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Storage of Photonic Signals in Voltage–Controlled Lateral Potential Superlattices

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Abstract New investigations on a "light storage device" [1] based on a lateral potential superlattice are presented. An improved sample structure enabled us to achieve storage of photogenerated electron-hole pairs for several seconds at storage efficiencies of about 10%.

1 Introduction

Optical interconnects and solid state memories are vital in today's communications networks. On the other hand, the current method to delay or store photonic signals is rather unhandy, using miles of optical-fiber delay-lines. A different approach is to store optically generated electron-hole-pairs in a modulated direct band-gap semiconductor and letting them recombine radiatively. This reduces device dimensions to the mm range, nevertheless providing rather long storage times. Such a modulation can be obtained for example with self-assembled quantum dots [2] or, as in our case, with a lateral potential. This modulation, which is in some respect similar to that of nipi-doping superlattices [3], is achieved either by the piezo-electric component of surface acoustic waves [4] or, as presented here, by static electrodes. The latter approach provides extremely long storage times, which are easily tunable over orders of magnitude.

2 Samples and Experiment

All samples are grown by molecular beam epitaxy. Sample A is a quantum well (QW) structure with 8nm GaAs cap, 41nm $Al_{0.5}Ga_{0.5}As$ top-barrier, 20nm GaAs QW, 300nm $Al_{0.3}Ga_{0.7}As$ rear-barrier and a 40nm Si-doped GaAs back contact with $n = 4\cdot10^{18}\text{cm}^{-3}$. Sample B consists of 10nm GaAs cap, 100nm $Al_{0.4}Ga_{0.6}As$ top-barrier, two 7nm wide $In_{0.17}Ga_{0.83}As$ QWs in a 50nm GaAs cladding layer, 1000nm $Al_{0.4}Ga_{0.6}As$ rear-barrier and 20nm Si-doped GaAs back contact with $n = 4\cdot10^{18}\text{cm}^{-3}$. All barriers are short-period-superlattices.

On top of the grown structure, semitransparent interdigitated titanium-electrodes are evaporated on an area of $400\times500\mu\text{m}^2$. Both electrode-finger width and spacing are 1μm. Applying different voltages V_1 and V_2 between each electrode and the back contact results in a stripe-like lateral potential modulation in the QW layer due to the voltage difference $\Delta V = V_1 - V_2$.

The sample to be examined is mounted in an optical cryostat. It is excited by a pulsed laser diode at 780nm, which is below the band gap of the barrier material but above the band gap of GaAs. The luminescent light is collected by a microscope objective, spectrally filtered by a Dilor XY-Spectrometer and detected by a photomultiplier with a gated counter, thus providing a temporal resolution of 10ns. The setup is also suitable for spatially resolved measurements with a resolution of about 10μm.

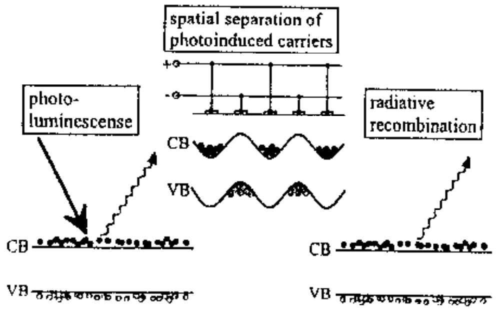

Fig. 1 Operation principle: photoinduced carriers are stored as long as the voltage is applied

Principle of Operation

Initially, a voltage difference is applied to the electrodes. Then the sample is illuminated by a short "loading" laser pulse to create electron-hole-pairs in the QW. Due to the interdigitated shape of the electrodes, ΔV induces a lateral potential modulation of the conduction and valence band, resulting in different potential minima for electrons and holes. This spatially separates the optically generated carriers. In addition, confinement along the growth direction is obtained by the QW potential, preventing the carriers from escaping to the electrodes. The carriers accumulate underneath the positive and negative electrode respectively and are stored for a desired time t_s. Turning off the bias restores the flat-band condition. The separated carriers attract each other via Coulomb interaction and recombine radiatively within less than 100ns (cf. Fig. 1): A short, intense light pulse can be detected, the stored signal is "read out".

3 Sample A

Sample A was designed with a thin top barrier, thus providing strong and homogeneous potential modulation in the QW layer at small voltage differences.

In Figure 2 the time resolved luminescence during the storage cycle is plotted: from $t = 0$ to $t = 1\mu\text{s}$, residual

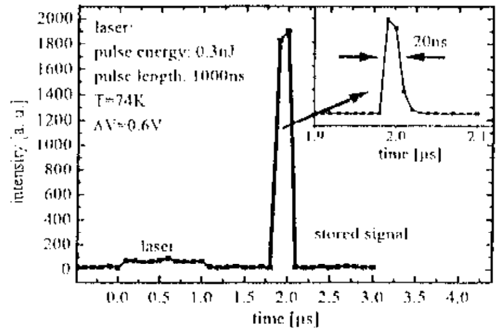

Fig. 2 Timeresolved measurement of the storage cycle on sample A; inset: same measurement with 10ns resolution

photoluminescence (PL) from the exciting laser pulse is visible. No light is emitted from the sample until the bias ΔV is removed after $t_s = 1.9\mu s$: then, a short, intense light pulse can be detected (cf. inset).

Figure 3 shows the intensity of the stored signal as a function of the storage time t_s at different parameters. It is clearly visible that lower ΔV initially leads to smaller signals, but also the loss of signal over time is slower: The life time $T_{1/2}$ doubles at $\Delta V = 0.4V$.

This can be understood, as low voltage differences result in weak potential modulations, reducing therefore the amount of storeable carriers. On the other hand, the thin top-barrier leads to a sufficient potential modulation even at low ΔV, resulting in rather long storage times at reasonable signal strength. However, this thin barrier cannot effectively prevent tunneling of the stored carriers to the electrodes. This seems to be the main reason for carrier losses. It especially explains the faster decrease of the signal at high ΔV. There is also an influence of the laser intensity on both storage time and efficiency. This behaviour is not fully understood, but we attribute it mainly to optically charging surface states and traps, creating local potential fluctuations.

With this sample, a tradeoff between storage time and storage efficiency has to be made. Storage is possible in this structure up to temperatures of about 100K.

4 Sample B

The second sample was in general designed with wider barriers, but keeping the ratio of barrier widths almost constant to achieve again strong lateral modulation in the QW layer. In addition, using InGaAs, deeper wells were achieved, and the GaAs cladding layer improves absorption of the initial laser pulse.

Figure 4 illustrates the storage capabilities of this sample, in particular the dramatic increase in storage time as compared to sample A. The inset on the upper right again shows a time resolved measurement of the storage cycle, now for $t_s = 1s$. With this sample, storage is possible for many seconds without any measurable loss of signal intensity. In the main figure, the stored signal is plotted vs. storage times up to 100ms for different ΔV. For $\Delta V = 3.5V$, no decrease at all occurs in the signal. Only for $\Delta V = 1.7V$, a slight decrease is visible.

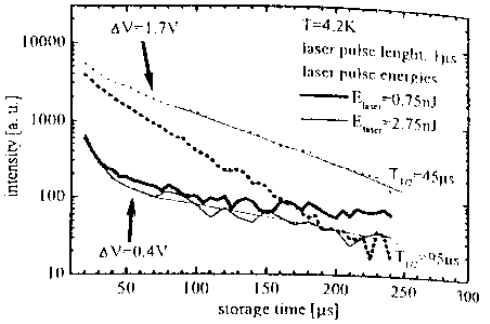

Fig. 3 Storage efficiency of sample A at different parameters, time axis linear

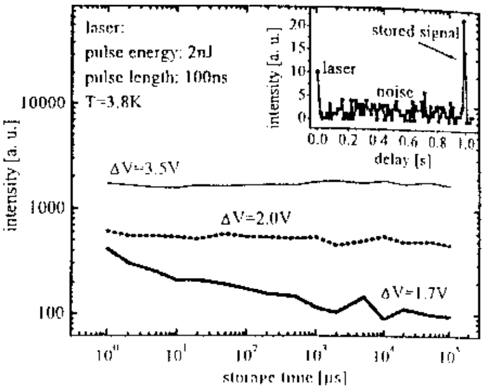

Fig. 4 Storage efficiency of sample B at different ΔV, both scales logarithmic; inset: 1s storage time

These results clearly indicate that the rather broad barriers effectively reduce carrier losses, providing an enormous increase in storage time as compared to sample A. In addition, higher voltages can be applied, resulting in strong potential modulations. This maintains an overall storage efficiency at $T \approx 4K$ in the range of 10% (compared to the PL of the structure with $\Delta V = 0$).

5 Conclusions

We present new investigations on a "light storage device" based on voltage-induced lateral potential superlattices, revealing losses through the QW barriers as main limitation in storage time. A new sample with broader QW-barriers now provides high storage efficiencies and storage times of several seconds at temperatures of 4K.

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References

1. S. Zimmerman et al., Science **283**, (1999) p. 1292.
2. T. Lundstrom et al., Science **286**, (1999) p. 2312.
3. G. H. Döhler et al., Phys. Rev. Lett. **47**, (1981) p. 864.
4. C. Rocke et al., Phys. Rev. Lett. **78**, (1997) p. 4099