shown in Fig. 2. Initially, the $J$ increased slowly with $V$ ranging from 1 to 8 V. This phenomenon would result from the series resistance of the n-type layer of the c-Si substrate and the conduction band offset ($\Delta E_c$) at the n-a-Si:H/n-c-Si hetero-interface. The cathode of the fabricated TFLED was fabricated on the backside of the c-Si substrate, hence the injected electrons had to move across the c-Si substrate and the current density as the voltage was within 1–8 V and was constrained by the series resistance of the n-layer of the c-Si substrate. Also, the $\Delta E_c$ at the n-a-Si:H/n-c-Si interface due to the difference of electron affinities for n-a-Si:H and n-c-Si would also retard transport of the injected electrons, as indicated in Fig. 1c. However, as the voltage is higher than 10 V, the device $J$ increased quickly with applied voltage. The increased device $J$ would be due to mainly two mechanisms, thermionic emission and multi-step tunneling capture-emission mechanisms [9]. For the first one, since the applied voltage was higher, the injected electrons would have more than sufficient energy to overcome the $\Delta E_c$ at the n-a-Si:H/n-c-Si interface and hence the device current density could be enhanced. For the second one, the electrons above the donor level in the n-c-Si substrate would multi-step-tunnel from the n-a-Si:H/n-c-Si interface and hence enough carriers could be supplied for radiative recombinations in the luminescent a-SiC:H layer. The obtained TFLEDs had a brightness of 855 cd/m² at an injected current density and light intensity of 8, 1500 mA/cm² and an EL spectrum was a broad one, as shown in the inset of Fig. 2. The broad EL spectrum could result from the radiative recombinations via tail states to tail states in the luminescent i-SiCH layer. The tail states near the band edge of i-a-SiC:H are quasi-continuously distributed, hence the energy differences for electron transition from conduction-band-edge tail states to valence-band-edge tail states are broad and would result in an EL intensity having a flat-top wavelength ranging from 600 to 690 nm and a wide FWHM of ~205 nm. This is also evidenced by the log ($J$) against log ($V$) curve having a slope of $n=0.98$, which indicated the tail-states-to-tail-states recombination was dominant [10].

Conclusions: The characteristics of SiO₂-isolated visible anormous Si-based TFLEDs having n-a-Si:H/n-c-Si hetero-interface were investigated. This intentionally-made amorphous Si-based TFLED structure could be integrated with the silicon n-channel MOSFET driving circuits. The results of this work demonstrate an alternative for developing Si-based light-emitting devices on c-Si substrate.

References

Variable semiconductor all-optical buffer

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A compact variable all-optical buffer using semiconductor quantum dot structures is proposed. The buffering effect is achieved by slowing down the optical signal using an external control light source to vary the propagation characteristic of the medium. The theoretical model shows that a slow-down factor of more than 10 with negligible group velocity dispersion is achievable.

Introduction: The all-optical packet switched network is highly promising for next generation broadband optical fibre communications. A most critical yet missing component is an all-optical buffer. An ideal buffer should have a storage length that is adjustable by an external control. Furthermore, the turn-on (store) and turn-off (release) time should be shorter than a fraction of a bit period. In this Letter, a semiconductor optical buffer is proposed to attain the required functionalities. The principle is based on designing a device with a group velocity that can be controllably slowed down, which effectively constitutes an adjustable memory.

Fig. 1 Schematic diagram of optical buffer device based on semiconductor quantum dot structures

Fig. 2 TFLED current density and brightness against applied voltage

Inset: EL spectrum

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There have been major breakthroughs recently in achieving slow light using electromagnetically induced transparency (EIT) [1]. Slowdown factors as high as seven-orders of magnitude have been reported in both atomic vapour cells [2] and Fe-doped Y2SiO5 crystals [3]. The slow light principle is based on creating destructive interference between two optical transitions in electronic states by means of an optical pump field, modifying the dispersion spectrum experienced by the optical signal. Other mechanisms such as a Mie-grating [4], have also been found to modify the dispersive characteristics. We propose a buffer using EIT in semiconductor quantum dot (QD) structures. A schematic diagram of the proposed buffer is shown in Fig. 1 with QD layers to slow down the light. The signal and the pump lights co-propagate or counter-propagate in the same waveguide. The pump light induces EIT and slows down the signal light velocity. QDs act like giant 'atoms' in which the potential confinement in three dimensions creates quantized electron and hole levels. The number of confined energy states can be controlled by choosing the materials and geometries of the QD.

Model description and analysis: For a three-level system in which |1⟩→|2⟩ and |2⟩→|3⟩ transitions are dipole-allowed, the time-dependent optical dielectric constant ε for the signal light can be derived from the density-matrix formulation. For simplicity, we assume the signal (S) is weak compared to the pump (P) light such that the Rabi frequencies Ω = e_{12} / 2 where Ω_S = e_{12} S / 2 and Ω_P are the complex electric field amplitudes. We choose signal and pump light frequencies to coincide with |1⟩→|2⟩ and |2⟩→|3⟩ transitions, respectively, but allow the signal to have a small detuning δ = ε_{12} - ε_{23} from the energy separation hω_{23} between |1⟩ and |2⟩. In this case, the system has optimum performance and we can write the dimensionless dielectric constant at the steady state for the signal light as

\[
e = \varepsilon_{\text{vac}} + \frac{U_{23}}{\varepsilon_0 c^2 \omega^2} (\delta - \gamma_{23})
\]

In (1), \( U_{23} = (\Gamma / V) |\langle \mu_2 | \mu_1 \rangle|^2 f_1 f_2 e_{12} / 4 h^2 c^2 \), \( \varepsilon_0 c^2 \omega^2 \) is the background dielectric constant without coupling to any light; \( \varepsilon_0 = 8.85 \times 10^{-12} \, \text{F/m} \); \( \Gamma \) is the optical confinement factor; \( V \) is the volume of the QD; \( f_2 \) is the pump power density (MW/cm²), \( c \) is the speed of the light in the vacuum; \( \gamma_{23} \) is the coherently damped coupling rate (linewidth) between the QD and the signal field; \( \gamma_{12} \) accounts for the dephasing between |2⟩ and |1⟩; \( f_1 \) and \( f_2 \) are Fermi-Dirac occupation factors. The signal velocity is given by the group velocity if there is no distortion from group velocity dispersion. The signal velocity slowdown factor \( S \), the absorption coefficient \( \alpha \), and the group velocity dispersion \( D \) are determined from the first and the second derivatives of \( e \) with respect to the frequency. In the following discussions, we assume the signal detuning \( \delta = 0 \). In this case, \( \alpha = 0 \).

\[
\alpha = \frac{\sqrt{2} \omega c U_{23}}{\varepsilon_0 c^2 \omega^2 \varepsilon_{\text{vac}} (\varepsilon_{\text{vac}} + \varepsilon_{2Pc}(\varepsilon_{20c} + \varepsilon_{2PP}))} \left( \frac{\varepsilon_{20c} + \varepsilon_{2PP} + \varepsilon_{2Pc}}{\varepsilon_{20c} + \varepsilon_{2PP} + \varepsilon_{2Pc}} \right)^{1/2}
\]

and \( S \) is given by

\[
S = \sqrt{\frac{\varepsilon_{\text{vac}} + \varepsilon_{20c} + \varepsilon_{2PP}}{\varepsilon_{\text{vac}} + \varepsilon_{20c} + \varepsilon_{2PP}}} \left( \frac{1 + \frac{h\omega^2}{2 \sqrt{\varepsilon_{\text{vac}} + \varepsilon_{20c} + \varepsilon_{2PP}^2}}}{\sqrt{\varepsilon_{\text{vac}} + \varepsilon_{20c} + \varepsilon_{2PP}^2}} \right)^{1/2}
\]

where \( \omega_{20c} (\Omega_{2PP}) = \omega_{20c} (\Omega_{2PP}) \cdot (\varepsilon_{20c} - \varepsilon_{2PP}) \) and \( \omega_{20c} = \omega_{20c} (\Omega_{2PP} = 0) \). The buffer has a storage time \( \tau = L \varepsilon_{20c} / c \) for a device of length \( L \) and a turn-on threshold at pump power density \( \Omega_{20c} \). For a small \( \omega_{20c} \), \( S \) has a maximum when \( \Omega_{2PP} = \omega_{20c} (\varepsilon_{20c} + \varepsilon_{2PP}^2) \). For high pump power density and small \( \omega_{20c} \), \( S \) approaches the upper bound of system performance given by

\[
S_{\text{max}} = \frac{\omega_{20c}}{2 \sqrt{2} \omega_{2PP}}
\]

Conversely, for low pump power density and large \( \omega_{20c} \), we no longer have EIT and the QD resumes a Lorentzian absorption spectrum. For a large \( \omega_{20c} \) or \( \omega_{20c} \), \( \alpha \propto 1 / \omega_0^2 \) and for a small \( \omega_{20c} \) or \( \omega_{20c} \), \( \alpha \propto \sqrt{\omega_{20c}} / \omega_0 \).

The absorption coefficient can be reduced by choosing different pump power. We define a figure-of-merit \( F \) as the measure of total buffer time before the signal has to be re-amplified. For small product of \( SL \), which is the case for practical applications, \( F \) is given by

\[
F = \frac{S}{\omega_0}
\]

F has a minimum at finite pump power density and scales as \( F \propto P \) when \( P \) is large. Therefore the buffer performance can be optimised by choosing the best combination of slow-down factor and the absorption.

The absorption coefficient can be reduced by choosing different pump power. We define a figure-of-merit \( F \) as the measure of total buffer time before the signal has to be re-amplified. For small product of \( SL \), which is the case for practical applications, \( F \) is given by

\[
F = \frac{S}{\omega_0}
\]

Numerical results: In this numerical calculation, we use disk-shaped QD; |1⟩ is chosen to be the hole level in the valence band; |2⟩ and |3⟩ are chosen to be the electronic levels in the conduction band. In our calculations, \( \omega_{20c} = 1.55 \mu \text{m} \), \( \omega_{20c} = 0 \), \( |\mu_2 | / e = 25 \text{ A} \), \( |\mu_2 | / e = 15 \text{ A} \) and \( e_0 \) are electron charge and excitonic enhancement factor [5] due to the confinement of electrons and holes inside the QD, respectively. Ten vertically stacked QD layers with 8 nm diameter, 10 nm height, and surface density of 4 x 10^{12} cm^{-2} are used. Fig. 2 shows the slow-down factor \( S \) and the loss \( \alpha \) experienced by the signal light under different pump power density. Three different linewidth regimes are compared. \( \omega_{20c} = \beta \) takes the values of 1 μeV, 50 μeV and 1 meV in cases A, B, and C, respectively. The slow-down factors reach maximum values of 10^{2}, 2.4 x 10^{3} and 39 at pump powers of 3 x 10^{-5}, 8 x 10^{-2} and 1.9 MW/cm² with corresponding group velocity dispersions of -2 x 10^{4}, -0.7 x 10^{-3} ps/λm, for cases A, B, and C, respectively.
power density. All are improved with the decrease of $j_{PD}$. Experimentally a single QD has been shown to have $\mu$eV dephasing at low temperatures [6]. This would correspond to a slow-down factor of more than $10^4$, requiring $\sim 10 \text{ W/cm}^2$ pump power density. At room temperature, the dephasing time $\tau_{PD}$ is 2.2 $\text{meV}$, and is attributed to phonon scattering. But, with the optimisation of the enhancement factor $\mathcal{g}$, a slow-down factor of 55 can still be achieved. For linewidths greater than $10 \text{meV}$, the required pump laser intensity may create catastrophic facet damage for semiconductor materials. The buffer to QD coupling has been shown to have $\mu$eV dephasing at low power densities. All are improved with the decrease of $g_{PD}$.

Conclusions: We propose the first semiconductor all-optical buffer based on EIT effect in QDs. We have established the conditions and formulation necessary to achieve a large slow-down factor. The light pulses can slow down significantly with a negligible dispersion, making it desirable for making optical buffers with an adjustable storage. Narrow linewidth QD fabrication is found to be critical to the overall device performance.

References

**Accurate fault location based on transients extraction using mathematical morphology**

D.J. Zhang, Q.H. Wu, J.F. Zhang and K.I. Nuttall

A multi-resolution morphological gradient method is developed to efficiently extract fault-generated transients and accurately identify fault locations in a power transmission line system.

**Introduction:** Accurate fault location in a transmission line system is desirable in order that electric utilities may quickly pinpoint the location of the disturbances. Compared with the widely used impedance based fault locator, the travelling wave based fault locator has been recognised as a preferred tool in recent years [1]. In particular, the successful combination of the global position system (GPS) and wavelet transform analysis has initiated considerable research activity concerned with improving the accuracy of fault location techniques. However, the need to correctly determine the travelling wave propagation speed and timing of the wavefronts are two crucial factors affecting the accuracy of detecting fault distance. Conventionally, the theoretically calculated travelling wave speed derived from the system parameters is required, but it is unreliable in practice because it is affected by geographic features and the physical configuration of the transmission lines. Time-tagging of the wavefronts has been a challenging problem for power system protection for a long time. In this Letter, a novel but effective signal processing tool—the multi-resolution morphological gradient (MMG) method—is proposed to extract the amplitudes and polarities of transient waves and exactly detect the arrival time of wavefronts at the measurement point. Based on discriminating the first three transient sequences of travelling waves according to their amplitudes and polarities to calculate the fault distance without requiring knowledge of the speed value.

**Analysis of fault location principle:** Fig. 1 shows a double-source transmission line system under fault condition and its Bewley-lattice diagram. The transient current and voltage waves generated by a fault at point $F$ travel away from the fault point at speed $v$. They arrive some time later at busbars $R$ and $S$ where part of the wave passes into the adjacent section and the rest is reflected backwards. This process continues until the transient wavefronts become indistinguishable due to the multi-reflection and attenuation.

**Fig. 1 Single-line diagram of 400 kV power transmission lines system and its Bewley-lattice diagram under fault condition**

The operating principle of a type A fault locator is developed on the successive identification of the travelling high frequency transients arriving at the measurement point. With reference to the first and subsequent captured transients, including their polarities, the distance to the fault from each end of the line can be obtained from Fig. 1 using the following formulas:

\[ L_R = L - \frac{(T_2 - T_3)v}{2} \]
\[ L_S = \frac{(T_3 - T_4)v}{2} \]

where $L_R$ and $L_S$ indicate the measured distance between the fault and the busbars $R$ and $S$, respectively, $T_1$, $T_2$, $T_3$, $T_4$ are the times at which the captured transient sequences are observed, $v$ is the propagation speed which is related to the transmission line parameters and $L$ is the full length of transmission line.

To eliminate errors arising from a theoretical speed value, an alternative calculation is proposed using the first three transient sequences, which allows speed $v$ to be eliminated from (1) and gives the formulas:

\[ L_R = \frac{(T_3 - T_4)L}{(T_2 - T_3) + (T_3 - T_1)} \]
\[ L_S = \frac{(T_2 - T_3)L}{(T_2 - T_3) + (T_3 - T_1)} \]

The operating principle of a type D fault locator relies on the first transient waves observed at each end of the line. The advantage of this method lies in avoiding the need to identify multi-reflecting transient waves. However, an accurate time reference system like GPS is necessary to synchronize the time-tagging at each end of the line. The distance to the fault is calculated according to the time difference between $T_1$ and $T_2$ as indicated in Fig. 1 and is given as:

\[ L_R = \frac{(L + (T_1 - T_3)v)}{2} \]
\[ L_S = \frac{(L + (T_2 - T_3)v)}{2} \]

**Conclusion:** Accurate fault location based on transients extraction using mathematical morphology is developed from set theory and integral geometry [2], and is concerned with the shape of a signal waveform in the time domain rather than the frequency domain which is concerned by the conventional integral transform algorithms, e.g. Fourier and wavelet transform.