Ring resonator with cascaded arrayed waveguide gratings for accurate insertion loss measurement

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Abstract: A device with two identical arrayed waveguide gratings (AWGs) in a DEMUX-MUX configuration within a ring resonator is proposed and modeled. This allows extracting the insertion loss of a single AWG, independent of the coupling efficiency, with less error than previous methods.

Recent interest for integrated, multi-spectral, and high-brightness light sources [1, 2] calls for low-loss arrayed waveguide gratings (AWGs). Certain applications, *e.g.* power scaling by spectral beam combining or intra-cavity AWG lasers, require insertion loss smaller than 1 dB. Such low-loss AWGs have been demonstrated on silicon dioxide (SiO_2) [3] and silicon nitride (Si_3N_4) [4, 5]. This was realized by normalizing the transmission spectra of the AWG to the transmission spectrum of a waveguide with similar facet geometry, propagation length, and bends. Variation in coupling efficiency limits the accuracy of this method [6] and new AWG designs for reducing loss are extremely difficult to experimentally characterize and compare.

To measure the insertion loss independent of coupling efficiency, we propose the structure in Fig. 1 with two identical AWGs within a ring resonator, which we refer to as the AWG^2-ring.

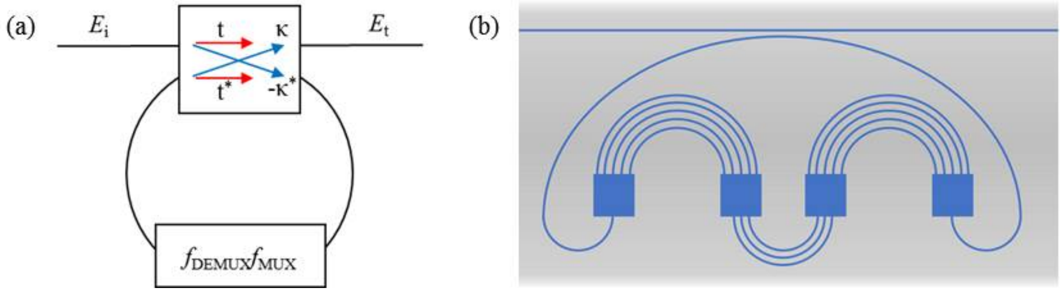

Fig. 1. (a) Block diagram of the AWG^2-ring device and (b) top-view schematic. E_i and E_t are the input and output guided electric fields; t and κ are the transmission and coupling coefficients of the coupler.

The well-known ring resonator transfer function [7] is modified by including the cascaded AWGs. This results in the following transfer function for the AWG^2-ring:

$$\frac{E_t}{E_i} = \frac{t - f_{\mathrm{DEMUX}} f_{\mathrm{MUX}}}{1 - t^* f_{\mathrm{DEMUX}} f_{\mathrm{MUX}}}, \tag{1}$$

where $f_{\mathrm{DEMUX}} f_{\mathrm{MUX}}$ is the transfer function of the cascaded AWGs. The transfer function $f(\lambda)$ of a single AWG accounts for the entire path length through each AWG. The model used in [4, 5] is modified to account for the path lengths of the input and output waveguides and each free propagation region (FPR). The result is as follows:

$$f(\lambda) = T \exp\left(ik_0 n_a L_{\mathrm{in,out}}\right) \sum_{j=0}^{N_a - 1} A_j (1 + \delta_j) \exp\left\{ik_0 [n_a L_{\mathrm{arm},j} + n_{\mathrm{FPR}} (R_a + L_{\mathrm{FPR},j})] + i\phi_j\right\}, \tag{2}$$

where T is the transmission to each receiver channel from the waveguide grating, k_0 the propagation constant, n_a the complex effective refractive index of the waveguides, $L_{\mathrm{in,out}}$ the total length of the input and output waveguides, N_a the total number of AWs, A_j the amplitude in each arrayed waveguide (AW), δ_j and ϕ_j the amplitude and phase errors in each AW, $L_{\mathrm{arm},j}$ the length of each AW, n_{FPR} the complex effective refractive index in the FPR, R_a the Rowland radius [8], and $L_{\mathrm{FPR},j}$ the length from each AW to each receiver waveguide.

An AWG with silicon core and silicon dioxide clad waveguides is modeled and Fig. 2(a) shows the transmission spectra of a single AWG $|f(\lambda)|^2$ while Fig. 2(b) shows the cascaded AWG spectrum $|f_{\mathrm{DEMUX}} f_{\mathrm{MUX}}|^2$. The overall transmittance of the AWG^2-ring is shown in Fig. 2(c). We find the insertion loss Θ of a single AWG is given by:

$$\Theta = |t|\frac{\sqrt{T_{\max}/T_0}-1}{1-|t|^2\sqrt{T_{\max}/T_0}}, \tag{3}$$

where $T_{\max}$ is the peak, off-resonance transmission measured for each channel and T_0 is the transmission outside the AWG passbands, as shown in Fig. 2(d). Each of these transmission levels are proportional to the total coupling efficiency. Therefore, the ratio $T_{\max}/T_0$ is independent of coupling efficiency, and from (3), so is the insertion loss.

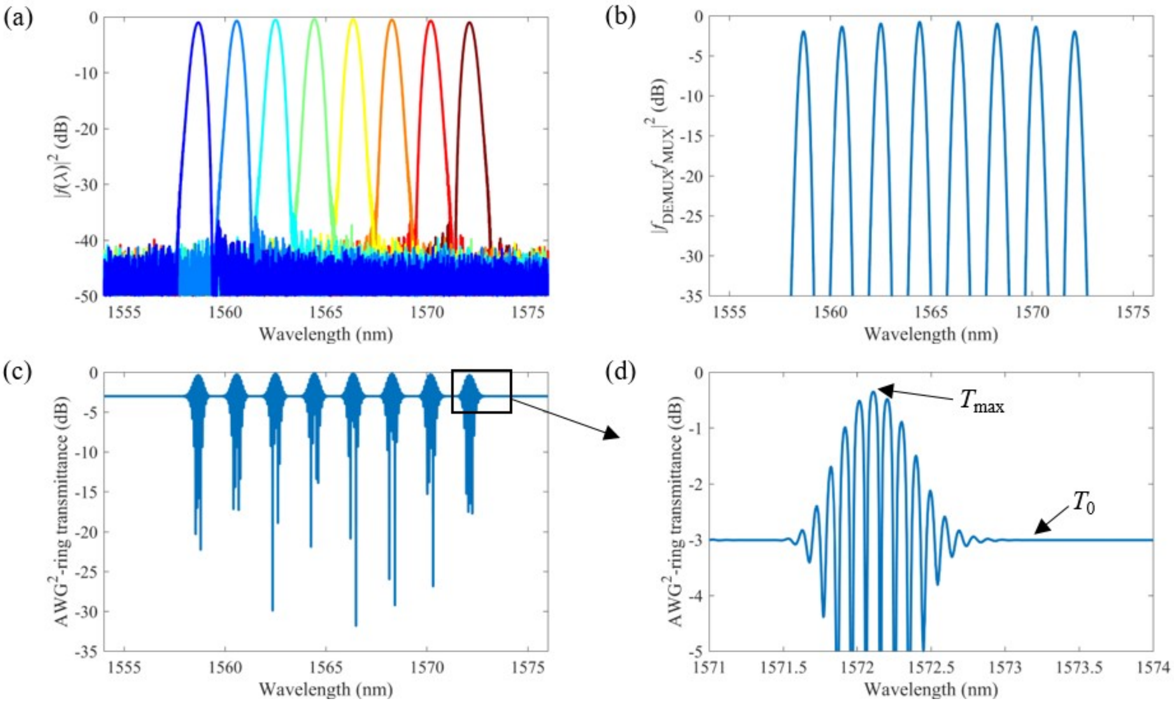

Fig. 2. Modeled transmittance for (a) a single AWG $|f(\lambda)|^2$, (b) the cascaded AWGs $|f_{\mathrm{DEMUX}} f_{\mathrm{MUX}}|^2$, and (c) the AWG^2-ring device. (d) Enlargement of (c) indicating transmission levels $T_{\max}$ and T_0.

The coupler transmission coefficient t is characterized independent of coupling efficiency from the transmittance of an unbalanced Mach-Zehnder interferometer. In conclusion, an analytic expression is presented for characterizing the insertion loss of an AWG, independent of coupling efficiency. Fabrication of the device is in progress and we will present measurements at the conference.

E.J.S acknowledges support from Office of Naval Research (ONR) contract (N00014-13-C-0147) and N.V. acknowledges support from the Swiss National Science Foundation.

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