Using Complex Master Slave protocol for OCT with bidirectional sweeping laser

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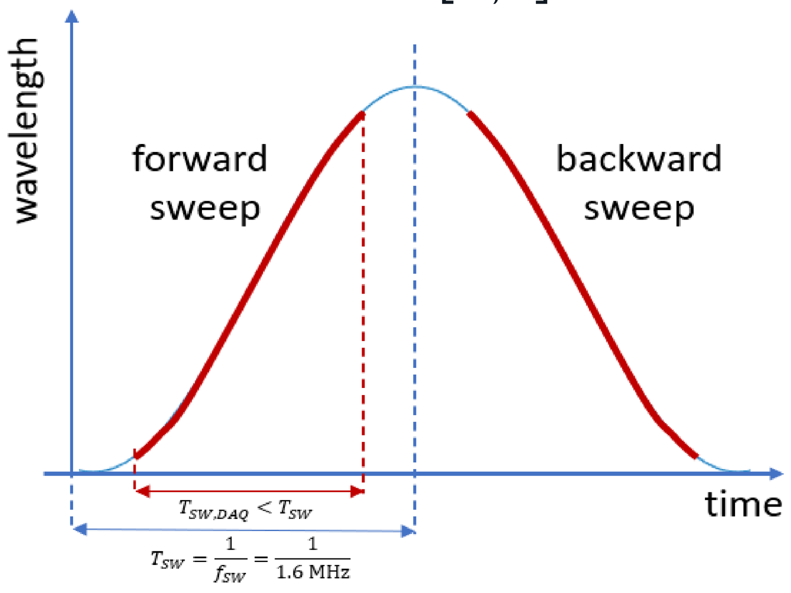
Introduction

In the past decade, sweeping techniques have improved tuning rates, yet speed limitations persist due to costly equipment and sensitivity issues. For example, in 1060 nm eye-imaging, compliance with ANSI ZI1361.1 regulations restricts power to 1.4 mW while scanning, limiting sensitivity at ultra-high speeds. MEMS-VCSEL offers a solution with MHz sweep rates but adds complexity in signal processing. Here we introduce a novel approach to leverage bidirectional sweeping, breaking the MHz barrier.

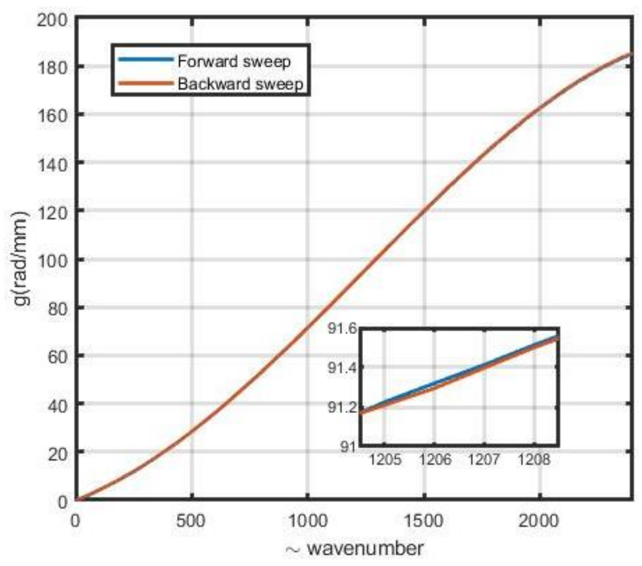
Method

In this work, the light source used is a MEMS-VCSEL with a bidirectional sweeping rate of 1.6 MHz [1]. To exploit the full performance of the swept source, both sweeps i.e. forward and backward as shown in Fig.1 (A), must be used. Bidirectional sweeping carries one central issue: the tuning curve might differ from forward to backward direction.

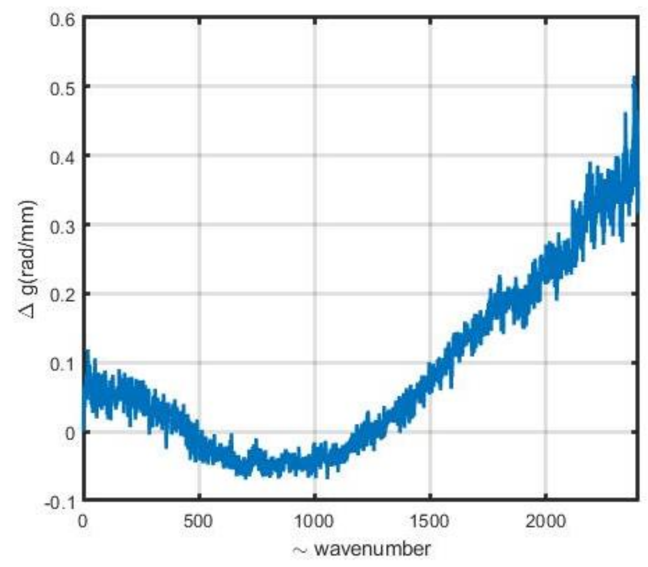
Instead of devising an additional interferometer providing the k-clock signal, we opted for a software solution based on the use of the Complex Master Slave (CMS) protocol, where for each sweep, a different set of theoretically inferred channelled spectra (masks) are used, with the masks prepared for each sweep in advance of data collection [2,3].



(A)



(B)



(C)

Figure 1. Swept laser operation: Forward and backward. (A) Drawing of the waveform applied **(B)** Sweep linearity, forward and backward sweep. **(C)** Differences between forward and backward sweep.

CMS provides advantage in processing speed with respect other phase retrieval methods since the number of axial points are a free parameter.

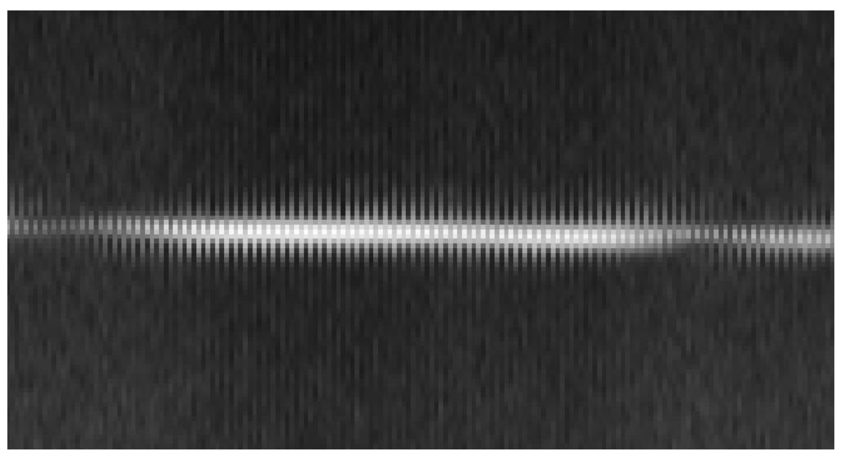
Using several experimental spectra (at least two), two functions are obtained: a function $g(k,z)$, which provides information on the nonlinear tuning and a function $h(k)$, related to the unbalanced dispersion in the interferometer

In our experiments, these functions are obtained using 5 different channelled spectra, collected for 5 optical path difference (OPD) values. The set of 5 channel spectra is used to infer all shapes of channelled spectra for any OPD. These theoretically inferred spectra are top hat channelled spectra, chirped due to sweeping nonlinearities. They are unique for each OPD; hence they are calculated for both forward and backward sweeps.

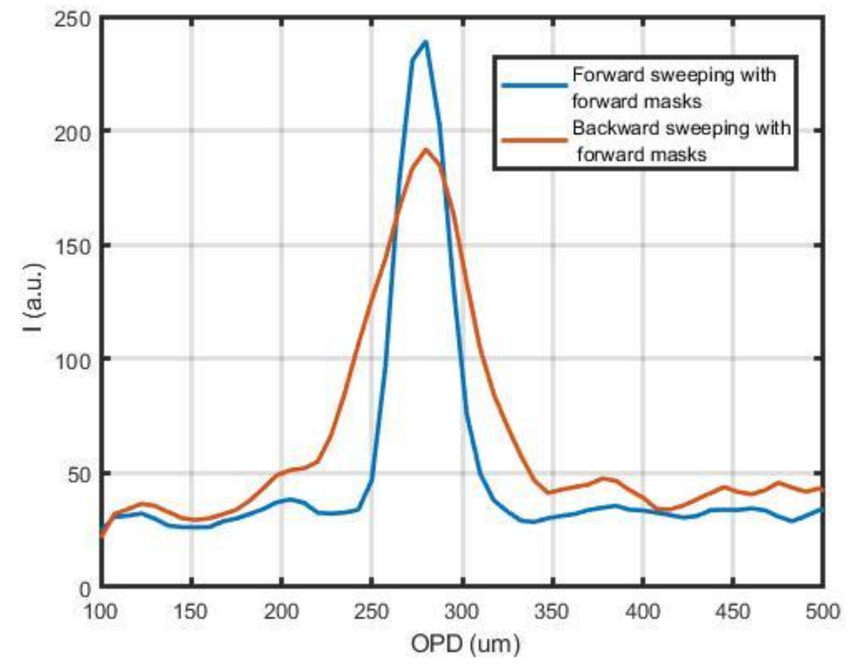
Results

The function $g(k,z)$ for the forward and the backward sweep are seen in Fig. 1 (B), with an inset showing a zoom to display better the small differences between them in Fig. 1 (C). Although the differences are small, as proven below, the A-scan peaks are affected in shape and position, especially for large OPD values.

The experimental axial resolution drops from $\sim 30\ \mu m$ to $\sim 70\ \mu m$ on the backwards sweep. Fig. 2 (A) depicts a B-Scan using forward masks for both sweeps. This difference is more noticeable at larger OPD values. However, even at a relatively small OPD (e.g. $0.3\ mm$), as shown in Fig. 2 (B).



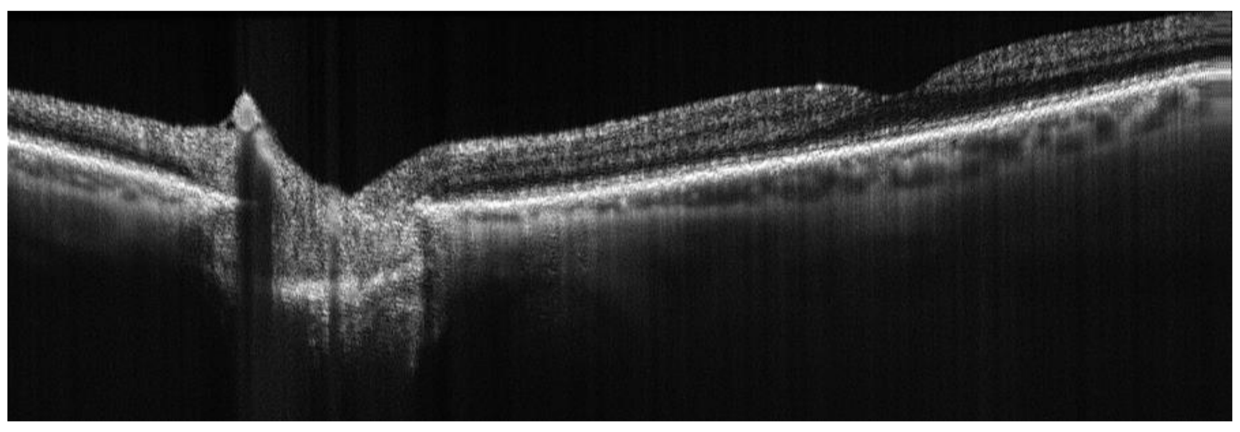
(A)



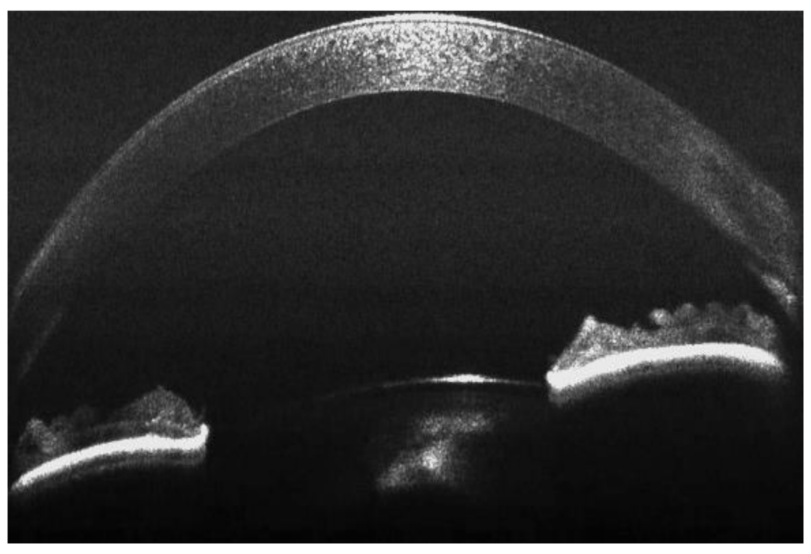
(B)

Figure 2. Bidirectional sweeping (A) B-Scan in which the masks of the forward sweep are used for forward and backward sweep. **(B) A scan** plots of consecutive sweeps.

Using this procedure, based on inferring theoretical masks on both sweeps, images of the anterior and posterior segments have been acquired. Fig. 3 (A) shows a B-Scan of the posterior segment and (B) of the anterior segment produced at 800 Hz using both sweeps. The OCT image shows that no difference in quality is perceptible once the individual masks have been used on forward and backward sweep.



(A)



(B)

Figure 3. B-Scan images using individual masks for forward and backward sweep. (A) B-Scan of the anterior segment, retina image. **(B) B-Scan** of the anterior segment.

Conclusions

As demonstrated, even small differences in the $g(k,z)$ functions between the two sweeping directions lead to significant deviations from accurate representations of A-Scans peaks. Therefore, the individual set of masks should be used for each sweep direction. The CMS processing algorithm for bidirectional sweeps is successfully tested on imaging the posterior and anterior chambers of a volunteer.

References

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