clean Energy Institute

Exploring high-volume, lower-cost alternatives for waveguide patterning.

PhosphorTech

High-performance phosphors for embedding into waveguides

BERKELEY LAB



State-of-the-art testing of microprinted substrates

LIGHT LABORATORY INC. Since 1974

NVLAP TESTING NVLAP LAB CODE 200927-0

Independent electric & photometric testing

CALIFORNIA ENERGY COMMISSION

R&D funding for CoreGLO luminaires development

NEW ENERGY NEXUS

CalTestBed

Funding for testing at National Labs