

# Surface Scatterers on Slab-Wave Guides for Uniform Bacteria Growth

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## Abstract:

Stacked bioreactors are built using slab-waveguides. Light is directed into the side of the waveguide and inside the light totally-internally reflects. Using photolithography, pillars of SU-8 photoresist, with a higher index than glass, were patterned on a waveguide. SU-8 pillars acted as a mechanism to scatter light into the reactor [1]. Experiments using fluorescent dyes, simulating a thin biofilm, were conducted to determine the rate at which the light intensity decreases at maximum SU-8 patterning density. The decrease was fit to an exponential and used to generate a gradient of coverage along the length of the reactor required for uniform scattering light distribution. To achieve uniform light distribution, the final gradient was generated by calculating the required percentage of coverage required at every mm along the reactor. The waveguide was fabricated and tested for uniform light distribution. Finally, single-stack reactors for algal growth were assembled to test the efficacy of different scattering schemes.

## Introduction:

Cultures of algae, such as the cyanobacteria *Synechococcus elongates*, grown in bioreactors are a promising source of renewable energy [2]. However, algae growth is highly

dependent on light intensity and standard bioreactors do a poor job at distributing light uniformly for algae utilization due to shading [3]. The goal of a stacked bioreactor is to uniformly distribute the optimum amount of light to all of the algae growing inside the reactor.

## Experimental Procedure:

Waveguides were made by applying SU-8 2002 photoresist (Microchem) on the surface of borosilicate glass slides with dimensions of 75 mm × 50 mm × 1 mm or 60 mm × 24 mm × 0.15 mm. The 25% uniform coverage waveguides were made by patterning an array of 5 μm by 5 μm pillars spaced 5.0 μm apart on the glass (Figure 1). Gradients of different percent coverage at each mm along the glass were constructed by changing the spacing between the pillars.

To fabricate the pillars, a 2.8 μm thick layer of SU-8 was exposed for seven seconds using hard contact exposure on the SUSS MA6-BA6 contact aligner and developed in SU-8 developer for 1 min. Chambers designed to hold fluorescent dye, with dimensions of 40 mm × 60 mm or 10 mm × 40 mm, were constructed using the waveguide for the top of the chamber. A mixture of 1:100 carbon black to polydimethylsiloxane (PDMS) was poured over a mold the dimensions of the SU-8 coverage, and placed in a 90°C oven for 30 min. The molded PDMS formed the base of the chamber and was bonded to the waveguide. The chambers were filled with Alexa Fluor 680 dye, by Life Technologies. The short edge of the chamber was placed 10 mm away from the center of a 10 × 10 array of LEDs, emission wavelength ~ 630 nm, spaced 2 mm apart.

The dye was imaged, at 10X magnification, with a Sony XCD-X710 Firewire Camera attached to a microscope. An image was taken over the length of the chamber every 1 mm. The average pixel intensity of each image was extracted and plotted on a graph. This data was fit to an exponential curve to determine the exponential decrease coefficient, k. The decrease coefficient for 25 percent coverage was doubled to obtain a maximum k value, at 50 percent coverage. The percentages of coverage required for the gradient design were calculated

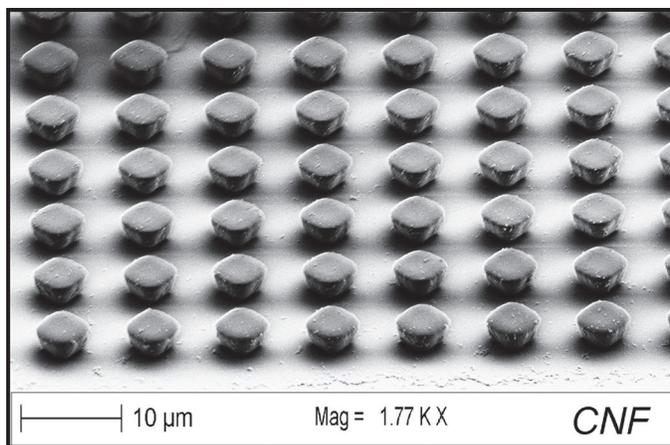


Figure 1: SEM of 25% coverage of SU-8 2002 pillars on glass surface.

$$k_{max} = k * \frac{SC_{max}}{SC}$$

$$k_0 = \frac{|k_{max}|}{1 + (L * |k_{max}|)}$$

$$k(x) = \frac{1}{(\frac{1}{k_0} - x)}$$

$$SC(x) = k(x) * \frac{SC_{max}}{k_{max}}$$

$k_{max}$ =maximum decrease coefficient

L= desired length of reactor

SC= SU-8 surface coverage

The maximum surface coverage ( $SC_{max}$ ) used was 50%.

Figure 2: Calculations that generate the required percent coverage of SU-8 necessary for uniform light distribution.

using k (Figure 2). The gradients for the 0.15 mm and 1 mm thick waveguides started at 6.9 and 17.8 percent coverage, respectively, and increased exponentially every 1 mm, reaching a maximum of 50% coverage at the end. The highest percent coverage used was 50%; spacing the pillars less than 2.1 μm apart resulted in pillars overlapping and forming a film.

### Results and Conclusions:

With 50% uniform coverage of SU-8, the maximum decrease coefficient ( $k_{max}$ ) was -0.156 for a 0.15 mm thick waveguide (Figure 3) and -0.028 for a 1 mm thick waveguide. These negative  $k_{max}$  values indicate a large exponential decrease in intensity. Our gradient of SU-8 coverage for the 0.15 mm thick waveguide improved the decrease coefficient  $k_{max}$  from -0.156 to 0.001. This low absolute value of k indicates no substantial change in light intensity along length of chamber. The gradient for the 1 mm thick waveguide was also successful, improving

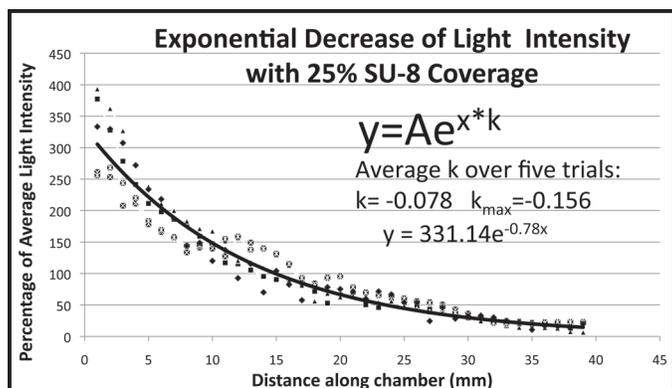


Figure 3: A graph of the exponential decrease of light intensity with 25% coverage.

the decrease coefficient from -0.028 to -0.0001 (Figure 4). We have demonstrated a successful design for uniformly distributing light into a bioreactor.

### Future Work:

Algae have been grown inside these waveguide chambers to measure growth. Florescent pictures of algae growing inside the reactor have been taken and will be analyzed to confirm uniform growth. The next step in our process will be to find a way to upscale our waveguide to the reactor scale. These manufacturing methods should allow for the waveguide to be mass produced. Once a manufacturing process has been selected, combining waveguide technology with nutrient delivery technology would result in a high efficiency bioreactor.

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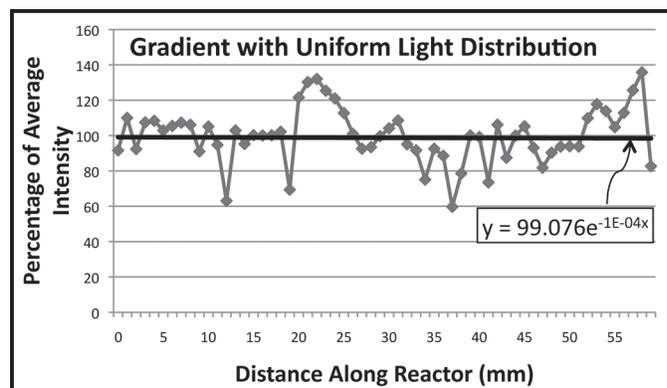


Figure 4: A graph of the light intensity over the length of a 60 mm chamber.