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MOLECULAR TRANSPORTER SYSTEM FOR QUBITS GENERATION

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Abstract. A molecular cryptography technique using optical tweezers, is proposed. The optical tweezer transports the molecules in the communication system. The optical tweezer generated by the dark soliton is in the form of a potential well. The dark soliton propagates inside nonlinear microring resonator (NMRR). Transportation of molecules is implemented when the dark soliton is used as input pulse. The input bright soliton control the output signal at the drop port of the system. Output optical tweezers can be connected to the quantum signal processing system consisting of transmitter and the receiver. The transmitter is used to generate the high capacity quantum codes within the series of MRR's and an add/drop filter. The receiver will detect the encoded signals known as quantum bits. The transmitter will generate the entangled photon pair which propagates via an optical communication link. Here the smallest optical tweezer with respect to the full width at half maximum FWHM is 17.6 nm in the form of potential well is obtained and transmitted through quantum signal processor via an optical link.

Keywords: Internet security; optical tweezers; quantum cryptography; quantum signal processing; entangled photon pair

1.0 INTRODUCTION

Dark-bright soliton controls within a semiconductor add/drop multiplexer has numerous applications in optical communication [1]. Optical tweezers technique is recognized as a powerful tool for manipulation of micrometer-sized particles in three spatial dimensions. It has the unique ability to trap and manipulate molecules at mesoscopic scales with widespread applications in biology and

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physical sciences [2]. The output is achieved when the high optical field is set up as an optical tweezers [3]. In many research areas, the optical tweezers is used to store and trap light, atom, molecule or particle within the proposed system.

The tweezers in the forms of valleys or potential wells are kept in the stable form within the add/drop filter. Schulz *et al.* [4] have shown that the transferring of trapped atoms between two optical potentials could be performed. MRR's are type of Fabry-Perot resonators which can be readily integrated in array geometries to implement many useful functions. Its nonlinear phase response can be readily incorporated into an interferometer system to produce specific intensity output function [5]. Several emerging technologies, such as integrated all optical signal processing and all-optical quantum information processing, require interactions between two distinct optical signals. Optical tweezer tools can be used to trap molecules or photons [6].

Internet security becomes an important function in the modern internet service. However, the security technique known as quantum cryptography has been widely used and investigated in many applications, using optical tweezers [7]. Yupapin *et al.* [8] have proposed a new technique for QKD (Quantum Key Distribution) which can be used to make the communication transmission security. It also can be implemented with a small device such as mobile telephone hand set. Mitatha *et al.* [9] have proposed a new design of secured packet switching. This method uses nonlinear behaviors of light in MRR which can be used for high-capacity and security switching. Recently quantum network shows promising usage for the perfect network security [10]. To date, QKD is the only form of information that can provide the perfect communication security. Yupapin *et al.* [11] have shown that the continuous wavelength can be generated by using a soliton pulse in a MRR. The secret key codes are generated via the entangled photon pair which is used to security purposes using the dark soliton pulse propagation. In this study, a molecular cryptography system based on optical soliton is developed.

2.0 THEORETICAL MODELING

The dark soliton pulse is introduced into the multiplexer system shown in Figure 1. Dynamic behavior of the optical tweezers is appeared when the bright soliton is input into the add port of the system. The add-drop optical filter system has radius of R_{ad} = 15 μm where the coupling coefficients are $\kappa_1 = 0.35$ and $\kappa_2 = 0.7$. The dark and bright solitons are propagating inside the proposed system with the centre wavelength of λ_0 = 1.4 μm. The nanoring resonator is connected to an add-drop interferometer system with radius (R_{ring}) of 100nm and coupling coefficient (κ) of 0.15.

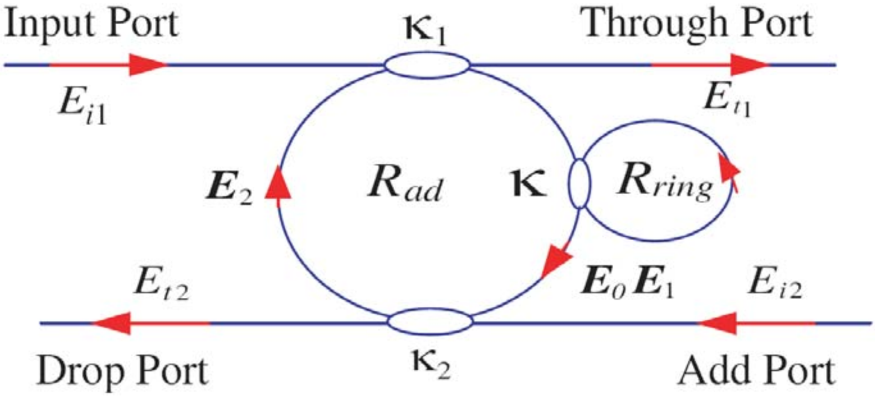

Figure 1 A schematic diagram of an add/drop filter [12]

The input optical field (E_{in}) of the dark soliton and add optical field (E_{add}) of the bright soliton pulses are given by [13]

$$E_{in} = A\tanh\left[\frac{T}{T_0}\right]\exp\left[\left(\frac{z}{2L_D}\right)-i\omega_0 t\right] , \tag{1}$$

$$E_{in} = A\sec h\left[\frac{T}{T_0}\right]\exp\left[\left(\frac{z}{2L_D}\right)-i\omega_0 t\right] \tag{2}$$

In Equations (1) and (2), A and z are the optical field amplitude and propagation distance, respectively. T is defined as soliton pulse propagation time in a frame moving at the group velocity, $T = t-\beta_1 \times z$, where β_1 and β_2 are the coefficients of the linear and second order terms of Taylor expansion of the propagation constant. $L_D = T_0^2 / |\beta_2|$ represents the dispersion length of the soliton pulse. The frequency shift of the soliton is ω_0. When a soliton pulse keeps its temporal width invariance as it propagates, it is called a temporal soliton. For the intensity of soliton peak as $\left(\left|\beta_2 / \Gamma T_0^2\right|\right)$, T_o is known. A balance should be achieved between the dispersion length *(L_D)* and the nonlinear length *(L_{NL}= $(1/\gamma\varphi_{NL})$*, where γ and φ_{NL} are the coupling loss of the field amplitude and nonlinear phase shift. They are the length scale over which dispersive or nonlinear effects makes the beam becomes wider or narrower. It means that the L_D=L_{NL} should be satisfied. During the propagating of light within the nonlinear medium, the refractive index (n) is given by

$$n = n_0 + n_2 I = n_0 + (\frac{n_2}{A_{eff}})P, \tag{3}$$

In Equation (3), n_0 and n_2 are the linear and nonlinear refractive indexes, respectively. I and P represent the optical intensity and optical power, respectively. The effective mode core area of the device is given by A_{eff}. For the MRR and NRR, the effective mode core area ranges from 0.50 to 0.10 μm^2 [14]. In Figure 1, the resonant output is formed, thus, the normalized output of the light field is the ratio between the output and input fields $E_{out}(t)$ and $E_{in}(t)$. The output and input signals in each roundtrip of the nanoring resonator at the right side can be calculated using equation (4).

$$\left|\frac{E_{out}(t)}{E_{in}(t)}\right|^2 = (1-\gamma)\left[1 - \frac{(1-(1-\gamma)x^2)\kappa}{(1-x\sqrt{1-\gamma}\sqrt{1-\kappa})^2 + 4x\sqrt{1-\gamma}\sqrt{1-\kappa}\sin^2(\frac{\phi}{2})}\right] \tag{4}$$

The close form of Equation (4) indicates that this ring resonator is comparable to a Febry-Perot cavity. It has an input and output mirror with a field reflectivity, $(1-\kappa)$, and a fully reflecting mirror. Here κ is the coupling coefficient, and $x=exp(-\alpha L/2)$ represents a roundtrip loss coefficient, $\Phi_0=kLn_0$ and $\Phi_{NL}=kLn_2|E_{in}|^2$ are the linear and nonlinear phase shifts, $k=2\pi/\lambda$ is the wave propagation number in a vacuum. L and α are a waveguide length and linear absorption coefficient, respectively. In this work, an iterative method is inserted to obtain the needed results using equation (4).

Cancelation of the chaotic signals noise can be done by using the add-drop device with the appropriate parameters. This is given in details as follows. The two complementary optical circuits of ring-resonator add-drop filters can be given by the Eqs. (5) and (6).

$$\left|\frac{E_t}{E_{in}}\right|^2 = \frac{(1-\kappa_1) - 2\sqrt{1-\kappa_1}\cdot\sqrt{1-\kappa_2}e^{-\frac{\alpha}{2}L}\cos(k_n L) + (1-\kappa_2)e^{-\alpha L}}{1 + (1-\kappa_1)(1-\kappa_2)e^{-\alpha L} - 2\sqrt{1-\kappa_1}\cdot\sqrt{1-\kappa_2}e^{-\frac{\alpha}{2}L}\cos(k_n L)} \tag{5}$$

and

$$\left|\frac{E_d}{E_{in}}\right|^2 = \frac{\kappa_1\kappa_2 e^{-\frac{\alpha}{2}L}}{1 + (1-\kappa_1)(1-\kappa_2)e^{-\alpha L} - 2\sqrt{1-\kappa_1}\cdot\sqrt{1-\kappa_2}e^{-\frac{\alpha}{2}L}\cos(k_n L)} \tag{6}$$

where E_t and E_d represent the optical fields of the throughput and drop ports respectively. $\beta = kn_{eff}$ is the propagation constant, n_{eff} is the effective refractive index of the waveguide and the circumference of the ring is $L=2\pi R$. R is the radius of the ring. The phase constant can be simplified as $\Phi=\beta L$. The chaotic noise cancellation can be managed by using the specific parameters of the add-drop device in which required signals can be retrieved by the specific users. The waveguide (ring resonator) loss is $\alpha = 0.5\ dBmm^{-1}$. The fractional coupler intensity loss is $\gamma = 0.1$. In the case of add-drop device, the nonlinear refractive index is neglected [15]. The output fields E_{t1} and E_{t2} at throughput and drop parts of the system are expressed by

$$E_{t1} = -x_1 x_2 y_2 \sqrt{\kappa_1} E_{i2} e^{-\frac{\alpha L}{2}} - jk_n \frac{L}{2} +$$

$$\left[\frac{x_2 x_3 \kappa_1 \sqrt{\kappa_2} E_0 E_{i1} (e^{-\frac{\alpha L}{2}} - jk_n \frac{L}{2})^2 + x_3 x_4 y_1 y_2 \sqrt{\kappa_1} \sqrt{\kappa_2} E_0 E_{i2} (e^{-\frac{\alpha L}{2}} - jk_n \frac{L}{2})^3}{1 - x_1 x_2 y_1 y_2 E_0 (e^{-\frac{\alpha L}{2}} - jk_n \frac{L}{2})^2} \right], \quad (7)$$

$$E_{t2} = x_2 y_2 E_{i2} + \left[\frac{x_1 x_2 \kappa_1 \sqrt{\kappa_1} \sqrt{\kappa_2} E_0 E_{i1} e^{-\frac{\alpha L}{2} - jkn\frac{L}{2}} + x_1 x_3 y_1 y_2 \sqrt{\kappa_2} E_0 E_{i2} (e^{-\alpha \frac{L}{2} - jk_n \frac{L}{2}})^2}{1 - x_1 x_2 y_1 y_2 E_0 (e^{-\frac{\alpha L}{2} - jk_n \frac{L}{2}})^2} \right]. \quad (8)$$

Where the $x_1 = \sqrt{1-\gamma_1}$, $x_2 = \sqrt{1-\gamma_2}$, $x_3 = 1-\gamma_1$, $x_4 = 1-\gamma_2$, $y_1 = \sqrt{1-\kappa_1}$ and $y_2 = \sqrt{1-\kappa_2}$.

3.0 RESULT AND DISCUSSION

Figs. 2(a)-(c), shows the tweezers in the form of potential wells which can be use to atom/molecule trapping. The storage time of 1.2 ns obtained. The widths of the storage tweezers at add-drop filter, throughput and drop ports are 19.2, 17.6 and 18.6 ns, respectively with 20,000 roundtrips of input power. By adjusting the parameters such as the bright soliton power at the input and add port and the coupling coefficients, the potential well depth would be controlled and tuned. For instance, the potential well of the tweezers is tuned to be the single well and seen at the add port, as shown in Figure 2(c). The smallest tweezers width of 17.6nm is generated and achieved. In application, such a behavior can be used to confine the suitable size of light pulse or molecule. The transportation of the trapped atom/molecule/photons can be obtained by a single photon. Therefore the detection of the transported single atom/molecule can be assembled by using the single photon detection method. Thus, the transported molecule/atom for long distance communication via molecular transporter is practical.

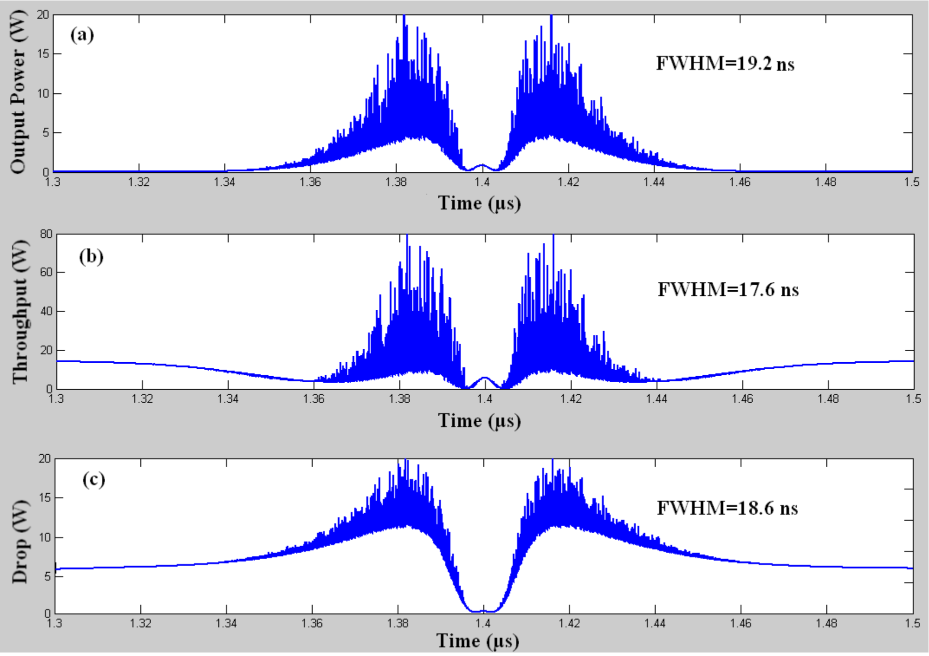

Figure 2 Result of the optical tweezers storage signals in the add/drop system, where R_{ad} = 15 μm and R_{ring} = 100 nm, κ = 0.15, κ_1 = 0.35 and κ_2 = 0.1. (a) storage tweezer, (throughput port signal, and (c)drop port signal

The proposed transmission unit is a quantum processing system that can be used to generate high capacity packet of quantum codes within the series of MRR's where, the cloning unit, is operated by the add/drop filter (R_{dN1}) shown in Figure 3 [16]. In operation, the computing data can be modulated and input into the system via a receiver unit which is encoded to the quantum signal processing system. The receiver unit can be used to detect the quantum bits. It is obtained via the end quantum processor and the reference states can be recognized by using the cloning unit, which is operated by the add/drop filter (R_{dN2}).

By using suitable dark-bright soliton input power, the tunable optical tweezer can be controlled. This provides the entangled photon as the dynamic optical tweezer probe [17]. The required data can be retrieved via the drop port of the add/drop filter in the router. The high data capacity can be applied by using more wavelength carriers provided by the correlated photon generated.

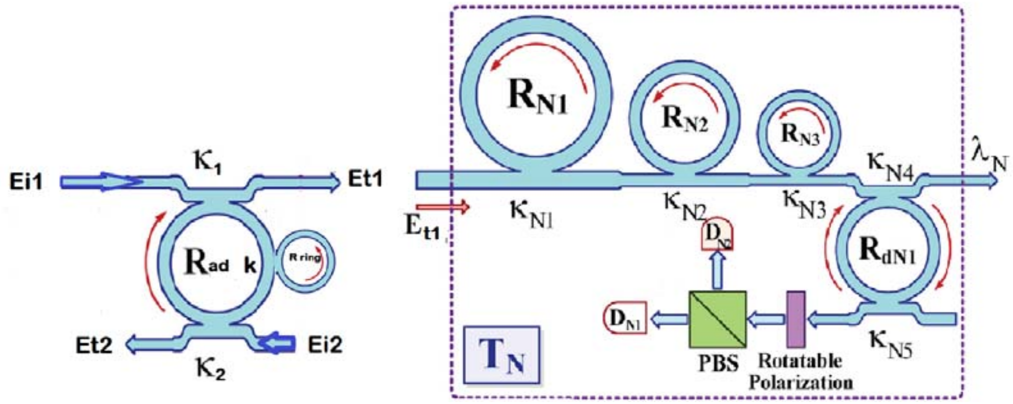

Figure 3 A schematic of the quantum tweezers manipulation within a ring resonator at the receiver unit (R_N) where R_{NS}: ring radii, κ_{NS}: coupling coefficients, R_{dNS}: an add/drop ring radius, can be used to be the received part

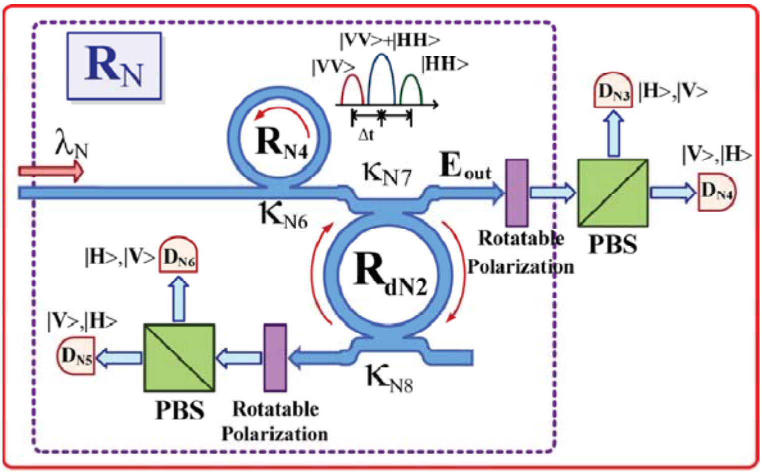

Figure 4 A schematic of an entangled photon pair manipulation within a ring resonator. The quantum state is propagating to a rotatable polarizer and then is split by a beam splitter (PBS) flying to detector D_{N3}, D_{N4}, D_{N5} and D_{N6}

From Figure 4 it can be seen that there are two pairs of possible polarization entangled photons forming within the MRR device, which are the four polarization orientation angles as [0°, 90°], [135° and 180°]. These can be done by using the optical component, called the polarization rotatable device and a polarizing beam splitter (PBS). The polarized photon is used in the proposed arrangement. Each pair of the transmitted qubits can itself forms the entangled photon pairs. Polarization coupler separates the basic vertical and horizontal polarization states. Each one corresponds to an optical switch between the short and the long pulses. The horizontally polarized pulses have a temporal separation of Δt. The coherence time of the consecutive pulses is larger than Δt. Then the following state is created by Equation (9) [18].

$$|\Phi>_p=|1, H>_s |1, H>_i+|2, H>_s |2, H>_i \qquad (9)$$

Here k is the number of time slots (1 or 2), which denotes the state of polarization (horizontal |H> or vertical |V>). The subscript identifies whether the state is the signal (s) or the idler (i) state. This two-photon state with |H> polarization shown by Equation (6) is input into the orthogonal polarization-delay circuit. The delay circuit consists of coupler and the difference between the round-trip times of the microring resonator, which is equal to Δt. The microring is tilted by changing the roundtrip of the ring is converted into |V> at the delay circuit output. The delay circuit converts |k, H> into

$$r|k, H> + t_2 \exp(i\Phi) |k+1, V> + rt_2 \exp(i_2\Phi) |k+2, H> + r_2t_2 \exp(i_3\Phi) |k+3, V>$$

Here t and r are the amplitude transmittances to cross and bar ports in a coupler. Equation (9) is converted into the polarized state by the delay circuit as

$$\begin{gathered}|\Phi>=[|1, H>_s + \exp(i\Phi_s) |2, V>_s] \times [|1, H>_i + \exp(i\Phi_i) |2, V>_i] \\ + [|2, H>_s + \exp(i\Phi_s) |3, V>_s \times [|2, H>_i + \exp(i\Phi_i) |2, V>_i] = \\ [|1, H>_s |1, H>_i + \exp(i\Phi_i) |1, H>_s |2, V>_i] + \exp(i\Phi_s) |2, V>_s |1, H>_i + \\ \exp[i(\Phi_s+\Phi_i)] |2, V>_s |2, V>_i + |2, H>_s |2, H>_i + \exp(i\Phi_i) |2, H>_s |3, V>_i + \\ \exp(i\Phi_s) |3, V>_s |2, H>_i + \exp[i(\Phi_s+\Phi_i)] |3, V>_s |3, V>_i \qquad (10)\end{gathered}$$

By the coincidence counts in the second time slot, we can extract the fourth and fifth terms. As a result, we can obtain the following polarization entangled state as

$$|\Phi>=|2, H>_s |2, H>_i + \exp[i(\Phi_s+\Phi_i)] |2, V>_s |2, V>_i \qquad (11)$$

The response time of the Kerr effect is assumed to be much less than the cavity round-trip time. Because of the Kerr nonlinearity type, the strong pulses acquire an intensity dependent phase shift during propagation. The interference of light pulses at the coupler introduces the entangled output beam. The polarization states of light pulses are changed and converted during the circulation in the delay circuit, leading to the formation of the polarized entangled photon pairs. The entangled photons of the nonlinear ring resonator are then separated into the signal and idler photon probability. The polarization angle adjustment device is applied to investigate the orientation and optical output intensity.

The transporter states can be controlled and identified using the quantum processing system as it is shown in Figs. 3 and 4. In operation, the encoded quantum secret codes computing data can be modulated and input into the system via a wavelength router. Schematic of the wavelength router is shown in Figure 5, in which quantum cryptography for internet security can be obtained.

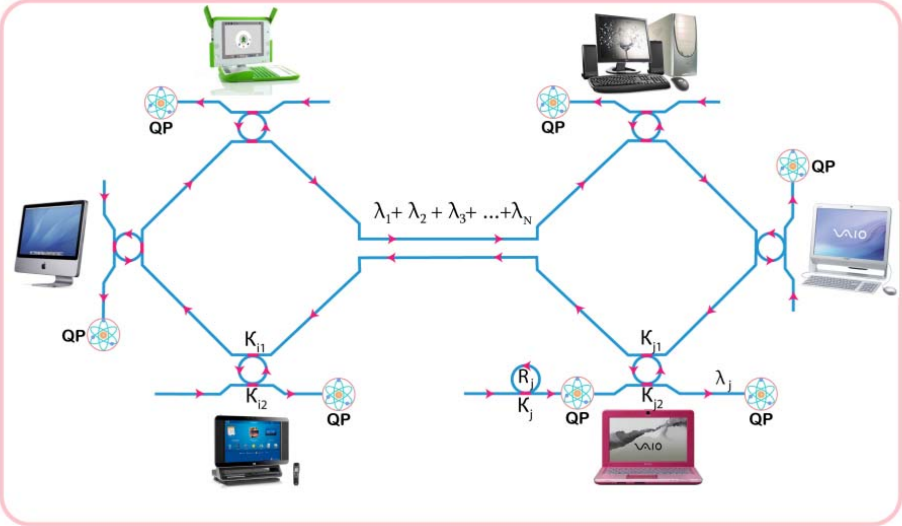

Figure 5 A system of quantum cryptography for internet security via a wavelength router, where QP: Quantum Processor, R_i : ring radii, λ_i : output wavelength, κ_j , κ_{ji} are coupling coefficients.

4.0 CONCLUSION

The novel system of molecular cryptography for secured optical communication has been demonstrated. The optical tweezer is generated by the dark soliton propagating in a MRR. The quantum signal processing unit is connected to the optical tweezer which is able to generate qubits thus providing the secured high capacity information. This secured coded information can be easily transmitted. This work can be extended and become very interesting if new system of micro and nano ring resonators are used to improve the capacity of the qubits date codes. The new system is known as PANDA ring resonator which consists of one add-drop interferometer connected to two nano ring resonators at the right and left sides. In order to enhance the capacity of transmission data codes, the multi tweezer in the form of potential well, can be generated when the dark soliton propagating inside the PANDA ring resonator.

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