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Design of all-optical memory cell using EIT and lasing without inversion phenomena in optical micro ring resonators

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ABSTRACT

The proposed design of the optical memory unit cell contains dual micro ring resonators in which the effect of lasing without inversion (LWI) in three-level nano particles doped over the optical resonators or integrators as the gain segment is used for loss compensation. Also, an on/off phase shifter based on electromagnetically induced transparency (EIT) in three-level quantum dots (QDs) has been used for data reading at requested time. Device minimizing for integrated purposes and high speed data storage are the main advantages of the optical integrator based memory.

1. Introduction

All-optical memory or buffer is a key element in optical packet switching (OPS) networks as it can resolve the packet contention problem. Tunable optical delay lines and optical memories will be important building blocks in advanced photonic integrated circuits (PICs) which offer the possibility to combine numerous optical functions including switching, modulation and amplification on a single substrate. Such integration offers new opportunities for optical information processing and all optical communication networks. Most of the optical buffering schemes produce a delay time of the data stream, such as slowing light, optical fiber loop and so on. In fiber loop optical memories, the storage time can be up to 1ms however, the setup is bulky because typically at least several meters long of fiber are required for the fiber loop [1,2].

Coupled resonator optical waveguides (CROW) have been extensively used to build slow light devices [3,4].Flip-flop memory is one kind of the most interesting memory types. However, it is still a great challenge to realize ultra-fast flip-flop operation with the switching time on picosecond time scale for GHz data memory [5]. An optical random access memory (RAM) cell has been demonstrated in [6] that employs two SOA-based ON/OFF switches and two coupled semiconductor optical amplifier- Mach Zender interferometer (SOA-MZI) gates forming an optical flip-flop. The transfer function of the optical RAM cell and its incorporated flip-flop device exhibit periodic resonance frequencies resembling the behavior of optical ring resonator configurations. Optimized RAM cell designed with waveguide coupling lengths lower than 5 mm can enable RAM operation at memory speeds well beyond 40 GHz. Its free spectral range is mainly dictated by the length of the waveguide that enables the coupling of the two SOA-MZI gates [6].

Ring resonators are also used in design of the random access all-optical memory unit cells in which a data bit is stored in a resonator. It is shown that the resonator-based optical memories are ultimately limited by losses in the resonators, the extinction ratio and chirp of the variable coupling medium that injects and extracts data into and out of the resonators, and the chirp on the input signal [7]. An all-optical 1-bit Random Access Memory (RAM) with massive use of nonlinear material has been proposed. The all-optical switch by a composite slab of linear medium (LM) and non-linear medium (NLM) is the building block of proposed 1-bit RAM circuit. An all-optical clocked D flip flop is the main storing element of the RAM. The storing and reading time of this memory cell will be in fs [8].

A nano-optomechanical static RAM (SRAM) integrated with light modulation system on a single silicon chip is reported in which bistability of silicon beam due to the non-linear optical gradient force generated from a ring resonator determines the memory states. The optical SRAM has write/read time around 120 ns, which is much faster as compared with traditional MEMS memory [9].

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A memory unit cell based on active micro ring resonators and electro absorption modulator (EAM) in Mach Zender interferometer (MZI) form has been presented in [10,11] which can operate as an optical switch. The proposed unit cell cannot operate as all-optical element and has large size to appear in integrated chip [10,11].

A dual-microring resonator configuration with a shared 3×3 coupler with far-field coupling has been used to demonstrate a dynamical slow light cell by controlling the group delay through thermo-optically detuning the resonant frequencies of the two rings in which usable group delays up to 24 ps are measured, with losses <1 dB [12].

Micro ring resonator (MRR) have been used to generate and trap chaotic signals along fiber optic communication [13]. The parameters such as refractive indices of a silicon waveguide, coupling coefficients, coupling loss and the input power can be selected properly to operate the nonlinear behavior. The trapping of signals could be obtained after the signals were transmitted along the fiber optic and finally received by suitable optical receiver. The FWHM and FSR of the trapped signals have been reported as 600 fm and 45 pm [13,14].

Various designs of all-optical information storage devices, e.g., photonic logic gates and optical switching for read-in and read-out has been suggested based on the EIT phenomenon. The steady and transient optical behaviors of a four-level N-type atomic vapor have been considered in [15]. It has been shown that the absorption (or transmittance) of the probe light in the atomic vapor depends on the intensity ratio of the signal field to the control field and the quantum interference between the two fields. Conditions for complete absorption and dissipation-free propagation of probe light has been discussed. Hence, the probe light can be stored and released by the atoms by adjusting the value of the discussed ratio. The present mechanism can be applicable to designs of new photonic and quantum optical devices such as light storage, optical switches and photonic logic gates.

The propagation of optical pulses in a media with EIT effect has been analyzed in both adiabatic and non-adiabatic situations. The possibility of changing the direction of the pulse by a switch of control beam direction has been proposed [16].

The optical response of an EIT-based periodic layered medium whose unit cells consist of dielectrics at the presence of EIT atomic vapor flexibly sensitive to probe frequency, has been presented in [17]. According to results, a very small change in probe frequency can lead to a drastic variation of reflectance and transmittance. Also, in the case of large layer number (i.e. $N=100$), the reflectance and transmittance depend sensitively on the Rabi frequency of the control field since the destructive quantum interference relevant to two-photon resonance arises in EIT atoms interacting with both control and probe fields. The sensitive optical switching control is utilized to design photonic logic gates such as NOT gate with the control and probe fields as the input and the output of the gate, respectively. Consequently, a two-input logic gate, such as NOR (NOT-OR) gate, based on the tunable optical response can be demonstrated [17].

A low-loss all-optical switch based on the EIT and the quantum Zeno effect in a microdisk resonator has been suggested in [18]. As it has been discussed, a control beam can modify the atomic absorption of the evanescent field which suppresses the cavity field buildup and alters the path of a weak signal beam with less than 0.1 dB loss.

All-optical switching (AOS) or cross-phase modulation based on the EIT effect has also been demonstrated in the recent years [19]. Studies show that the existence of four-wave mixing (FWM) process greatly diminishes the switching or phase-modulation efficiency and hinders the single-photon operation. However, with an optimum detuning the EIT-based AOS can be completely intact even under the influence of FWM. This makes the AOS and XPM schemes more flexible and the single-photon operation possible in FWM-allowed systems.

In this paper, an all-optical memory unit cell based on microring resonators and directional couplers is designed in which EIT and LWI techniques are used to achieve required phase shift and amplify optical pulse, respectively to make a delay line. A single optical integrator is known for generating an optical step function [10]. Our proposed dual optical integrators can realize a scheme of controllable optical memory unit, with a phase shift element introduced for the data reading control. The advantage of such all-optical memory unit is that it has a compact size for densely integration and large scale data storage and it is very convenient to be cascaded. Secondly it can realize the controllable read operation, we can read out the data bit at any time we need, and the read out response time of the read operation is very fast. The high speed operations in picoseconds scale is demonstrated. Compared to the flip-flop memory, the main advantage of the optical integrator based memory is that the rising edge is the cumulative time integral of the input pulse, so it is as fast as the bit rate, and this performance is very important for the high speed data storage. Also, by using three-level nanoparticles doped to the ring resonator and LWI method and EIT technique, optical power loss in data storage and the required phase shift for read process have been controlled. Thus, this designed all-optical memory unit cell can work in low power high-speed situations.

2. Memory design

A 2×2 direct coupler as an optical integrator is shown in Fig. 1, where, α' is the power coupling coefficient of the directional coupler. The field in the resonator is assumed to propagate in the counter clockwise direction. When light propagates a round-trip or a sampling period T, the field is enhanced due to the positive feedback until all the input light pulse is injected. After that the light intensity is still kept on, because of the loss compensation supplied by the active gain medium.

By doping 3-level nanocrystals (quantum dots) into gain and phase shifter segments in ring resonator and using LWI and EIT techniques we get the required gain and phase shift to read out the stored data. Fig. 1 illustrates Λ type 3-level nanoparticles doped into ring resonator as the gain segment. The control field is applied in resonant with $|2\rangle-|3\rangle$ transition and the probe field is applied to $|1\rangle-|3\rangle$ transition respectively.

2.1. EIT and LWI

Now, we consider a 3-level atom as show in Fig. 1. Levels $|1\rangle$ and $|3\rangle$ are coupled by probe field of amplitude E_p and frequency ν, whose dispersion and absorption we are interested. Level $|2\rangle$ is

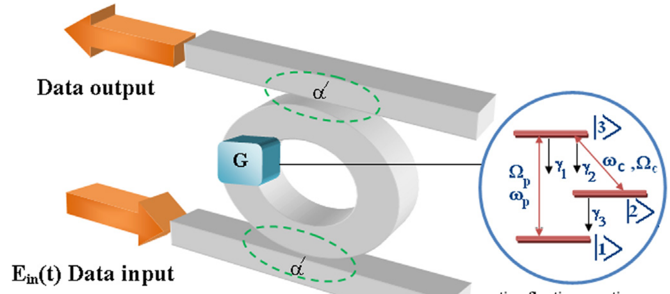

Fig. 1. The scheme of ring resonator as an optical integrator with three level Λ-type QD as gain segment.

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