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Optimum entangled photon generated by micro-ring resonators for new-generation interferometry use

P.P. Yupapin*, P. Yabosdee

Advanced Research Center for Photonics, Department of Applied Physics, Faculty of Science, King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520, Thailand

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Abstract

We first propose a concept of a new interferometric technique, where the ultra-narrow spectral width of light pulse generated by using the micro-ring resonators can be used to perform the ultra-high-resolution interferometer. Firstly, the SHG using micro-ring resonators is analyzed and described, Secondly, the increasing in optical path difference (OPD) depends on the full-width at half-maximum (FWHM) width of the generated pulse is discussed. Finally, the optimum entangled photon visibility can be formed the quantum interferometer where the measurement resolution of 10^{-5}–10^{-7} in term of birefringence is achieved. The use of such systems for quantum interferometer, high-resolution interferometer and surface characterization are described.

Keywords: New-generation interferometry; Harmonic generation; Micro-ring resonator; Ultra-high resolution

1. Introduction

Nonlinear behaviors of light in a ring resonator have been widely investigated by Yupapin et al. [1]. While more details of nonlinear behaviors in fiber optic with some benefits are also described by Ferreira [2]. They have shown that the nonlinear penalties such as chaos, bifurcation and bistability, which introduce the system degradation become benefits. Yupapin and Suwancharoen [3,4] have proposed the use of nonlinear behavior where the information security using the chaotic signals in the micro-ring device can be made. In principle, the chaotic codes could be generated and cancelled between the specific clients. By this technique, the capacity of the transmission data can be secured and increased when the chaotic packet switching is employed. They have also shown that the telephone networks can be included in the secure communication unit within the system. Alternatively, Yupapin and Suchat [5,6] have demonstrated that the use of nonlinear behavior known as four-wave mixing (FWM) of light in a fiber optic ring resonator could be used to generate a pair of the entangled photons. The advantage of such a system is that there is no optical pumping part and component included in the system (i.e. an all fiber optic scheme), which is a remarkably simple arrangement, and it is easy to implement in the practical applications. However, the problem of the fiber optic property known as a fiber birefringence could affect the optimum entangled state visibility after traveling within a length of the fiber. Trojek et al. [7] have analyzed the timing-walk off on the entangled photons in fiber optic, which could be

*Corresponding author. Tel.: +66 02 3264339; fax: +66 02 3264354.
E-mail address: kypreech@kmitl.ac.th (P.P. Yupapin).
URL: http://www.kmitl.ac.th/~arcp (P.P. Yupapin).

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compensated by using the phase retardation device. To shift the polarization orientation angle, therefore, the polarization controller (PC) device is recommended to use for adjusting and preserving the entangled states along the fiber optic length. Moreover, Fietz and Shvets [8] have reported that the polarized entangled photons can be generated by using a micro-ring device, which is associated with the practical devices which have been fabricated. Recently, Yang et al. [9] have shown the promising results when the enhanced second harmonic generation in AlGaAs micro-ring resonators is obtained. In this paper, the use of micro-ring device for SHG is proposed. The clear SHG is obtained by using chaotic signals propagating in a series of micro-ring resonators, where the specific wavelength of second harmonic modes is generated. The polarized photon is controlled by using the appropriate ring parameters, where the optimum entangled photon visibility after projection on the measurement detectors is achieved. Finally, we have shown that the ultra-narrow spectral width of the generated pulses; second harmonic and center wavelength pulses can be performed the high measurement resolution. Two ultra-high-resolution interferometers have been proposed, which one is a classical interferometer, the other is a quantum interferometer. The increasing in measurement resolution in term of optical path difference (OPD) and walk-off compensation (i.e. birefringence) is described.

2. SHG in micro-ring resonators

To generate the specific wavelength of a second harmonic pulse, the simple device schematic diagram is as shown in Fig. 1, when light from a monochromatic light source is launched into each ring resonator with constant light field amplitude (E_0) and random phase modulation (ϕ_0), which results in temporal coherence degradation. Hence, the input light field (E_{in}) can be expressed as

$$E_{in}(t) = E_0 \exp^{j\phi_0(t)} \tag{1}$$

We assume that the nonlinearity of the optical ring device is of the Kerr-type, i.e., the refractive index is given by

$$n = n_0 + n_2 I = n_0 + \left(\frac{n_2}{A_{eff}}\right) P \tag{2}$$

where n_0 and n_2 are the linear and nonlinear refractive indexes, respectively. I and P are the optical intensity and optical field power, respectively. The effective mode core area of the device is A_{eff}.

Thus, the normalized output of the light field can be expressed as

$$\left|\frac{E_{out}}{E_{in}}\right|^2 = (1-\gamma)^2 \times \left[1 - \frac{\kappa[1-(1-\gamma)^2\tau^2]}{1+(1-\gamma)^2(1-\kappa)\tau - 2(1-\gamma)\sqrt{1-\kappa}\tau\cos\phi}\right] \tag{3}$$

The close form of Eq. (3) indicates that a ring resonator in the particular case to very similar to a Fabry–Perot cavity, which has an input and output mirror with a field reflectivity, $1-\kappa$, and a fully reflecting mirror, where n_0 and n_2 are the linear and nonlinear refractive indices, the coupling coefficient is κ. Where $x = \exp^{-(\alpha L/2)}$ represents the one round-trip losses coefficient, $\phi_0 = kLn_0$ and $\phi_{NL} = kLn_2|E_1|^2$ are the linear and nonlinear phase shifts, respectively, and $k = 2\pi/\lambda$ is the wave propagation number in a vacuum.

This nonlinear behavior of light traveling in a single-ring resonator (SRR) is described. When the parameters of the system are fixed to optical input power = 450 mW, $\lambda_0 = 1.55\,\mu m$, $n_0 = 3.34$, $A_{eff} = 25\,\mu m^2$, where the waveguide ring resonator loss is $\alpha = 0.5\,dB\,mm^{-1}$. The practical bending loss of the waveguide fabricated by InGaAsP/InP is confirmed by Ref. [4], where the propagation loss as low as $1.3 \pm .02\,dB\,mm^{-1}$ at $1.55\,\mu m$, the fractional coupler intensity loss is $\gamma = 0.1$, and $R_1 = 17\,\mu m$. The coupling coefficient of the fiber coupler is fixed to $\kappa = 0.995$. The nonlinear refractive index used is $n_2 = 2.2 \times 10^{-15}\,m^2\,W^{-1}$, and the data of 20,000 iterations of roundtrips inside the optical micro-ring is plotted. We assume that $\phi_L = 0$ for simplicity, however, the change in phase is slightly altered the optical output, which means the dispersion can be neglected when the resonant output is occurred. In general, the input pulse can be a single pulse or pulse

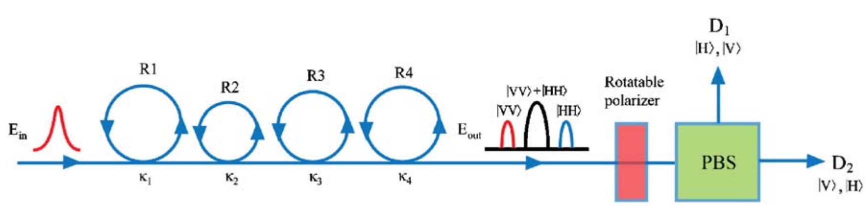

Fig. 1. A schematic of the design system. PCs: polarization controllers, Ds: detectors—Avalanche photo-detector and PBS: polarization beam splitter.