Bandwidth Expansion for Lippmann-Bragg Holographic Photopolymers

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Abstract:

A reflection hologram that has a high reflectance over a broad range of wavelengths is desirable for many applications. Thicker holograms, which have a higher reflectance, also have a very narrow bandwidth, thus obtaining a higher bandwidth typically requires layering. A post-processing method called "chirping" is used to expand the bandwidth of these reflection holograms. By diffusing mobile monomer into a recorded hologram, we are able to swell the material and create a distribution of fringe spacing that increases the bandwidth.

Starting with a bandwidth of 2.5 nm with a maximum reflectance of 2.25% occurring at 457.0 nm, after one hour of chirping the bandwidth expanded to 9.7 nm while the maximum reflectance dropped to 0.60% and shifted to 466.6 nm. This trend was observed until five hours of chirping at which point the bandwidth narrowed and the maximum reflectance went back up. The change in mass of the hologram was 8.05% that matches closely with the 8.35% swelling observed from the shift in maximum reflectance from 457.0 nm to 495.2 nm.

Introduction:

Reflection holograms are formed from interference from opposing beams of monochromatic and coherent light. To create a hologram, diode laser beams are focused on a urethane material containing photo-initiators and mobile monomer. When light hits the photo initiators, radicals are formed and free radical polymerization reaction is started forming polymer chains from the free monomer. Reflection holograms have many applications including use in Heads Up Displays (HUDs) and Holographic Optical Elements (HOEs). There is a design tradeoff with these holograms: the thicker the hologram the higher the reflectance, but this reflectance occurs over a smaller range of wavelength. This range is called the bandwidth and to obtain both a high reflectance and a high bandwidth, typically layering is required.

Another method to achieve a higher bandwidth is called "chirping." Chirping refers to the linear variation of pitch spacing in the gratings of the holograms, much like the frequency of a chirping bird. This process requires diffusing monomer into the sample [1]. The wavelengths reflected are a function of the pitch spacing, so as added monomer swells the gratings, the bandwidth is increased and can be tuned based on the distribution of monomer [2].

Procedure:

Spacers of known thickness were used to make the material a desired size. Two strips of 25 µm thick spacer were put on either end of the glass slide on which the material would be contained. After degassing the 5% monomer material in a vacuum, the liquid material was then pipetted onto one of the glass slides. Another glass slide coated in Rain-X® was then carefully placed on top of the glass slide. Binder clips were used to compress the glass slides together ensuring a uniform material thickness. After allowing the material to set, holograms could now be recorded into the sample.

Using 405 nm laser, the beams were split and focused on the material in the optical setup. Using various exposure times, holograms were recorded in the material. The glass slide with Rain-X was now removed and what remained was a glass slide with an even coating of material in which a hologram was recorded.

Next the chirping process began. A 100 µm sponge containing a 20% monomer within the urethane matrix was pressed against the recorded hologram sample with a vise to ensure contact.

To then read the holograms, a UV-Vis spectrophotometer was used. Black shim paper with a hole-punch in it was used to isolate the hologram. The black paper was also put behind the material for a better reading.

Results and Conclusions:

A simple model was created for the process using one dimension Fickian diffusion assumptions and an estimated diffusivity value [3]. The results of this model are shown in Figure 1. Initial chirping results show a predictable increase in bandwidth as seen in Figure 2. This linear increase is an indication that the diffusion process was not near steady state even after seven hours. A new material was used for the remainder of the study so that the hologram and sponge contained the same writing monomer, speeding the process. The results of this test as can be seen in Figure 3 closely match the model. The bandwidth had a large initial increase of around 250% and then decreased after around five hours as monomer concentration within the hologram became uniform, as well as the swelling of the diffraction gratings.

The percent increase of the wavelength shift of peak reflection matches with the percent increase in mass of the sample. This process allowed us to tune a hologram to reflect a range of wavelengths that we intended.

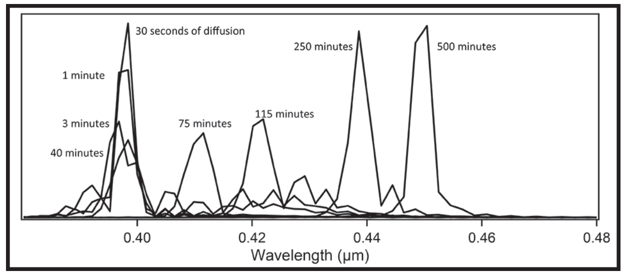

Figure 1: Model results of the chirping process.

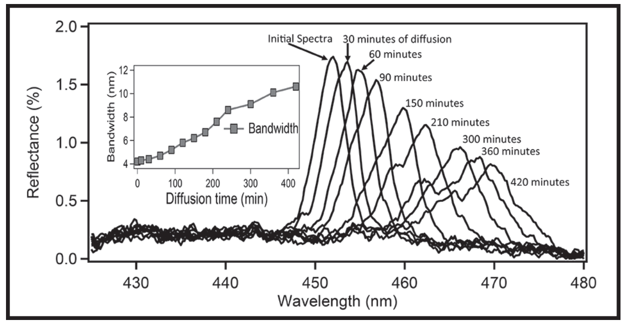

Figure 2: A linear increase in bandwidth was initially observed.

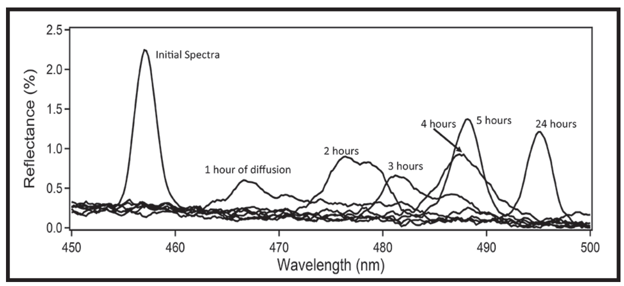

Figure 3: The initial bandwidth increase followed by a decrease matches the model.

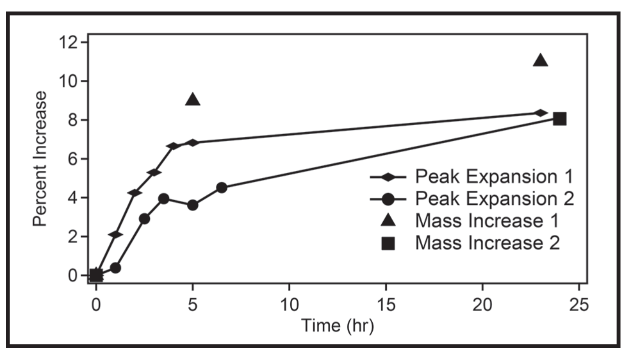

Figure 4: Wavelength shift and mass increase match closely as expected.

Future Work:

The initial reflectance of the holograms needs to be improved. Finding the time at which the hologram achieves its maximum bandwidth is another important topic that needs to be investigated. To shift the reflectance peak to a lower wavelength, monomer can be diffused out of the sample, allowing control of which wavelengths are reflected. Finally, we need to "lock in" the monomer. If allowed to sit, the free monomer in a chirped hologram will continue to diffuse throughout the sample, reaching steady state that will decrease the new bandwidth.

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