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Monostable-Bistable Transition Logic elements (MOBILEs) Based on Monolithic Integration of Resonant Tunneling Di mode and FET

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New functional devices based on resonant tunneling (RT) phenomena [1] have attracted much attention owing to the novel negative differential resistance (NDR) characteristics of these devices. A recently proposed logic gate, called MOBILE [2] (monostable-bistable transition logic element), takes advantage of the NDR feature of RT devices and has demonstrated its promising usefulness in constructing complicated computing systems such as cellular automata and neural networks [3,4]. In this letter, we propose and demonstrate a new approach in building devices suitable for MOBILE circuits. Our approach is based on integrating resonant tunneling diode (RTD) and FET in parallel.

A MOBILE consists of two resonant tunneling transistors (RTTs) connected in series and is driven by an oscillating bias voltage (V_{bias}) to produce the *monostable-to-bistable* transition (Fig. 1). The transition takes place when V_{bias} passes through twice the peak voltage ($2V_P$), where one stable point splits into two branches. A small difference in the peak current between the two RTTs determines the circuit's state after the transition. Therefore, the key in applying MOBILEs for logic operation is to develop a gate controlling scheme, in which gate voltage associated with each RTT can manipulate the magnitude of the peak current.

We have developed a new gate controlling scheme for constructing MOBILE circuits. The gates of FETs monolithically integrated with a resonant tunneling diode (RTD), instead of p^+/n junction gates used in our previous work [2]-[4], are employed to control the monostable-bistable transition. As shown in Fig. 2, a RTD and a FET are connected in parallel. Although I_{RTD} remains unchanged at different gate voltages, the total source-to-drain current $I_{DS}(=I_{RTD}+I_{FET})$ is modulated as a result of the changing I_{FET}. Therefore, each device can be considered a resonant tunneling transistor in which peak current is modulated by the gate voltage. Our new approach offers several important advantages including: (1) it allows the separate optimization of the device structures of RTDs and FETs; (2) the inclusion of conventional FETs provides flexibility in circuit design; (3) this approach can be easily employed to other semiconductor heterostructure material systems such as InGaAs/InAlAs.

Fig. 3 (a) and (b) show the room temperature I-V characteristics of a RTD and a FET on the same wafer, respectively. The RTD peak and valley current density are $1.5\times10^3 A/cm^2$ and $1.0\times10^3 A/cm^2$. The peak-to valley ratio is 1.5:1. The transconductance is 0.2mS at the resonant peak (V_{DS}=0.4V) for a FET with a 10μm wide gate (all FETs used in this work have a gate length of 1μm). The threshold voltage is 0.2V and the gate leakage current is less than 20μA at 1.0V. Fig. 3 (c) shows the I-V characteristics of an integrated device which includes one RTD with a $1\times10\mu m^2$ mesa and one FET with a 10μm wide gate. The peak current level is clearly modulated by the gate voltage.

To demonstrate that the integrated devices can be used to achieve MOBILE operation, an inverter operation together with the circuit configuration are shown in Fig. 4. A control voltage V_{con} of 0.75V is applied to the gate of the load to create the necessary difference between the peak currents of the driver and load. It should be noted that the output state is kept unchanged until V_{bias} becomes zero in spite of the change in V_{in}. To further confirm the operating principle, the input signal was intentionally delayed as shown in Fig. 4 (b). Inverter operation was not achieved when the input voltage was applied after the increase in V_{bias}. These facts demonstrate that the device operates according to the principle of *monostable-to-bistabe* transition.

In summary, we have demonstrated a new approach to achieve MOBILE operation based on the monolithic integration of RTD and FET.

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[2]. K. Maezawa, and T. Mizutani, *Jpn. J. Appl. Phys*, vol. 32 (1993), p. L42.
[3]. T. Akeyoshi, K. Maezawa, and T. Mizutani, *SSDM* 93, p. 1079.
[4]. K. Maezawa, T. Akeyoshi, and T. Mizutani, *IEDM* 93, p. 415.

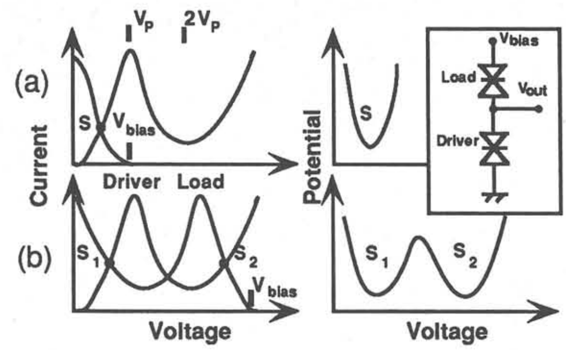

Fig. 1 The operating principle of the MOBILE. The left and right figures are load-line diagams and potential diagrams, respectively. The insert shows the connection of the NDR devices. (a)$V_{bias} < 2V_P$, (b) $V_{bias} > 2V_P$.

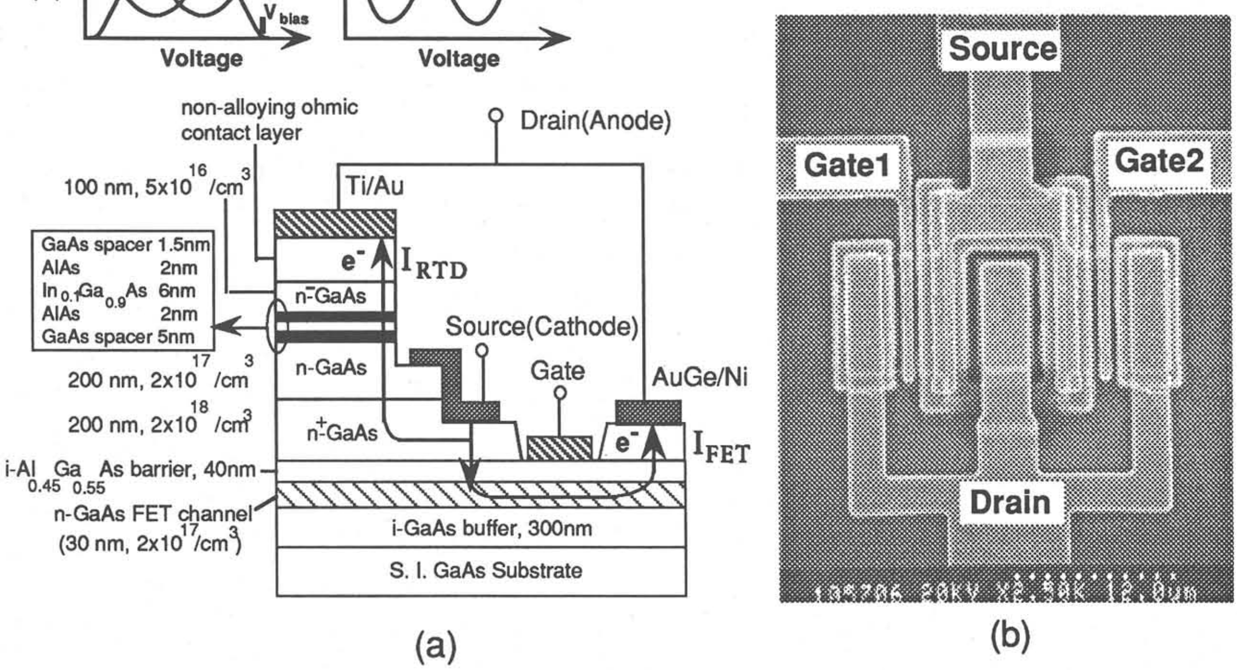

Fig. 2 (a)Schematic cross section of the integrated device. The cathode of the RTD and the source of the FET are connected. And the anode of the RTD and the drain of the FET are connected. (b) SEM photograph of the device with two FETs integrated with a RTD.

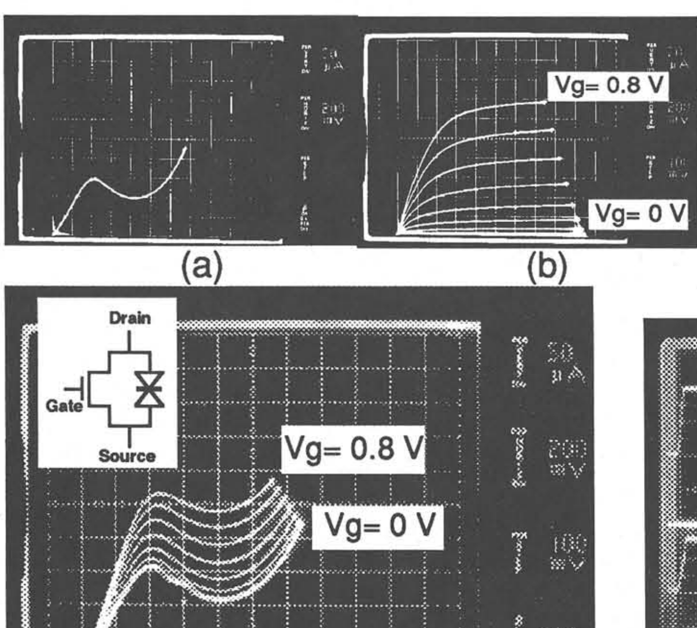

Fig. 3 I-V characteristics of (a) a RTD, (b) a FET, and (c) an integrated device, at room temperature.

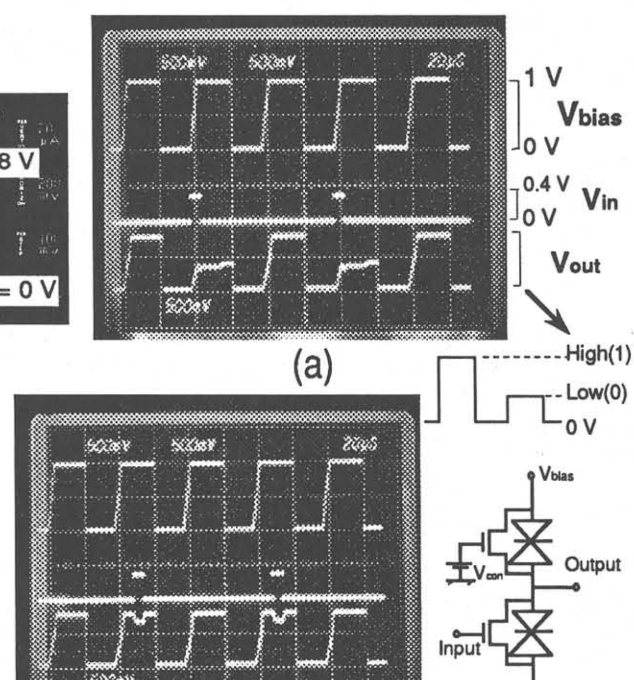

Fig. 4 The inverter operation of a MOBILE gate. The input voltage was applied (a) as the bias voltage began to rise and (b)after it rose.