Physical model of an Optical Memory Cell with coupling quantum dots

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Abstract: **The physical model was founded by Crosslight Apsys software for new type of photonic memory cell based on a quantum dot (QD)-quantum well (QW) hybrid structure. The physical mechanisms involved such as interband optical transition of quantum dots. The scan conditions and iterative algorithm was also set up to finish solving. Photon storage process has well proved based on I-V curve and transient time response obtained from the model. These are crucial in the signal readout-circuit design afterward.**

Key Words: **photon storage; quantum-dots; quantum-well; APSYS; physical model**

Ⅰ. Introduction

There has been great interest in studying the storage and retrieval of the semiconductor optical memory cells [1-5]. In such devices, incoming optical signals are first stored as spatially separated electron-hole pairs and then retrieved by bringing stored electrons and holes to recombine at the same location radioactively. Generally speaking, a normal memorizer require over 10 million atoms for storage of a single bit of information while this kind of optical memory cell only needs a few thousand atoms involved to complete the same operation, which means smaller, cheaper and faster[4]. Crosslight Apsys package could be effectively applied to model performance of the optical memory cell and design.

This paper discusses the physical modeling of an Optical Storage Cell with coupling quantum dots in a well by using Crosslight Apsys software. First, an asymmetrical structure of quantum well-quantum dots was established by means of graphic user interface. Second, computer was programmed about the physical mechanisms involved such as interband optical Transition for quantum dots. The scan conditions and iterative algorithm was also set up to finish solving. Finally, some valuable diagrams are available including band, I-V and transient response, which give good agreements with measurements. Photon storage process is well proved based on I-V curve and transient time response obtained from the new model.

II. Model Fo unded

Structure of the optical memory cell with quantum dots in well is shown in Fig.1 [5]. After a 1μm Si-doped (10^{18} cm^{-3}) GaAs buffer layer and an undoped 30 nm GaAs spacer, the undoped double barrier structure was deposited in the sequence of the first 25nm AlAs barrier, a 3nm GaAs interlayer, a 6 nm In0.15Ga0.85As QW, a 45 nm GaAs wide well, a 1.8 ML self-assembled InAs QD layer with a 5nm GaAs overlayer, and the second 25nm AlAs barrier. On the top, an undoped 30nm GaAs spacer and a Si-doped ($10^{18}$$cm^{-3}$) 30nm GaAs capping layer were overgrown. The ohmic contacts were separately made to the top and back contact layers. The top contacts was placed onto the cap layer with square aperture (50×50μm^2) left for the optical access.

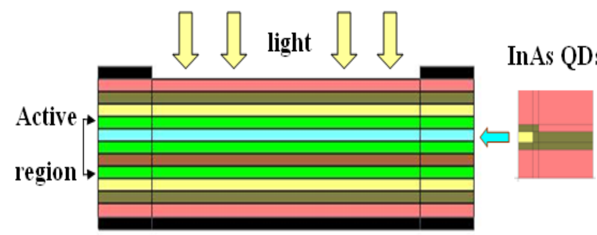

Fig.1 Structure of the memory optical cell

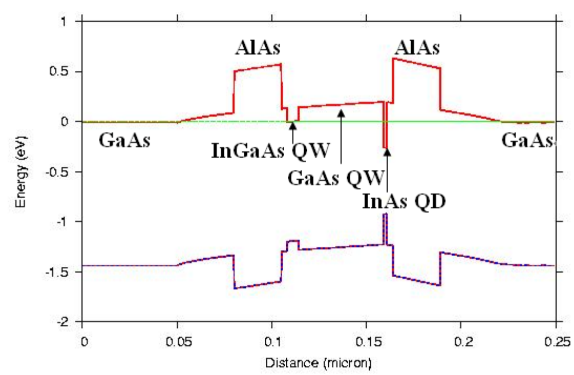

Fig.2 Band diagram profile along epitaxial direction

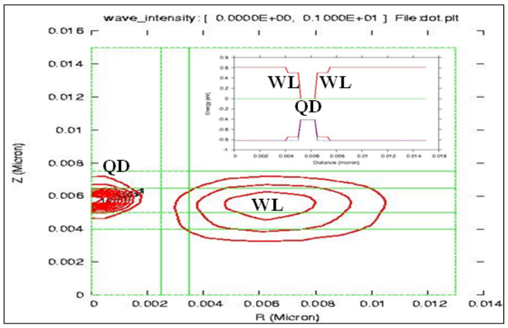

Fig.3 Band diagram profile of QD and its wave intensity

The band diagram of the device is depicted in Fig.2. Electron-hole pairs in the active region were first generated by laser pulse, and then dissociated by the reverse bias. Electrons generated in the wide well or in the QDs would drift or tunnel toward the lower potential energy and eventually would be captured by the thin InGaAs QW. The similar process would also occur to holes, except that they would drift in the opposite direction and would be trapped in the QDs. Due to the spatial separation of electrons and holes as well as the additional in-plane localization provided by the QDs, as the structure is reversely biased, excess electrons and holes can be stored at some time in the thin QW and QDs respectively. Fig.3 shows the band diagram profile of QD and its wave intensity.

III. Result And Discuss

The photon storage characteristics of the device have been proved by its photoelectric response. Under the illumination of the wavelength 650 nm, the response current shows a step-like enhancement when reverse biased as shown in Fig.4. By contrast, whose photon energies were smaller than GaAs band gap, the step-like enhancement no longer appears. It is believed that the photovoltaic effect caused by the stored spatially separated electron-hole pairs pulls down the GaAs X minimum at the

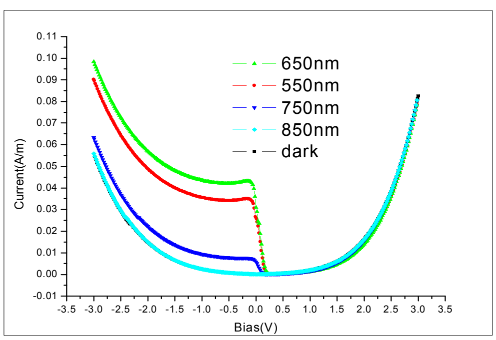

Fig. 4 Photocurrent & dark current versus bias voltage

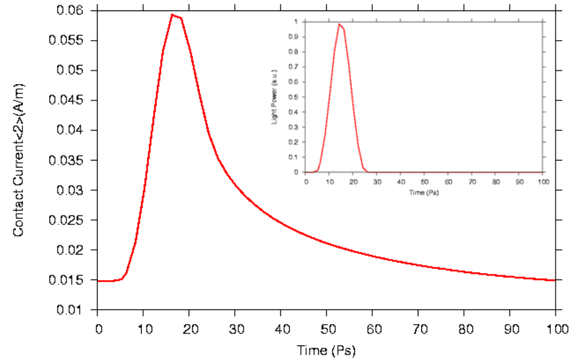

Fig.5 Transient response of the device at light pulse

outgoing interface of the AlAs emitter barrier, which eventually initiate the new Γ-X-X tunneling compared with that in the dark and result in the observed step-like photocurrent response.

As shown in Fig.5, the transient time response of the device demonstrates its photon storage characteristics. It still shows the stimulus of light pulse. The falling transient edge of the photocurrent as the photoexcitation turns off, mainly maps the decaying of electrons and holes, which were previously stored in the cell during the illumination. Its time constant is a measure of photonic memory time.

Ⅳ. Conclusion

An Optical Memory Cell with coupling quantum dots was successfully simulated. The photon storage process may well been proved by advanced numerical simulation.

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