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Résumé étendu

Gouy Phase Shift in Fourier-Domain Optical Coherence Tomography

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The Gouy phase shift results from the transverse confinement of a beam. It was first demonstrated in 1890 by R. Gouy and has been the subject of numerous theoretical and experimental papers up to very recently, including non-interferometric observation in the terahertz regime. On a practical point of view, it must be considered whenever the phase of a focused beam is of importance like in the determination of the laser cavity modes.

It is a common practice in OCT systems to focus the light on a sample to obtain a good transverse resolution in addition to the axial resolution provided by the coherence gating. Each time a beam crosses a focus, it acquires a Gouy phase shift that accumulates. The spatial extent over which the phase shift is acquired is frequency dependent. When the light is collected at a fixed point in space, the accumulated phase shift is thus intrinsically frequency dependent and this dependence is amplified by chromatic aberrations. The resulting frequency dependent phase factor affects the envelope of the interferogram and can thus have a strong impact on the axial position accuracy as measured by an OCT system using the maximum of the envelope.

In a previous paper [Lamouche et al., Optics Comm., **239**,297 (2004)], we looked at this problem using Optical Coherence Tomography. A model was developed to evaluate the effect of the Gouy phase shift on the measured position of an object in a commonly used configuration in which light is delivered and collected through a fiber. An additional phase-shift contribution (the effective transverse phase shift) related to the average phase of the wavefront over the fiber aperture upon collection was considered. To illustrate the variation in apparent position related to the Gouy and effective transverse phase shifts, we performed measurements with our "`in-house"' OCT system using a supraluminescent diode (Superlum) centered at 1.310 microns. Light was delivered to the sample through a SMF-28 single mode fiber, a collimating lens of 18mm focal length (LightPath 350280), and focusing lens of 14.5 mm focal length (Melles Griot 06GLC003). Fig. 1 presents the measured position of the front face of a glass window as a function of its position relative to the focal point of the focusing lens. During the measurements, only the focusing lens was axially shifted, thus the optical thickness separating the sample and the fiber output remained constant. We observed a significant variation in the apparent position of the window when it is close to the focal region. The solid line was evaluated with the model developed taking into account the output mode diameter of the fiber and the longitudinal chromatic aberrations of the lenses by using frequency dependent focal lengths. To illustrate separately the two contributions, the dashed line presents the error in apparent position when only the accumulated Gouy phase shift is considered while the dash-dot line considers only the influence of the effective tranverse phase shift. The agreement between the measurements and the model prediction was rather good, the model providing a good estimate of the amplitude and the spatial extent of the effect.

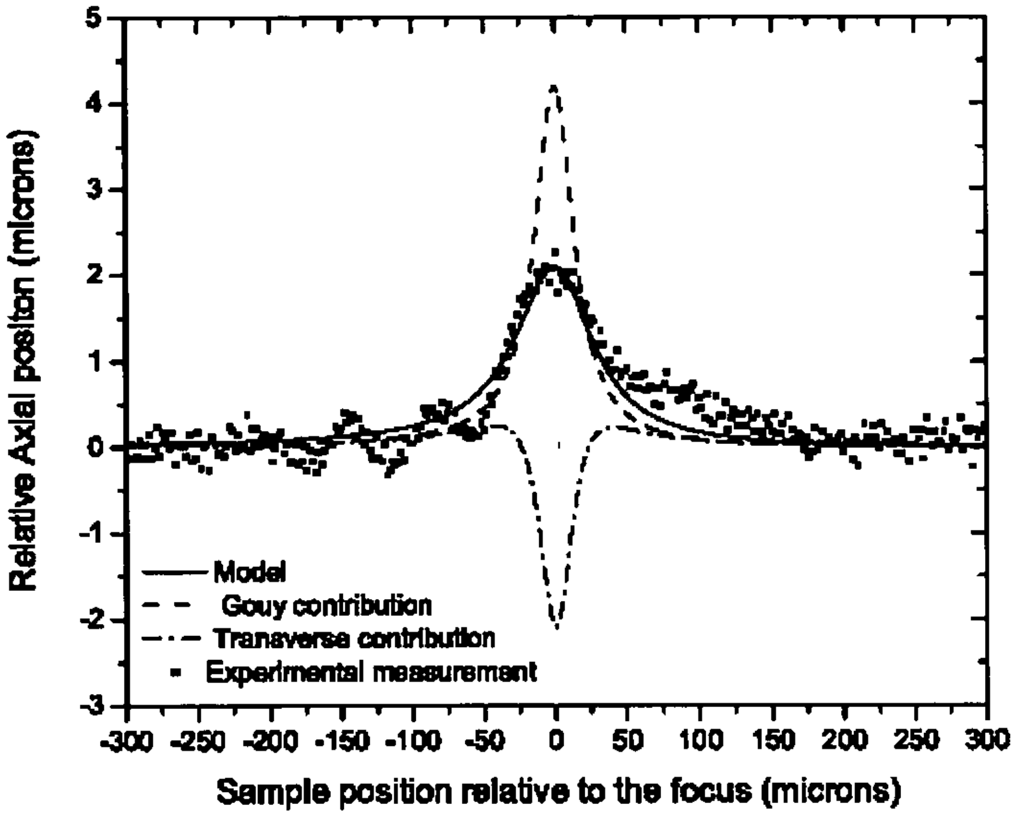

Figure 1. Experimental (dots) and modeled (solid line) apparent position of the front face of glass window as a function of its position relative to the focal point of the focusing lens. The detailed contributions of the Gouy (dash) and the effective transverse (dash-dot) phase shifts are also illustrated.

Measurements were also performed on a Mitutoyo step gauge with five levels identified as A, B, C, D, and E on Fig. 2. The calibrated step values are 10 microns, 5 microns, 2 microns, and 1 micron. The upper curve presents the surface profile as measured with our OCT system with the step B being placed at about 20 microns in front of the focal point of the focusing lens. For the combination of lenses used (collimation: Melles Griot 01LA0034 with a 36 mm focal length, focalization: Melles Griot 06GLC001 with a 6.5 mm focal length), the model suggests that such a distance is far enough from the focal point to neglect the phase shift effect on the apparent position of the levels (less than 1 micron). The agreement of the measured steps with the nominal values was very good and well within the expected OCT measurement precision. The lower curve was obtained with the beam focused on step B. The phase shifts mostly affected the apparent position of level B, giving an erroneous step value of about 15 microns between A and B and a negative step between B and C. The step value between levels A and B is was in rather good agreement with the 17 microns value predicted by the model.

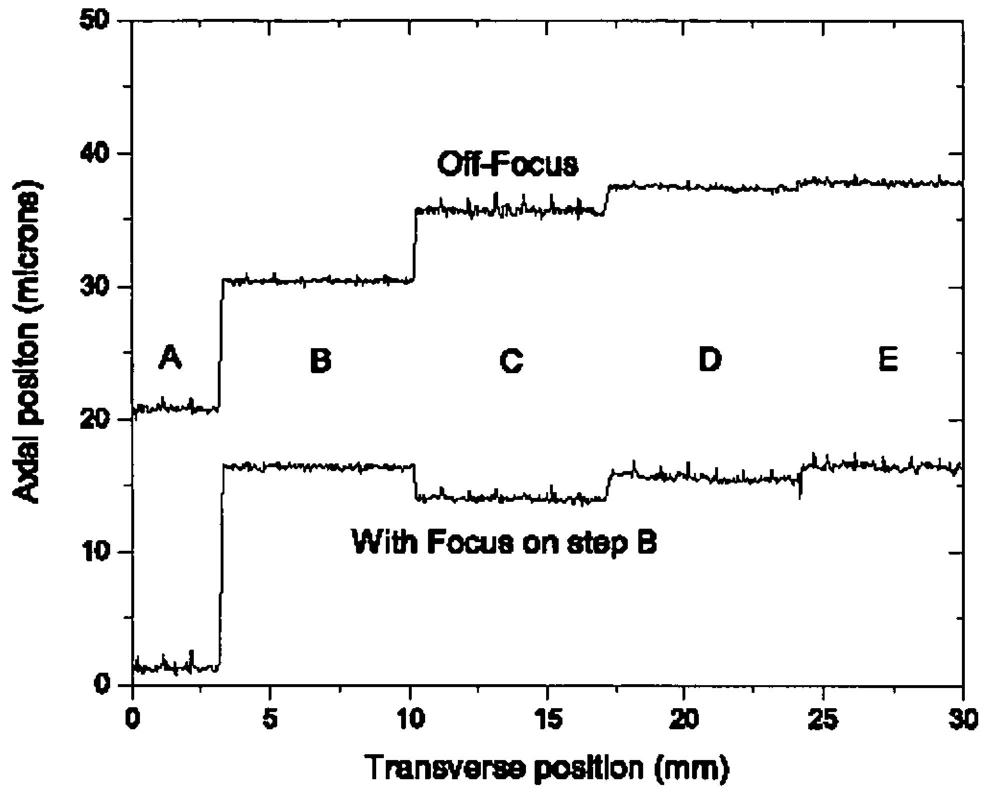

Figure 2. Surface profile of a Mitutoyo step gauge. The steps are identifed with letters. Measurements were performed with step B at a distance of 20 microns in front of the focal point of the collimating lens (upper curve) and also at the focal point (lower curve).

In the current paper, this problem is revisited with Fourier-Domain OCT by performing measurements with a Swept-Source OCT system. The amplitude of the effects is considered for various optical components. The spectral range used in the SS-OCT data processing is also varied, showing that the width of the envelope varies, but that the amplitude of the Gouy and transverse phase effects remains about the same. Since the data in Fourier-Domain OCT is collected in the frequency domain, we propose a wavelength-dependent phase shift correction that can be easily implemented in the data processing to remove the effect of these phase shifts. This work is of interest for OCT measurements that require accurate relative position measurements in the focal region.