

Determination of 20 GHz InP AWG Phase Errors by Measurement of AWG Pulse Train

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Abstract: The phase errors of a 20 GHz AWG fabricated on InP are determined by measuring the intensity and phase of the pulse train produced by the transmission of a short pulse through an AWG.

High resolution array waveguide gratings (AWG) in InP expect to play important roles in future high-performance optical communications, signal processing, and computing systems. High resolution AWGs in InP are difficult to realize due to strong sensitivity of the phase relation in the AWG to even a small amount of fabrication errors in the AWG arms. The inverse Fourier transform method[1] and optical low coherence technique[2] have determined phase errors. As a direct measurement method, this paper presents the cross-correlation frequency-resolved optical gating (XFROG) technique using an optical pulse shorter than the arm length difference to measure the intensity and phase of output pulse train. Each resolved pulse in the output pulse train travels through only one arm and provides the phase and amplitude transmission characteristics of that arm. These measurements are conducted on a 20 GHz InP AWG[3].

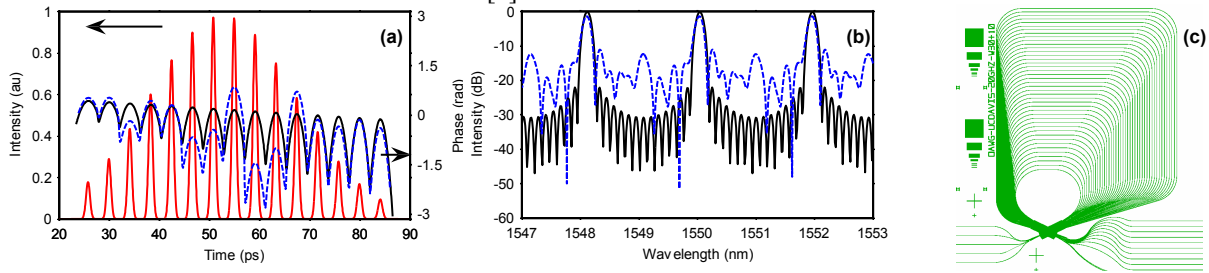


Figure 1 Description of AWG phase error measurement technique. (a) pulse train (intensity and phase) produced by AWG without (solid) and with (dashed) phase errors. (b) Optical spectrum of pulse train without (solid) and with (dashed) phase errors. (c) layout of AWG

AWGs' primary applications include narrow frequency filters and routers, therefore the description of AWG transmission frequently involved, in the spectral domain, the interference of a single wavelength travelling across many paths. In an AWG a single wavelength will travel on each arm of the AWG and acquire a different phase depending upon the optical length of the AWG arm. Following the ideal AWG transmission spectrum in Figure 1 (b) (solid), the wavelengths at the peaks of the transmission will acquire multiple of 2π phase shift from each arm and will add coherently in phase. Likewise, at all other wavelengths the phases acquired from each arm will add out of phase creating clear extinction. Small optical path length fluctuations on the AWG arms deteriorate this relationship and are referred to as the phase errors. Description of an AWG is equally informative in the time domain. Imagine transmitting a short pulse through the AWG. The pulse will split onto all the array arms, with intensity in each arm being directly related to how much diffraction occurs in the free propagation region. The pulses travel through all the arms and recombine in the output free propagation region creating a pulse train (AWG pulse train). Unlike the spectral description of an AWG, each pulse travels through a single arm, therefore the properties of each AWG arm can be separately determined by examining the intensity and phase of each pulse in the AWG pulse train. For example, the pulses travelling through shorter arms arrive earlier and acquire less dispersion, less attenuation, than the pulses travelling through the longer arms. The pulses will be spaced by the difference in propagation time between the arms. Very small changes in arm length differences, or the AWG phase errors, will appear as the phase differences of the pulses in the AWG pulse train. In the ideal situation, all the delays are perfectly equal and the phase of each pulse is the same. Figure 1(a) depicts the pulse train produced by the AWG when a short pulse (less than the arm spacing) was transmitted for an AWG with and without phase errors. Each pulse has a different amplitude due to AWG operation, peak phase deviation due to phase errors, and different phase curvature due to waveguide dispersion.

Figure 2 shows the simplified experiment to measure the AWG pulse train. A 10 GHz harmonically modelocked fiber ring laser producing 2.5 ps pulses, undergo external compressions to 500 fs, and probe the AWG. The pulses are polarization controlled to

be TE with respect to the optical chip and coupled in and out of the AWG using lensed fiber. XFROG is used to characterize the temporal intensity and phase of the AWG pulse train and the current setup has been demonstrated effective at characterizing complex waveforms[4]. Because of strong amplitude filtering associated with the AWG, losses from the waveguides, and coupling into the chip, the short pulse is amplified to 21 dBm before being launched through the chip. The output is at -17 dBm and needs to be amplified before measuring the XFROG trace. Figure 3 (c) shows the measured XFROG trace of the AWG pulse train when using a 2.5-ps transform limited reference pulse.

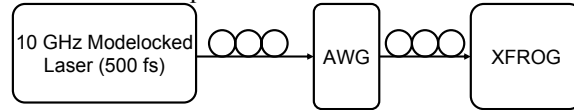


Figure 2. Simplified experimental setup

XFROG traces show the time frequency distribution of the signal as the reference pulse is delayed with respect to the signal. When using a transform limited reference pulse, the XFROG trace is generally visually informative because it shows the frequency evolution of the pulse with time. In this measurement, when the reference pulse temporally overlaps one of the pulses in the AWG pulse train the gated spectrum of that pulse appears in the XFROG trace as a vertical stripe (see Figure 3 (c)). When the reference pulse is inbetween two adjacent pulses, the gated spectrum will contain interference fringes resulting from the delay and relative phases between the two adjacent pulses. Having this interference in the XFROG trace ensures the AWG pulse train retrieved from the XFROG trace will not contain ambiguities in the phases between adjacent pulses and therefore the phase of each pulse in the AWG pulse train is known (or the phase errors). In a pulse train produced by a perfect AWG, the XFROG trace will look like a uniform grid.

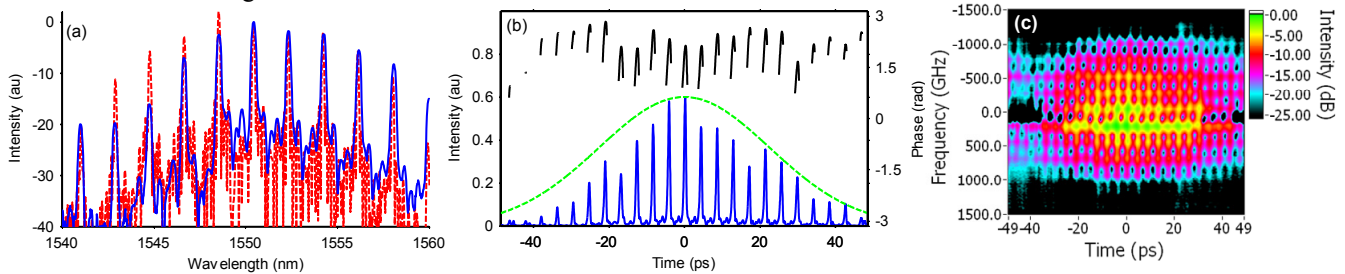


Figure 3 (a) Independently measured spectrum (solid), retrieved spectrum (dashed). (b) Retrieved pulsetrain intensity (solid line), theoretical intensity (dashed line), and phase (solid broken lines). (c) Measured XFROG trace.

To retrieve the intensity and phase of the AWG pulse train, the XFROG trace is binned to a 512x512 grid due to its complexity, the time window of the binned trace is set to the pulse period of the laser (100 ps), and the periodicity of the laser is assumed in the XFROG retrieval algorithm. Figure 3(a) shows the comparison of the independently measured spectrum to the XFROG retrieved spectrum of the output pulse train. Notice the strong resemblance of the two spectra. The shape of the passband, the noise level (15 dB), and the AWG free-spectral range match. The phase errors of the AWG are directly obtained from the phase of the AWG pulse train shown in Figure 3(b) as the phase at the peak intensity of each pulse (root mean square (rms) deviation of 28 degrees, or 0.49 radians). Each pulse is spaced by 4.2 ps and the envelope of the AWG pulse train follows a gaussian shape. The periodicity of the input pulse only allows for characterization of only a 100 ps time-window, or 23 pulses. Approximately 9 pulses from the AWG pulse trains produced by the previous and later input pulses will wrap around the edges of the time window and interfere with energy within the time window. Three of these interfering pulses can be seen in the retrieval as double pulses at the edges of the time window. However, these pulses' intensities are much weaker and their effect of the strong pulses which traveled through the central arms of the AWG are minimal. Future measurements will use pulse picking, or a lower repetition rate laser to cleanly isolate the AWG pulse train.

In conclusion, the AWG phase errors of a 20 GHz InP AWG were determined from the pulse train produced by an AWG. The rms phase errors are only 28 degrees allowing for the AWG to obtain the peak-to-background level ratio of >15 dB.

References:

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