Realization of a planar Bragg grating for all-optical Hilbert transformer

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***Abstract*—An all-optical Hilbert transformer is proposed and demonstrated experimentally. We preliminarily show that an all-optical Hilbert transformer can be implemented using an apodized planar Bragg grating with a single π phase-shift. The proposed planar Bragg grating is fabricated by Direct UV writing technology in silica-on-silicon.**

Keywords-Planar Bragg grating; photonic Hilbert transformer; optical signal processing; Direct UV writing

I. INTRODUCTION

Hilbert transformers are important devices widely used in communication, information processing and signal analysis in the electronic domain [1]. An all-optical Hilbert transformer or photonic Hilbert transformer (PHT) could be expected for a similar range of applications, which would enable the direct processing of optical signals at high speeds as well as operation bandwidths far beyond current electronic technologies.

Based on discrete free space photonic components, PHTs have been realized, e.g., multi-tap fiber-optics transversal filters and sampled fiber Bragg gratings [2–5]. Recently, derived from the first-order Born approximation (weak-coupling FBG), a single phase-shifted Fiber Bragg grating (FBG) with a proper apodization profile for PHT has also been presented [6]. However, most of the references mentioned above are mainly about theoretical simulation or with multiple components; to date no simple PHT device has been experimentally reported. Here we present initial efforts to fabricate an integrated PHT, which provides a route to realize compact optical modules for applications such as single sideband (SSB) modulation.

In this letter, we practically demonstrate that an all-optical Hilbert transformer can be implemented using an appropriate apodized planar Bragg grating with a π-phase shift in the grating length. The planar Bragg grating is fabricated by direct UV grating writing technology [7].

II. OPERATION PRINCIPLE

The Hilbert transform H[g(t)] of a signal g(t) is defined as [1]:

$$H[g(t)] = \hat{g}(t) = g(t) * \frac{1}{\pi t} = \frac{1}{\pi} P\int_{-\infty}^{\infty} \frac{g(\tau)}{t-\tau} d\tau \qquad (1)$$

P stands for the Cauchy principal value of the singular integral. Its Fourier transform is given as [1]:

$$\hat{H}[g(\omega)] = -j\,\mathrm{sgn}(\omega)\hat{g}(\omega) \qquad (2)$$

Where sgn(ω) is the sign function (which is +1 for ω>0 and -1otherwise), and ω is the baseband frequency. Thus, the frequency response of the HT filter has a π-phase shift at ω=0, whereas the amplitude remains constant.

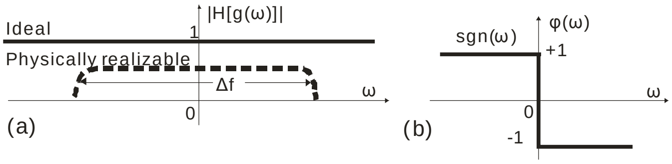

Figure 1. The magnitude responses (a) and phase response (b) of an ideal Hilbert transformer (solid lines) and physically realizable PHT (dashed lines) [8].

The π-phase shift which is the primary function of a Hilbert transformer is simply induced by placing a π-phase shift in the refractive index modulation of the Bragg grating. However in practice such a filter would have a limited frequency bandwidth and temporal impulse response. The ideal practical Bragg device could incorporate an apodization profile with the necessary π-phase shift, similar to the simple weak-coupling uniform FBG in [6]. To obtain the temporal impulse response given by (1) along a finite-time interval, the grating apodization profile is given by [6]:

$$\Delta n(z) \propto \frac{\sin^2(\pi n_{av}\Delta f(z-z_0)/c)}{(z-z_0)} \qquad (3)$$

For 0≤ z≤ L, where n_{av} is the average refractive index of the planar Bragg grating, c is the light speed in vacuum, L is the total grating length, z_0 is the zero-crossing point in the apodization function, and Δf is the operative bandwidth. z_0 is set to the centre of the grating length for simplicity. The grating period is $\Lambda=\lambda_B/2n_{eff}$.

As anticipated, the resulting grating apodization profile requires a single π-phase shift along the grating length. Besides, the zero-to-zero width of the side lobes Δz in the apodization profile is directly related to the full operation spectral bandwidth Δf of the PHT, where $\Delta z= c/(n_{av}\Delta f)$.

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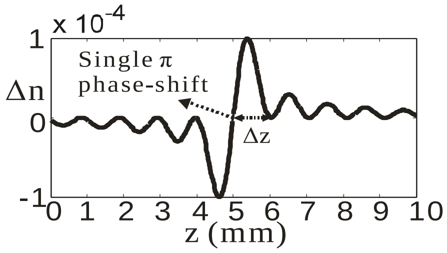

Figure 2. The apodization profile of the refractive index change Δn of the planar Bragg grating, with a single π-phase shift.

III. FABRICATION AND PRELIMILARY RESULTS

The proposed planar Bragg grating was fabricated using direct UV grating writing (DGW) technology. This method involves focusing two crossed laser beams (λ=244nm) into a photosensitive core of a planar sample. Precise translation of the sample and modulation of the interference pattern create grating structures and simultaneously define the channel waveguide [7]. This spot size is approximately 6μm in diameter, providing the unique ability over traditional FBG to manipulate the grating's structure at the micron level. This ability allows precise engineering of the amplitude and phase response of the gratings for PHT.

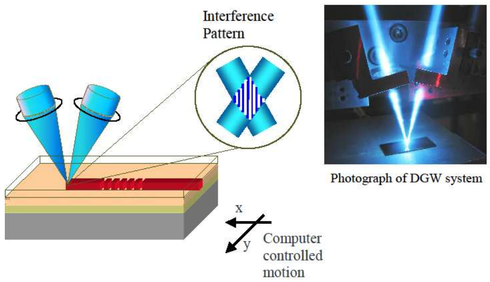

Figure 3. Illustration of the fabrication process with direct UV grating writing in silica-on-silicon.

The preliminary step is to fabricate a planar Bragg grating with exact π-phase shift. The effective refractive index of the mode within the Bragg grating was n_{eff} =1.4472, the total grating length was L = 2mm, the grating period was Λ=540.5nm and the zero-crossing point (π-phase shift point) was z_0=1mm. For this first step the grating was given a Gaussian apodization. The grating group delay in reflection was directly measured using the modulation phase-shift technique in [9].The reflection power and relative group delay are shown in Fig. 4.

IV. CONCLUSIONS

We have presented preliminarily data demonstrating the ability to fabricate exact π-phase shifted Bragg gratings with a simple apodization profile, for application as a PHT. We will present our latest work on more complex apodized gratings required to obtain the ideal realizable frequency and temporal bandwidth responses for all-optical Hilbert transformers.

In the future, the integrated nature of planar geometry will allow these devices to be combined with other functions, such as liquid crystals and thermal tuning elements to generate reconfigurable devices.

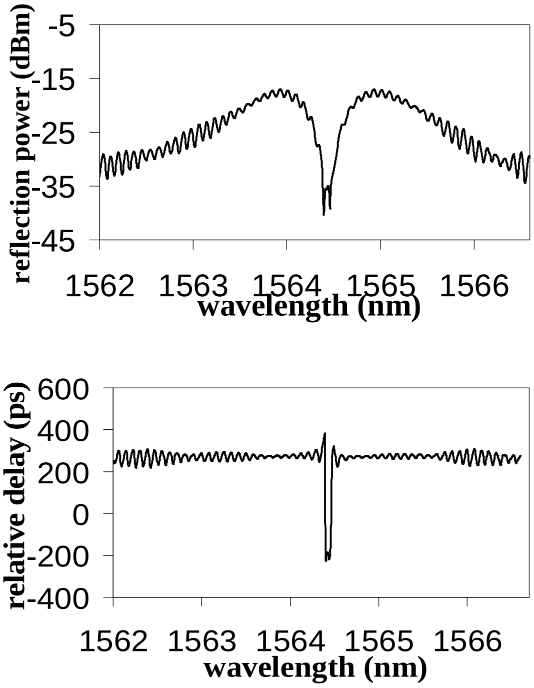

Figure 4. The measured reflection spectrum (a) and relative group delay (b) of the single π phase-shifted planar Bragg grating

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