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Collective Tunneling Model in Charge Trap Type NVM Cell

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1. Introduction

We propose a new tunneling model between two-dimensional electron gas (2DEG) and the trap sites in the charge trap type (CT-) Nonvolatile Memory (NVM) cell. Recently, the floating gate type NVM suffer in keeping its program speed because of the floating gate interference effect. To overcome this drawback, many types of cell structures have been studied. One of the most promising candidate structure is the CT-cell such as Silicon-Oxide-Nitride-Oxide-Silicon (SONOS) type NVM, because CT-NVM cell is free from this interference effect (Fig.1).

On the other hand, the mechanism of program/erase (P/E) operation of CT-NVM is still unclear. In order to reveal the mechanism of P/E operation, many studies have been devoted. However most studies have focused on the position and the structure of the trap sites. Here, we point out that a more primitive problem in the CT- NVM cell exists in the charge injection from the 2DEG in channel to the trap sites. The reason why this problem is significant is the mismatch of size and dimension between the 2DEG and the trap sites.

In this study, we theoretically investigate the electron injection process to the trap sites of the CT- NVM cell structure and suggest that the new electron tunneling model between the 2DEG and trap sites. This tunneling model determines the P/E features of the CT- memory cell. By using this tunneling model, the amount of injection charge can be controlled discretely with the time. It is useful to realize the multi level charge trap cell.

2. Collective Tunneling Model

In this study, we have particularly focused on the role of the electronic states of the 2DEG in the charge injection process. We have verified the importance of the electronic state of the 2DEG for the electron injection process for this kind of system in our previous studies [1,2]

2-1 Geometrical mismatch between 2DEG and trap site

At first we consider the mismatch between a trap site and the 2DEG of the channel in programming mode, where the 2DEG is spread two-dimensionally, whereas the trap site covers only a part of the electrode (Fig.2). Therefore, the electrons are inevitably injected from a large area to a small area in this system. Based on this viewpoint, we proposed that the sufficient overlap of electron density is necessary between the electronic states in the 2DEG and the trap site as shown Fig.2.

2-2 Importance of the transiently localized state

This new insight indicates that the transiently localized state would be a main contribution to the tunneling between 2DEG and the trap site. This assumption introduces the new tunneling model, where the tunneling is induced by a rare event. This means that in order to model the electron injection in CT- NVM cell in the programming time, we have to include the long waiting time. This assumption does not match with the conventional tunneling model, but quite intuitive, because, in the 2DEG, electronic state of electron should be fluctuated due to the several types of scatterings. Thus, the electronic state of 2DEG is in a transient state, and the spatial distributions of electrons should fluctuate with time.

2-3 Collective motion of electron tunneling

The rare tunneling event also introduces another important phenomena, which is the collective electron tunneling. We again focus on the electronic state of the 2DEG. During the first tunneling event to the trap site, a dip of potential is induced in the 2DEG just below the trap site and it becomes deeper and wider during the tunneling. We report this phenomenon in our previous study. This dip induces the electron localization (rare event) around the occupied trap site and it triggers the next tunneling. The number of induced localized electron would exponentially increase and the electrons successively tunnel to the trap sites. The resulting tunneling time should be very fast.

2-4 New tunneling model

From above all, we propose the new tunneling model for programming mode of CT-cell. Fig.3 shows our new tunneling model. Once the electron in the 2DEG matches to the tunneling condition, electron localization occurs successively due to the fluctuation of potential field of 2DEG and electrons tunnels to trap sites successively. This tunneling model says several important features for the device operation of CT- NVM cell. One of them is the asymmetry of the time scale between the electron tunneling time and the waiting time. Here, the time scale of the tunneling is very fast due to the collective tunneling; however, on the other hand, the opportunity of tunneling event is very rare.

As shown in Fig.4, the electron tunneling current in programming mode depends on the programming time. The fast electron tunneling (collective tunneling) should occur after the long waiting time. We experimentally observe this type of tunneling in a similar structure [3]. For the device design, this feature is useful for developing a stable multi level CT-NVM cell. By controlling the period of one trial of collective electron tunneling, we obtain the discrete charge injection to the memory cell.

3. Theoretical Analysis with 2D-Trap Tunnel Scheme

In order to investigate the suggested tunneling model, we emulate the experiment by the numerical simulation, where we assume that the main contribution to the electron tunneling was induced by the wave-packet-like state below the trap site. Fig.5 indicates the overview of our calculation model. In the calculation, we introduce that once tunneling occurs, potential field of the 2DEG fluctuates and the electron tends to localize around the trap site. We also include several conditions to emulate our calculation to the experimental conditions, where the gate bias is set to a certain value during the finite measurement time, then it is stepped up to the next bias voltage (Fig.5). As a result, we successfully reproduce the suggested tunneling model as shown in Fig.6.

4. Conclusions

We study the electron injection process from the 2DEG to the trap site in the CT-NVM cell. We reveal that the electron tunneling would be induced by a rare event by considering the geometrical mismatch between the 2DEG in channel and the trap site of CT-NVM cell. From this assumption, we suggest the new tunneling model, where the electron tunnels to the trap sites collectively with the long waiting time. This insight is very important to design the CT- NVM cell. This tunneling model determines the P/E features of CT- memory cell. By using this tunneling model, the amount of injection charge can be controlled discretely with the programming time. This model is useful to realize the Multi level charge trap cell.

Acknowledgements:

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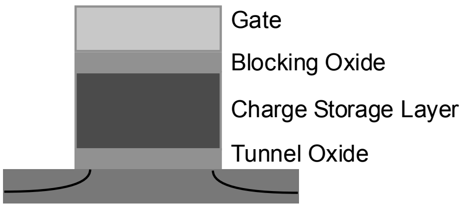

Fig.1 Schematic illustration of SONOS type NVM cell structure

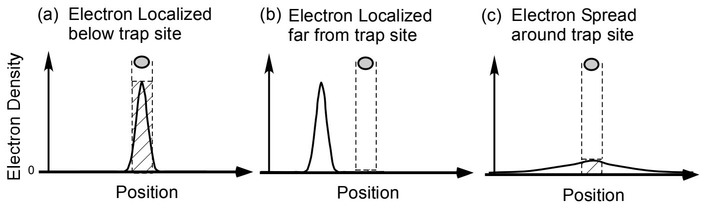

Fig. 2 Schematic illustration of tunneling conditions. Transient localized electron induces the tunneling from 2DEG to Dot.

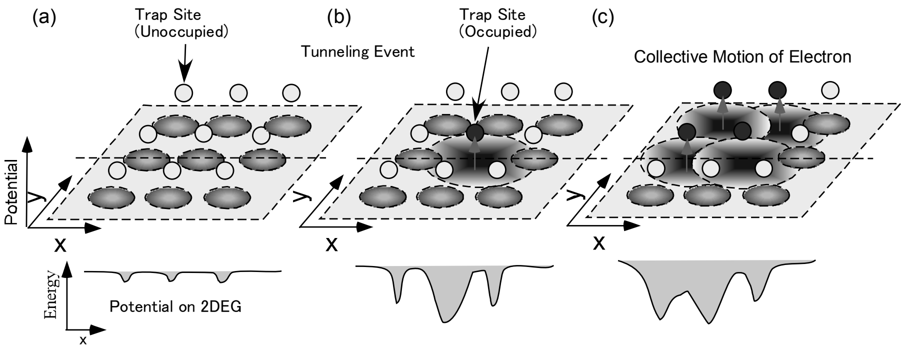

Fig. 3 The potential profiles in the suggested tunneling model. a) Unoccupied state, b) first electron tunneling, c) collective tunneling.

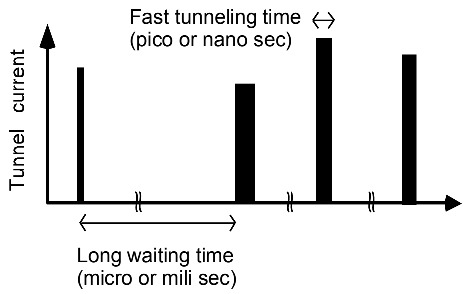

Fig. 4 The dependency of tunneling current on the programming time induced by proposed rare events.

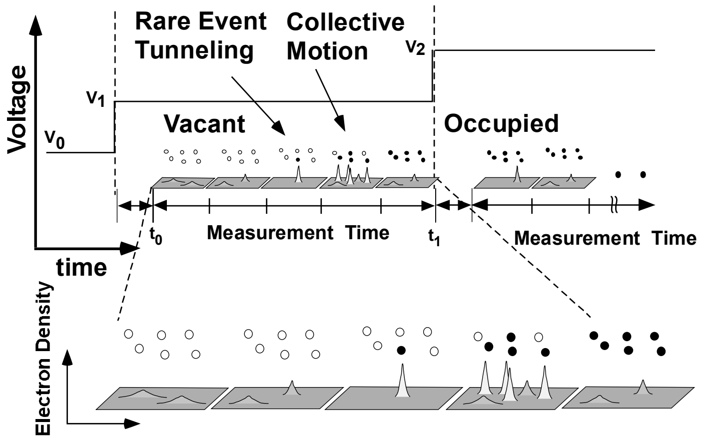

Fig. 5 Schematic illustration of our calculation Model.

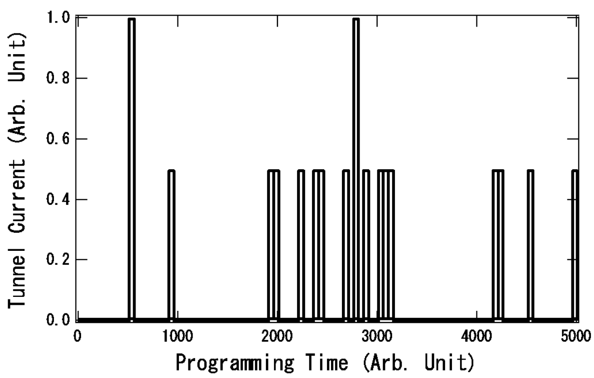

Fig. 6 The dependency of tunneling current on the programming time with proposed collective tunneling model.