High-Speed Operation of a Novel Frequency Divider Using Resonant Tunneling Chaos Circuit

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Resonant tunneling devices have a lot of attractive features for high-speed and low-power applications. Moreover, extremely strong non-linearity due to negative differential resistance is useful for microwave analog applications [1]. Recently, we have proposed a novel frequency divider using a resonant tunneling chaos circuit [2], which exploits the nonlinearity of the resonant tunneling diode (RTD). In this report, we have demonstrated high-frequency divider operations of the circuit composed of an RTD and a high electron mobility transistor (HEMT).

Figure 1 shows the configuration of the fabricated circuit. This frequency divider consists of a resonant tunneling diode, an inductor L and a capacitor C. This circuit outputs various types of signal patterns including chaos, when an external oscillating signal with dc bias ($V_{in}= V_0 + A\sin(2\pi ft)$) is applied [2]. Generally, in the nonlinear systems which generate chaos, long-period behavior is also observed in some parameter regions [3]. This is called the bifurcation phenomenon. In the bifurcation region, the system's output period is the integer-multiple of that of the input. Our proposal uses this long period behavior to fabricate frequency dividers. The output buffer using a HEMT was integrated in the circuit. Without the buffer a high-frequency operation is impossible due to the interference with the measurement system.

The circuit was fabricated using InP-based RTD/HEMT integration technology. Figure 2 shows (a) schematic cross section of the fabricated circuit, and (b) chip microphotograph. The gate length of HEMT for output buffer is 1.5 μm. The circuit parameters are designed to be L = 5.9 nH and C_{tot} = 0.48 pF, so that the characteristic frequency f_{LC} ($=1/2\pi(LC_{tot})^{1/2}$) is about 3.0 GHz. In general, C_{tot} is a sum of C and the gate input capacitance of the HEMT. But in this particular case, no C was implemented, since the gate input capacitance was large enough. The static current-voltage characteristics of the fabricated RTD are shown in Fig. 3. In this measurement, we used the negative voltage region of the RTD. The peak voltage of the RTD is about –0.25 V, the peak current density is -4.5×10^4 A/cm^2, and the peak-to-valley current ratio is about 5 at room temperature.

We have performed high-frequency experiments of the fabricated circuit. The input signal amplitude A and bias V_0 was fixed at 0.35 V and –0.4 V, respectively. Figure 4 shows the input and the output wave patterns at (a) f_{in} = 4.5 GHz, and (b) f_{in} = 5.0 GHz. These results show this frequency divider can output the signal with different dividing ratio by changing the input frequency. Chaos signals were also observed at the higher frequency range. It should be noted that the operation frequency range depends on the characteristic frequency f_{LC}, so that an extremely high operating frequency (much higher than 100 GHz) is expected with appropriate circuit parameters design.

In summary, we have demonstrated the high-speed operation of a novel frequency divider using resonant tunneling chaos circuit. Clear frequency divider operations of 1/2 and 1/3 were obtained in a microwave range.

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[2] Y. Kawano et al: Jpn. J. Appl. Phys. **38** (1999) L1321.
[3] J. M. T. Thompson and H. B. Stewart: *Nonlinear Dynamics and Chaos -Geometrical Methods for Engineers and Scientists* (John Wiley and Sons, 1986)

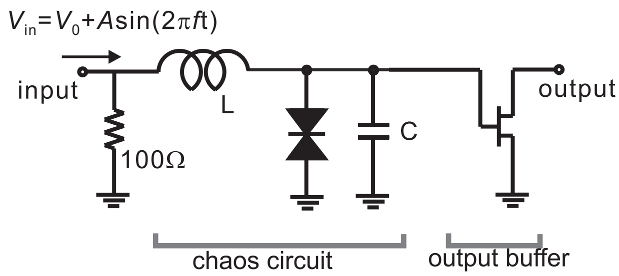

Fig. 1 Circuit configuration of the fabricated frequency divider.

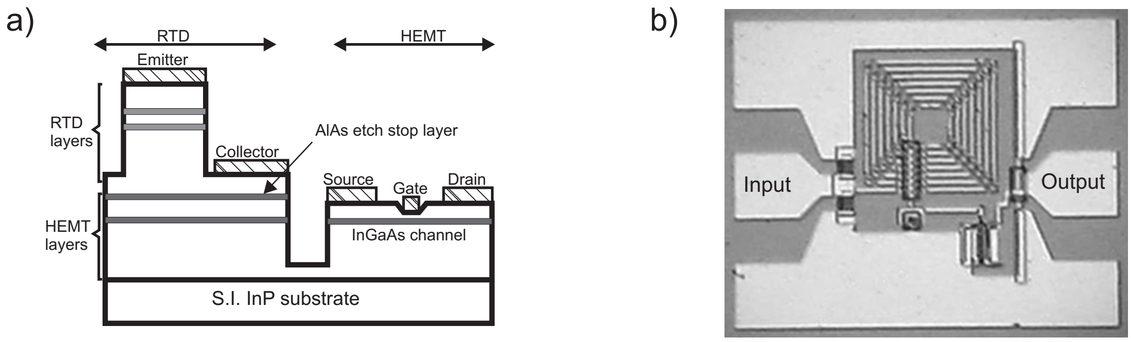

Fig. 2 (a) Schematic cross section of the fabricated circuit, and (b) chip microphotograph.

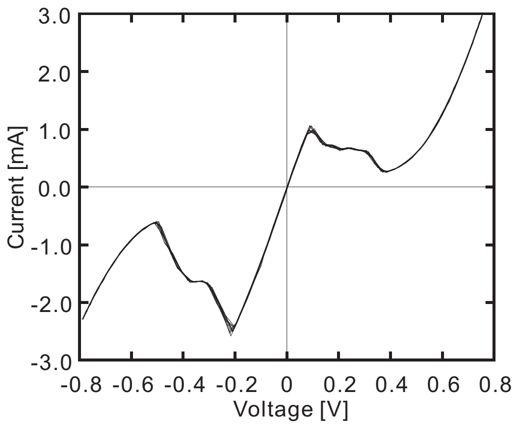

Fig. 3 Current-voltage characteristics of the fabricated RTD.

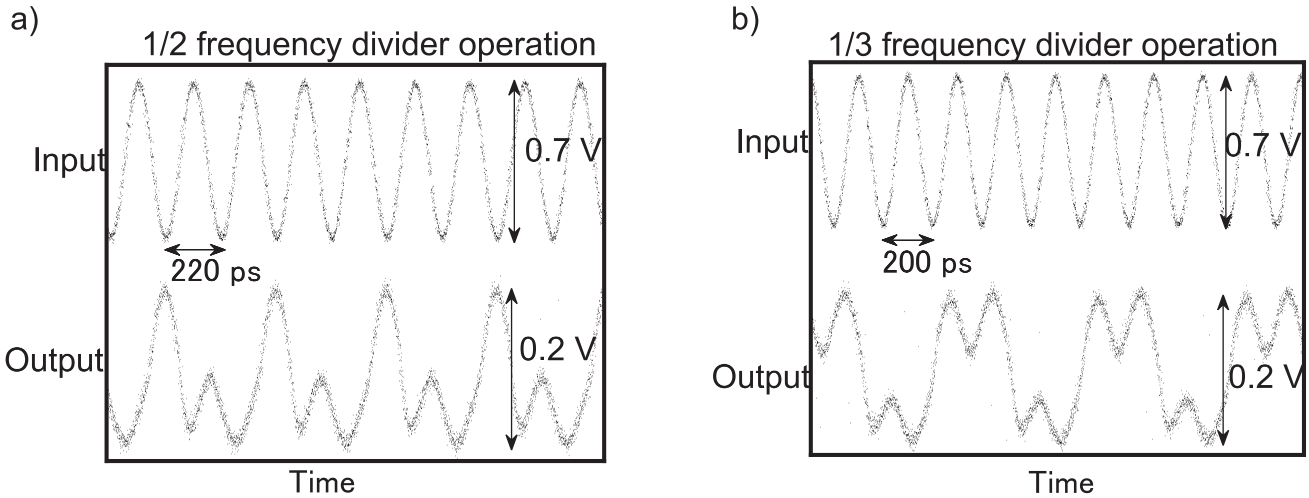

Fig. 4 Input and output waveforms of the measurement circuit. The circuit parameters are designed to be L = 5.9 nH, and C_{tot} = 0.48 pF, so that the characteristic frequency f_{LC} $(=1/2\pi(LC_{tot})^{1/2})$ is about 3.0 GHz. The input frequencies are (a) 4.5 GHz, and (b) 5.0 GHz, respectively. Clear frequency divider operations of (a) 1/2 and (b) 1/3 are shown in the figure.