this alignment holds also at the output end of the fiber. The output pump SOP is defined solely by the source, and as such it is supposed to be well defined and deterministic. As regarding the theory, one can repeat the derivations with the opposite sign of the z-derivative in the equation governing the evolution of the pump beam. As shown in Ref. [3], this reversing of the sign brings some changes in the components of the XPolM and Raman tensors. They become

$$J_x^{counter} = -\frac{8}{9}\mathrm{diag}(1,\,-1,\,1)\exp(-z/L_d)\,, \tag{8}$$

$$J_R^{counter} = \frac{1}{3}\mathrm{diag}(1,\,-1,\,1)\exp(-z/L_d)\,. \tag{9}$$

The factor $\frac{1}{3}$ in front of the Raman tensor immediately leads to the conclusion that the counter-propagating Raman polarizer is significantly less effective in re-polarization than its co-propagating analog. In order to get similar performances we need either to increase the pump power or lengthen the fiber, or both. If we now solve the equation of motion in the undepleted pump regime, the average gain turns out to be

$$G = \frac{1}{2}\left(\mathrm{e}^{\frac{2}{3}gPL} + \mathrm{e}^{\frac{1}{3}gPL}\right)\,, \tag{10}$$

which is significantly smaller than that of a Raman polarizer operating in the co-propagating configuration, although it is still larger than that of an ideal Raman amplifier. For the same value of the product PL, the output signal DOP in the conter-propagating configuration is also smaller than in the co-propagating case:

$$DOP = 1 - 2\left(\mathrm{e}^{\frac{1}{3}gPL} + 1\right)^{-1} \approx 1 - 2\mathrm{e}^{-\frac{1}{3}gPL}(for\, gPL \gg 1) \approx 1 - \sqrt{2}G^{-1/2}\,. \tag{11}$$

As an example, for $G = 20$ dB in the co-propagating case the DOP is as high as 99%, while in the counter-propagating configuration it is only 86%. The alignment parameter for the counter-propagating geometry is different from the co-propagating case. Still, for an unpolarized signal, the alignment parameter coincides with the DOP, $A_{\uparrow\downarrow} \approx 1 - \sqrt{2}G^{-1/2}$.

The PDG parameter $\Delta = G_{\max} - G_{\min}$ is easily calculated, resulting in

$$\Delta = \frac{1}{2}\left(\mathrm{e}^{\frac{2}{3}gPL} - \mathrm{e}^{\frac{1}{3}gPL}\right) = \frac{1}{2}\left(1 + 2G - \sqrt{1+8G}\right)\,. \tag{12}$$

Similarly, the RIN is expected to be lower. This is confirmed by its obtained variance:

$$\sigma_s^2 = \frac{1}{3}\left[1 - 2\left(\mathrm{e}^{\frac{1}{3}gPL} + 1\right)^{-1}\right]^2\,. \tag{13}$$

In conclusion, we have presented a tractable analytical model for Raman polarizers that is able to predict their most relevant parameters, providing accurate estimations for the output DOP, alignment parameter, PDG and mean gain, as well as being capable of predicting the variance of the RIN noise produced by PDG. This analytical approximation is reduced, in the diffusion limit, to the traditional description of the depolarized Raman amplifier, whereas in the Manakov limit it describes the behavior of an ideal Raman polarizer.

Acknowledgments

The authors wish to thank the financial support of Italian Ministry of University and Research project no.2008MPSSNX and the Spanish Ministerio de Economía y competitividad (MINECO) grant TEC2011-27314. The work of Javier Nuño is partly supported by the Ministerio de Economía y competitividad (MINECO) through an FPI Fellowship.