Development of AirSpaced VIPA's for Use in Optical Coherence Tomography

Timothy Welsh

Electrical Engineering/Physics, University of San Diego

NNIN REU Site: Stanford Nanofabrication Facility, Stanford University, Stanford, CA

NNIN REU Principal Investigator: Audrey Ellerbee, Electrical Engineering, Stanford University

NNIN REU Mentors: Tahereh Marvdashti and Heeyoon Lee, Electrical Engineering, Stanford University

Contact: twelsh-13@sandiego.edu, audrey@ee.stanford.edu, tahereh@stanford.edu, lhy2090@stanford.edu

Abstract:

Optical coherence tomography (OCT) is a high resolution, non-invasive technique for imaging scattering media (e.g., biological tissue). Similar to ultrasound, OCT nominally produces one-dimensional cross-sectional images called A-scans. The number of data points acquirable in an A-scan, and consequently imaging depth, is related to the spectral resolution of the detector being used. To increase the spectral resolution, we fabricated a low-cost cross-dispersing spectrometer based on an air-spaced virtually imaged phased array (VIPA). A VIPA is a slightly tilted etalon that allows for high angular dispersion of broadband incident light. The performance of a VIPA depends heavily on surface reflectivity, as well as cavity dimensions and the index of refraction of the cavity medium. VIPAs of various reflectivities were constructed via metal deposition on glass slides and optical flats; the reflectivities were measured via the Hitachi 4001 Spectrophotometer. Their finesse, FSR, and spectral dispersion characteristics were measured via photodetector. We show that sufficiently capable VIPAs can be constructed far more cheaply than commercial varieties, and will enable the development of high performance, affordable OCT systems.

Introduction:

OCT is essentially a white light interferometer: in a Michelson configuration, polychromatic light travels different paths to a reference reflector (mirror) and multi-layered sample after passing through a beamsplitter. Reflected light from both paths interfere constructively at the detector for spatial frequencies corresponding to the position of layers in the sample. The resulting interferogram may be sampled in k-space either by using a spectrometer to collect wavelength information directly (spectral domain OCT), or as a function of time using a photodiode and swept-source laser (swept-source OCT). Similar to ultrasound, OCT nominally produces one-dimensional cross-sectional images called A-scans; 2D (B-scans) and 3D (C-Scans) images can be generated by raster scanning the OCT beam. The primary signal that OCT measures is the intensity of light that is back-scattered from various layers in the sample. Modern OCT systems offer resolutions of 1-10 μm and 5-15 μm in the axial and lateral dimensions, respectively.

In SDOCT, a range of wavelengths can encode depth information in your sample. Your imaging depth is dependent on the number of data points (pixels) that you can detect in the A-scan using a spectrometer. After the

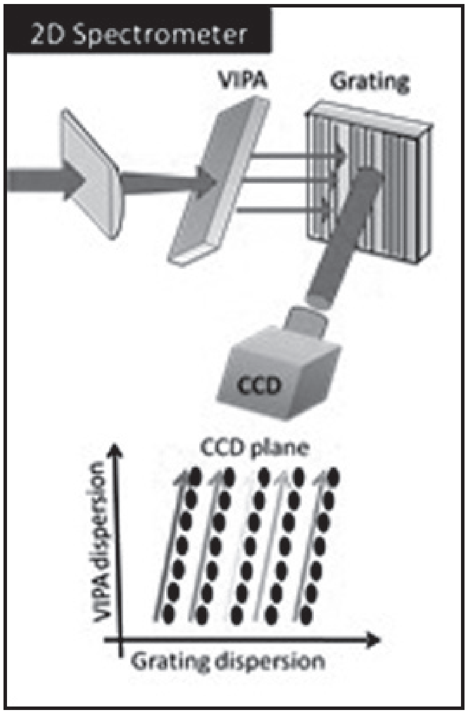

Figure 1: Schematic of VIPA operation in an SDOCT setup.

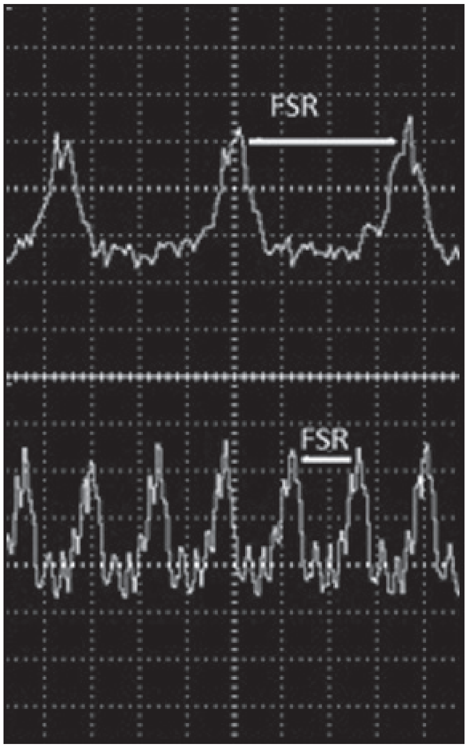

Figure 2: VIPA transmission peaks of 1.1 MHz (top) and 2 MHz (bottom).

beam passes through the VIPA it impinges on an ordinary diffraction grating. The product of this is a 2D dispersion pattern as seen in Figure 1; this allows more pixels on a detector to be utilized and thus increases the imaging depth of the OCT system.

A VIPA is a slightly tilted etalon that allows for high angular dispersion of light by wavelength. When a ray of light enters the VIPA, it undergoes multiple internal reflections between the partially reflecting plates. Each time a ray is reflected, it is partially transmitted, and the remaining reflected light undergoes a phase change. This leads to an important property of the VIPA, due to constructive and destructive interference: there is only a single angle at which a certain wavelength may propagate. Furthermore different wavelengths may overlap on the same position if the FSR of the cavity is sufficient.

Procedure:

We hoped to reduce the cost of obtaining a VIPA by cheaply fabricating one from readily available equipment. In order to control the reflectivity of each side of the VIPA and thus control the finesse of the VIPA, silver was deposited on glass slides and optical flats via metal sputtering. An Innotech metal deposition system was used. The thickness of the deposited metal film could be precisely controlled by modifying the beam power and exposure time. In total we produced four different thicknesses: 50 nm, 15 nm, 10 nm, and 8 nm. These should have corresponded to reflectivities of 92%, 82%, 70%, and 50%, respectively; however of the slides we measured, we found this was not the case. We tested the 50 nm and 15 nm slides on the Hitachi 4001 spectrophotometer and found they corresponded to reflectivites of 75% and 50%, respectively.

We built a holder for the VIPA in order to test it. A Santec broadband swept source laser centered at 1300 nm was line-focused by a cylindrical lens; the beam then passed through the VIPA into a normal focusing lens, which focused the VIPA output into the fiber-coupled photodetector. Since we used a swept-source laser, the photodetector read out was a series of peaks from which we gathered the finesse and FSR data.

Results:

The VIPA we tested had a finesse of 4.5, which exceeded the goal of 4. As well, we found we could tune the finesse of the VIPA with an acceptable degree of accuracy. Figure 2 shows the observed transmission data for an FSR of 1.1 MHz and 2 MHz, respectively. This shows we were successful in meeting our design goals, having constructed a sufficiently capable VIPA for approximately $300, a significant improvement over the original $6000 price tag.

Additionally we have shown fabrication is low-cost and simple, and the drawbacks due to the air-spaced nature of the VIPA can be overcome and turned into an advantage with proper construction of a holding apparatus.

Acknowledgments:

Michael Deal and the NNIN REU Program, along with the NSF for funding the project. Heeyoon Lee, Tahereh Marvdashti, and Audrey Ellerbee for guiding me and assisting me in this project. J. Provine for contributing his time and expertise at ungodly hours to make fabrication possible.

References:

[1] Lipson, S.G.; Lipson, H.; Tannhauser, D.S. (1995). Optical Physics (3rd ed.). London: Cambridge U.P.. pp. 248.

[2] Hernandez, G. (1986). Fabry–Pérot Interferometers. Cambridge: Cambridge University Press.

[3] Xiao, S.; Weiner, A.M.; Lin, C.; 2004. IEEE Journal of Quantum Electronics(Vol. 40 No. 4).