High-Efficiency Broadband Lippmann-Bragg Reflection Holograms

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Abstract:

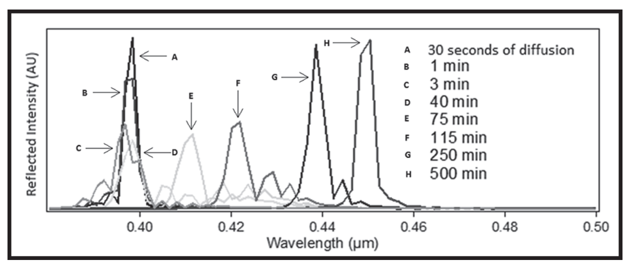
Reflection holograms are written into a light-sensitive media using a source of coherent monochromatic light. The interference pattern between two interfering light waves causes polymerization of certain regions of the recording medium. Unreacted monomer diffuses into the regions that polymerized, creating a nonuniform refractive index across the media. This uniform fringe pattern that occurs, a reflection hologram, reflects light. Typically, reflection holograms are very wavelength selective. In order to broaden the region over which the reflection holograms are reflective, the fringe patterns must be non-uniformly stretched. By introducing a monomer sponge next to the holographic media, monomer diffuses into the fringes and stretches the ones closest to the interface first, causing nonuniform swelling. We have found that reflection holograms, once chirping has begun, take one hour in order to reach their maximum FWHM bandwidth state. During the entire chirping process, the peak wavelength location is steadily increasing. Concluding after 79 hours, the bandwidth decreased and reflectivity increased to near their original values as monomer equally diffused. At maximum FWHM bandwidth, reflectivity decreased by 230% and bandwidth increased by 200%. After 79 hours, holograms experienced a volumetric expansion of 11% coupled with a peak wavelength shift wavelength shift of 12%.

Introduction:

When two sources of coherent monochromatic light interact, they interfere with one another forming an interference pattern. Once exposed to a recording medium, a fringe grating of uniform thickness called a reflection hologram appears. Only wavelengths of light that match the pattern are reflected. Therefore, these holograms tend to have a narrow bandwidth and high reflectivity.

Bright regions in the media cause polymerization of the monomer. Unreacted monomer from the dark regions diffuses into these, causing a change in the refractive index across the media. This index change is the desired fringe pattern.

Reflection holograms find uses in applications such as the heads-up-display of fighter pilots. The bandwidth of these reflection holograms, however, is insufficient for common light sources such as LEDs. This can be increased with a thinner recording media, however, diffraction efficiency is sacrificed. We chose a thicker media for a higher diffraction efficiency and expanded the bandwidth by diffusion of new monomer into the holographic media.



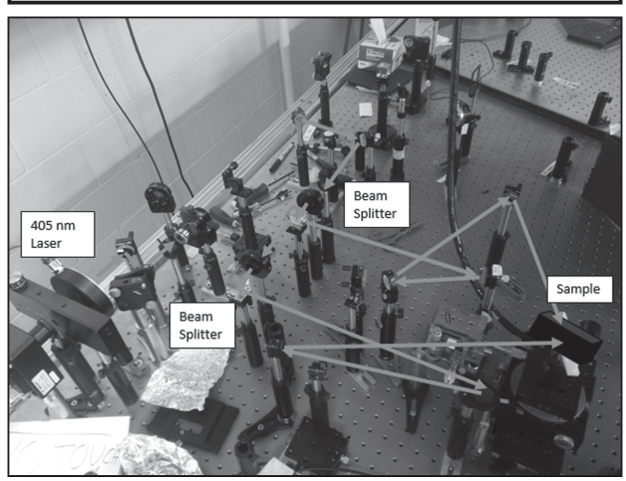


***Figure 1, top:** Model reflectivity vs. wavelength at different diffusion times. **Figure 2, bottom:** Optical setup.*

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Experimental Procedure:

A model was developed to simulate reflectivity after bandwidth expansion. Ideal Fickian diffusion was assumed, therefore an analytic solution exists for the 1D diffusion equation. The diffusion rate was estimated from previous measurements that used other similar materials. The output plot, which includes curves for varying amounts of diffusion, is included in Figure 1.

A light-sensitive polyurethane matrix solution of 5% monomer was created and placed on one glass plate. This matrix was a scaffold for the monomer; once exposed to light the monomer would be held in place to record the fringe pattern. Two spacers of 25 µm were placed on either side of the glass plate, another plate was placed on top, and the setup was squeezed. This was left to cure, typically overnight.

Once cured, the sample was placed in an optical setup, seen in Figure 2. Using a 405 nm laser, light was redirected and split with beam splitters, so that two of the same light sources would come from opposite sides of the sample and interfere within the recording media.

Exposure times varied from 0.2s to 60s, however, we found that 20s gave the largest reflectivity. Shorter times would not polymerize enough monomer and longer times would diffract light more from within the sample, degrading its quality.

The top glass plate was removed and the hologram was tested in a UV-VIS spectrophotometer. After, a sponge of 20% monomer (the same polyurethane matrix as before, but not light-sensitive) was pressed on the holographic media. At specified time intervals, the reflectivity was retested.

The application of the sponge caused diffusion of new monomer into the holographic media. This pulled the fringes closest to the interface first, creating a nonuniform fringe spacing. There are locations for various wavelengths of light to reflect from, increasing the bandwidth.

Results and Conclusions:

After one hour of diffusion, maximum full-width-half-max bandwidth was achieved, an expansion of 200%, Reflectivity decreased at the same time by 230%. This data is shown in Figure 3, along with the curves for other diffusion times.

Initially, FWHM bandwidth increased rapidly due to a large diffusion gradient across the hologram and sponge. Over time as monomer more evenly distributed, the fringe spaces became uniform once again. This explains why with time, bandwidth decreased and reflectivity increased about a higher peak-wavelength-location.

As diffusion occurred, the weight of the holographic material increased 11%. This increase closely matched the peak-wavelength-location increase of the sample, 12%, as seen in Figure 4.

The computer model was quite accurate, given that the timescales were off by about a factor of two. Once appropriate values for the material used are found, the model accuracy can be improved.

Future Work:

Future work could focus on creating new polymer solutions to increase hologram reflectivity. These holograms can be seen quite well before diffusion but not at maximum bandwidth. A method to keep reflectivity high, even after bandwidth expansion, could also be researched.

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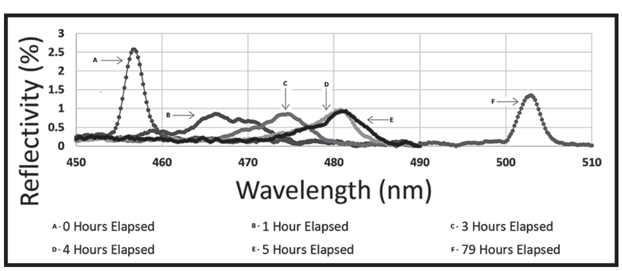

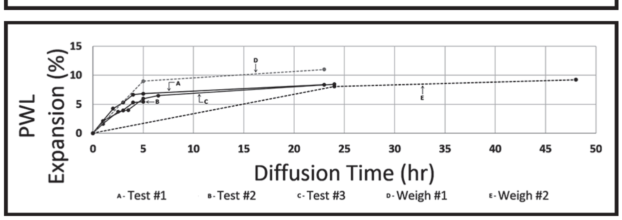

Figure 3, top: Experimental reflectivity vs. wavelength at different diffusion times. Figure 4, bottom: Peak-wavelength-location expansion and weight vs. diffusion time.