Soft Lithographic Fabrication of Bar Chart Phantoms for Axial Resolution Measurements in Optical Coherence Tomography

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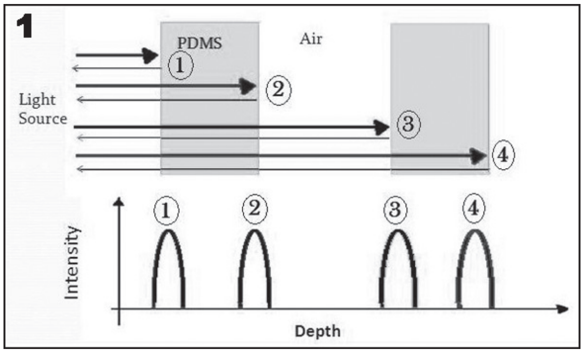
Abstract:

Optical coherence tomography (OCT) enables non-invasive, three dimensional imaging of biological materials based upon reflection of light within a sample. As a relatively new technology, convenient methods for characterizing OCT systems, such as measuring resolution, are needed. Methods for determining lateral resolution must be adapted for use in axial resolution. In this project, we created a phantom with features of known characteristics in the axial rather than lateral plane. We used photolithography to create a master template, which was then used to create polydimethylsiloxane (PDMS) phantoms with soft lithography. PDMS was used for this phantom because it is less reflective than the standard chrome and allows light to penetrate to multiple features at various depths. Using the OCT systems in lab, we determined the advantages and limitations of the phantom through comparison with other accepted characterization methods. A variation of this phantom may provide a convenient method for measuring axial resolution in OCT systems.

Introduction:

Optical coherence tomography (OCT) is a growing technology that enables non-invasive, three dimensional imaging of biological structures. OCT systems have been used to image the sub-layers of the back of the eye (retina) without injury or discomfort to the patient. Unlike traditional microscopy, which images in the lateral plane, OCT images in the axial plane. Characterizing the resolution of an OCT system is important for determining what sizes of features can be detected. In this research project, we created an adaptation of a standard lateral resolution bar chart to measure axial resolution.

OCT works by propagating polychromatic light into a biological sample [1]. When a change in the index of refraction occurs at a boundary between two different sub-layers, some of the light reflects back out of the sample into a detector. The detected signal from the light is mathematically analyzed and plotted as Gaussian-shaped intensity peaks that correspond to the location of the interfaces in depth (Figure 1). When features are close together, the peaks overlap and appear as one peak instead of two. The distance between two features determines the amount of overlap between the peaks, as illustrated in Figure 2. The current trend in OCT is to define the axial resolution as the full width at half maximum of a single peak, which represents the closest distance at which two peaks are still resolvable. This number, however, does not fully characterize the resolution. In Figure 2, the height from the peak to the valley between the peaks



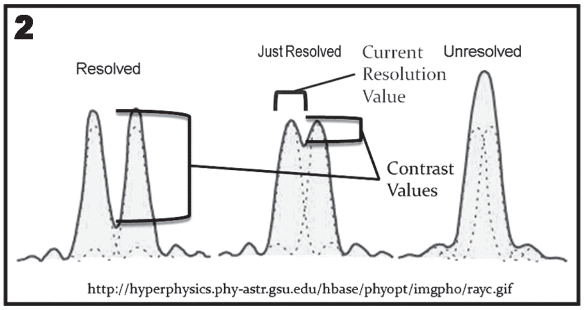


Figure 1, top: OCT images the layers of a sample by sending in light and detecting the reflected light at the boundaries between sub-layers.

Figure 2, bottom: Current axial resolution estimate, compared with contrast information available with a test chart.

correlates to the amount of contrast between features in the final OCT image. A more complete assessment of resolution is a function relating the contrast and spatial frequency of features, called the modular transfer function (MTF). By creating an object with features of known size and a range of spatial frequencies, called a phantom, the MTF for the axial resolution can be determined from the resulting cross-sectional OCT image [2]. The goal of this project was to create a phantom that can be used to fully characterize the resolution of an OCT system in the axial plane.

Experimental Procedure:

Using a mask with features of a known range of spatial frequencies in the axial plane, we performed traditional photolithography to create a silicon wafer mold. The wafers were etched using deep reactive ion etching. After applying a silane coat to the etched wafer, a clear polymer called polydimethylsiloxane (PDMS) was mixed and poured into the mold [3]. Cured PDMS was removed from the mold, cut, and placed into the OCT system for imaging. Prior to imaging the phantom in the OCT system, we also wrote code in MATLAB® to simulate how the OCT image should appear.

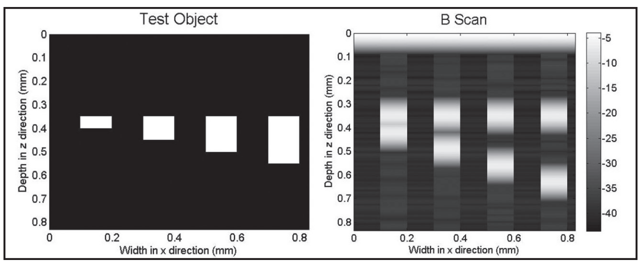


Figure 3: MATLAB simulation written to determine how the expected OCT image would appear. On the left is the object to be imaged (i.e., the mask), and the image on the right is the ideal OCT image we expect to see.

Results and Conclusions:

The results of the simulation (Figure 3) illustrate the true object being imaged and the OCT image; only the top and bottom boundaries of features can be detected. Once the PDMS features were aligned in the plane of the moving OCT light, the features were successfully imaged in the OCT system (Figure 4). We observed that the PDMS did not perfectly fill the rectangular wells of the silicon mold, likely due to the ripping of smaller PDMS features upon removal from the mold. The upper and lower boundaries of the PDMS features can be clearly seen, corresponding to the simulation. The OCT image is repeated several times due to additional reflection between features, called multiple interference. Our simulation did not model this.

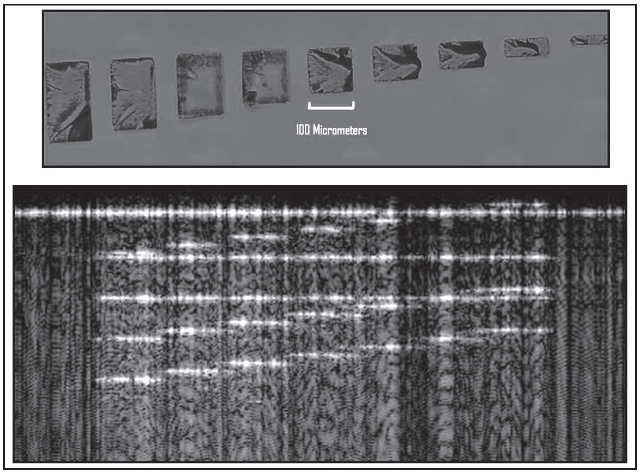


Figure 4: Above, single bars in PDMS imaged in a microscope; below, the corresponding OCT scan in plane of the bars.

To create a better PDMS phantom, the process for removing the PDMS stamp must be improved to ensure smooth, rectangular features. Next, the design should be altered to minimize multiple interference in the final image. Once these design problems are solved, this phantom has potential to become a standard for characterizing the axial resolution of OCT systems.

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