Parameter Estimation in QOCT

Julia Pavlovich, Darryl Goode, W. Clem Karl, Bahaa E. A. Saleh, Malvin C. Teich, Alexander V. Sergienko
(oska, goode, wckarl, besaleh, teich, alexsereg@bu.edu)

Abstract

Quantum optical coherence tomography (QOCT) exploits an entangled twin-photon light source to carry out axial optical sectioning. In this work we present a novel method that by the use of QOCT interferometric data from a given layered medium, can produce the internal structure of the sample. We formulate the problem of retrieving the internal structure of the layered sample in QOCT as a parameter estimation problem. Our parameter estimation approach utilizes the QOCT observation model and determines the following model parameters: the positions of reflecting surfaces $\tau_s$, the quantities related to group-delay dispersion coefficients of the layers $D_j$, refractive indices $\mu_j$, and group-velocity dispersion (GVD) coefficients of the layers.

We applied our method to closely spaced layered samples (fused silica windows). Our experiments demonstrated the capability of our numerical technique to retrieve the correct structure of the sample as well as further improve the axial resolution of the QOCT signal. In particular, we have shown that our method can recover the correct layer positions in the complicated case of the closely spaced layered sample where the direct visual examination would fail to determine the correct values of layer positions. We test our method against both simulated and real data.

I. Problem Formulation

Problem: Retrieving the internal structure of the layered samples

Parameter Estimation Problem

Determine the model parameters: refractive indices $\mu_j$, the positions of the reflective surfaces $\tau_s$, the quantities related to group-delay dispersion coefficients of the layers $D_j$, the group-velocity dispersion coefficients of the layers $G_j$

Challenges:

- Physical modeling
  - Propagation in layered media
  - Signal processing
  - Need good initialization
  - Narrow region of convergence
  - Noise

IV. Computational Challenges

- The problem is poorly scaled
- The functional $J$ exhibits an oscillatory behavior as a function of layer thickness $d$.

V. Closely Spaced Layered Sample

- Minimize cost functional $J(t)$ via fitting the model-based coincidence rate to the available observation data.

VI. Closely Spaced Layered Sample (Example 2)

- Retrieve the correct structure of the closely spaced layered sample (2 surfaces) where the direct visual examination would fail to determine the correct values of layer positions.

VII. Real Data: Model Mismatch

QOCT Scan of a Mirror

- Sufficiently accurate and robust estimations of Coincidence Rate even with sparse and noisy data
- Demonstrated in both simulations and real data

VIII. Real Data: One Pellicle Membrane

QOCT Scan of a 2 Micron Thick Pellicle Membrane

- Retrieve the correct structure of the closely spaced layered sample.