Scattering Effect in Optical Microring Resonators

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INTRODUCTION

Optical microring resonators are of great interest for monolithic and integrated optoelectronic applications. In fact, passive ring resonators side-coupled to signal waveguides provide compact, narrow band, and large free spectral range optical channel dropping filters [1]. On the other hand, active ring resonators lead to obtain small occupation area, high side-mode suppression ratio, and reduced sensitivity to feedback. Due to the fabrication advances, the performance limits of both passive and active microring resonators are mainly influenced by optical scattering effects.

THEORY

In general, the ring resonator sidewall roughness or boundary imperfections can have two significant detrimental effects: 1) energy scattering towards the radiation field, reducing the total quality factor of the optical mode; 2) power redistribution between two counter-propagating modes. The backscattering coefficient and scattering losses have been calculated using the volume current method [2], by assuming that the sidewall imperfections can be described by a random function having a Gaussian distribution for its self-correlation function as:

$$corr(s-s') = \sigma_c^2 \exp\left[-\left(s-s'\right)^2 / L_c^2\right] \qquad (1)$$

being s the relevant curvilinear coordinate, L_c the correlation length and σ_c the standard deviation.

NUMERICAL RESULTS

The numerical simulations for a passive ring resonator have been performed by considering a tightly confined GaAs-AlGaAs input waveguide at λ=1.55 μm, a microring with radius 5 μm, and an output waveguide. Fig. 1 shows the normalized power at the end of input waveguide versus the wavelength detuning for different values of L_c with σ_c=4.7 nm. Fig. 2 shows the detuning from the travelling-wave optimal condition (minimum trasmittivity) as influenced by roughness-induced scattering in terms of L_c and different values of σ_c. Fig. 3 plots the optimal coupling factor versus L_c for various σ_c. It is clear that the optimum travelling-wave condition cannot be met in the presence of strong scattering effects.

Numerical simulations for an active microring resonator have been performed by considering a standard GaAs-AlGaAs quantum well structure. Fig. 4 shows the stationary values of the two counter-propagating mode intensities (Modes 1 and 2) versus L_c for various σ_c, by assuming an injection current I=100mA (one well). The plot shows a critical value $\sigma_{c,th}$ (4.7 nm in this case), depending of injection current. where the unidirectional changes to bidirectional regime. In Fig. 5, the mode intensities are sketched versus the ring radius for various injection currents with L_c=0.07 μm and σ_c= 12 nm. Thus, it is possible to observe that the operating regime of the active ring resonator is influenced by the ring cavity sizes. Finally, Fig. 6 describes the influence of the grating included in the output waveguide to induce an unidirectional behavior. The 3D plot shows the intensities of the Mode 1 (red surface) and Mode 2 (blue surface) versus the grating reflectivity and the output coupling coefficient (I=100 mA, L_c=0.07 μm, σ_c= 12 nm).

CONCLUSION

In this paper we present an investigation of the detrimental effects due to roughness-induced scattering on the properties of both passive and active optical microring resonators.

REFERENCES

[1] C. Manolatou and H. A. Haus, *Passive components for dense optical integration,* Kluwer Acad. Publ., (2002).

[2] M.N. Armenise, V.M.N. Passaro, F. De Leonardis, M. Armenise, *Modeling and design of a novel miniaturized integrated optical sensor for gyroscope systems*, J. Lightwave Technol., **19**, 1476 (2001).

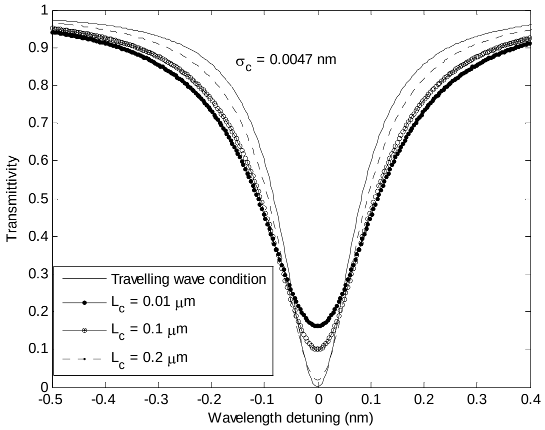

Fig. 1. Transmittivity versus wavelength detuning for different correlation lengths (σ_c = 4.7 nm) in a passive ring.

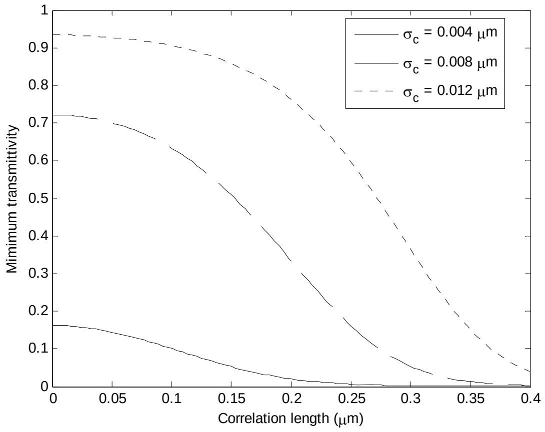

Fig. 2. Minimum transmittivity versus correlation length for various standard deviations of ring sidewall roughness function.

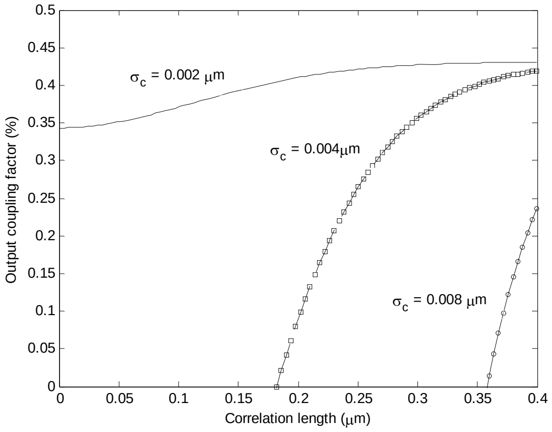

Fig. 3. Output coupling factor versus correlation length for different standard deviations in a passive microring.

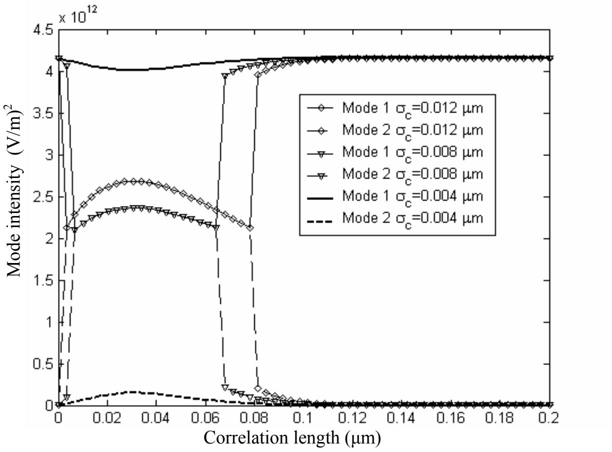

Fig. 4. Mode intensities versus correlation length for various standard deviations of the active ring roughness function.

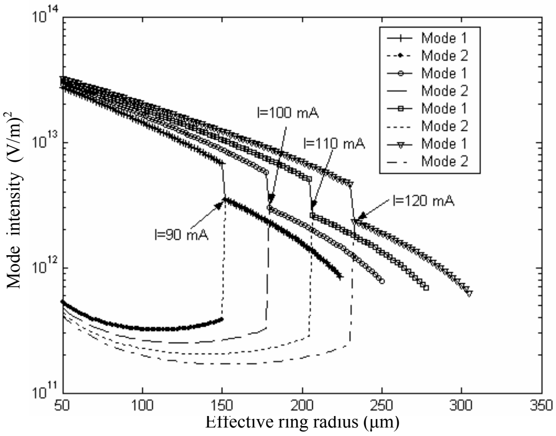

Fig. 5. Mode intensities versus effective ring radius for various injection currents.

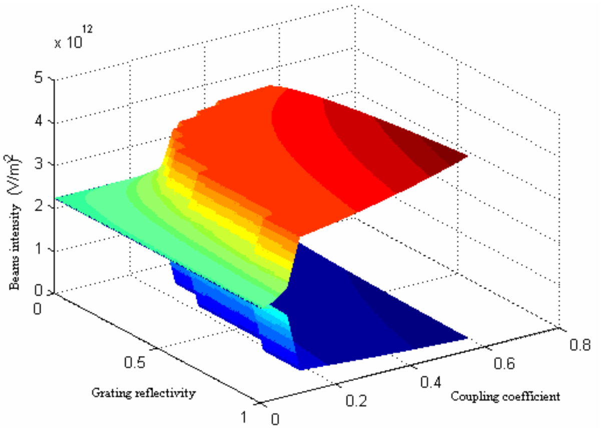

Fig. 6. Mode intensities versus grating reflectivity and output coupling coefficient in an active microring.