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Ultrasmall Area and Ultralow Frequency Ring-oscillator Using GIDL Current for IoT Edge Applications

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Abstract

This paper has described an ultrasmall circuit area and ultralow oscillation frequency ring-oscillator based on the gate-induced drain-leakage (GIDL) current. By using the GIDL current, we succeeded in limiting the charge and discharge current of the current-starved type voltage-controlled ring-oscillator, enabling the generation of ultralow oscillation frequency. In addition, the proposed ring-oscillator had much more temperature stability than the ring-oscillator controlled by subthreshold current. The proposed circuit was fabricated with a 0.18-μm standard CMOS technology. From experimental results, we confirmed that the GIDL ring-oscillator oscillated at the lowest frequency of 0.94 Hz with a 1.8 V power supply and also showed higher temperature stability and controllability compared to subthreshold current based ring-oscillator. The GIDL ring-oscillator presented here only used MOSFETs and realized an area of only 0.0062 mm^2.

1. Introduction

In recent years, several industries such as distribution, smart home, and smart medicine utilize wireless sensor networks called Internet of Things (IoT). As shown in Fig. 1, in the IoT system, edge devices use sensors to collect various types of physical information and send data to the cloud. As the edge devices are used in remote areas, their power dissipations become significant problems. In some event-driven applications, wake-up function is very important for power saving of the edge devices. Generally, the edge devices have three clocks: a system clock, a high-frequency oscillator, and a sleep timer. Crystal, MEMS, RC oscillator, and MOS circuits are usually used in these oscillators. This paper focuses on the ultralow frequency oscillator used for the sleep timer for energy-efficient IoT applications. In previous studies, the ultralow oscillators reported in [1] and [2] have huge circuit sizes due to large capacitances and resistances. To realize small area and ultralow frequency oscillation, we designed the GIDL current based ring-oscillator (GIDL-RO), which only used MOSFETs.

2. Circuit design

Figure 2 shows the schematic of the GIDL-RO. This circuit consists of four parts: GIDL current source, current mirror circuits, ring-oscillator circuit, and buffer circuit.

A pico-ampere-order current, generated by GIDL current source, is copied by current mirror circuits to limit the charge/discharge current of the 9-stages current-starved ring-oscillator. Due to the ultralow charge/discharge current, the inversion time of inverters in ring-oscillator circuit become longer, hence the output frequency of the ring-oscillator circuit decreases. After that, the output signal is buffered by the buffer circuit. The use of GIDL current for starved current of the ring-oscillator improves the temperature stability. The GIDL current source consists of several parallel connected NMOS transistors. The GIDL current originates from a band-to-band tunneling of electrons in the gate-drain overlap region when we apply negative bias voltages to gate and positive bias voltages to drain of NMOS transistors [3]. On the other hand, subthreshold currents which flow in weak inversion region of MOS transistors are usually used as an ultralow current. Thanks to the tunnel effect of electron, which is independent of the temperature, GIDL current indicates a higher stability to temperature than subthreshold current. In addition, GIDL current also has a better controllability owing to small dependence on gate voltages than subthreshold current. Therefore, the GIDL ring-oscillator has both superior temperature stability and controllability compared to the subthreshold ring-oscillator.

3. Measurement results

Figure 3 shows the microphotograph of the GIDL-RO which was fabricated with 0.18-μm 1P6M CMOS technology. By using the GIDL current as the starved-current of the ring-oscillator, the GIDL-RO circuit realized very small area of 119 μm × 52 μm (0.0062 mm^2). The measured output waveform of the GIDL-RO under 25 °C is shown in Fig. 4. Supply power voltages (AVDD and DVDD) were 1.8 V, and control signal V_{ctrl} was -0.5 V to supply a negative bias voltage as the gate terminal of GIDL current source. The output waveform showed an ultralow oscillation frequency of 5.05 Hz. Fig. 5 shows the output frequency characteristics of the GIDL-RO with V_{ctrl} of -1.0 V~ -0.1V and subthreshold-RO with V_{ctrl} of -0.1 V ~ 0.5 V. The output waveform became triangular wave when V_{ctrl} increased over 0.3 V. The output frequency slope of subthreshold-RO (0.076 V/dec) is larger than that of GIDL-RO (0.440 V/dec). In Fig. 6, the oscillation frequency of subthreshold-RO increased accordingly with temperatures from 20 °C to 90 °C, which is larger than that of the GIDL-RO.

4. Conclusions

In this paper, we reported the ultrasmall circuit area and ultralow oscillation frequency ring-oscillator using the GIDL current. In comparison with other oscillator circuits shown in Table 1, the GIDL-RO achieved the smallest circuit area of 119 × 52 μm^2, since there is no large capacitances and resistances. The GIDL-RO successfully oscillated at 0.94 Hz at V_{ctrl} of -0.1 V. The GIDL-RO achieved both better temperature stability and V_{ctrl} controllability, enabling the circuit operation robust.

Acknowledgments

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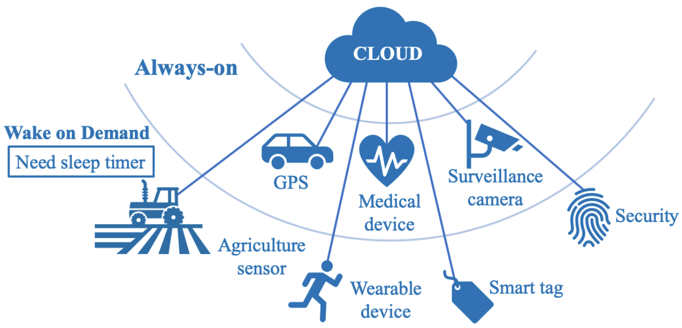

Fig. 1. Conceptual drawing of IoT.

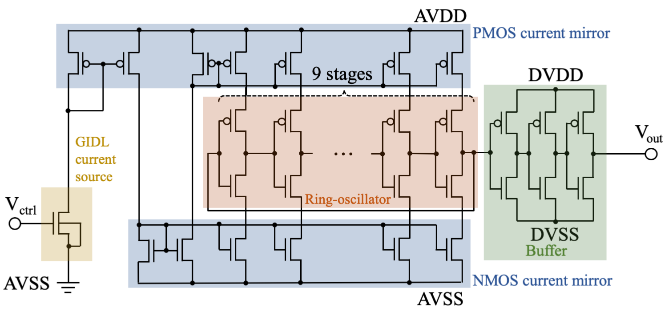

Fig. 2. Schematic drawing of the GIDL-RO.

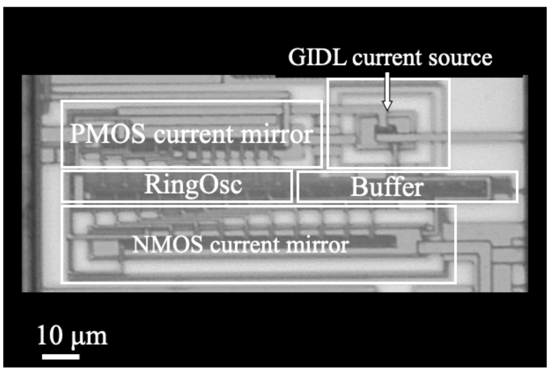

Fig. 3. Microphotograph of the GIDL-RO.

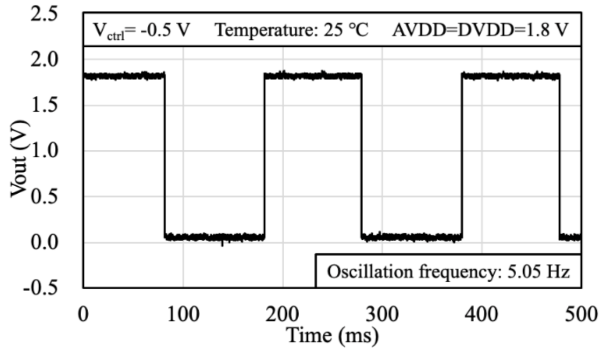

Fig. 4. Measured output waveform of the GIDL-RO.

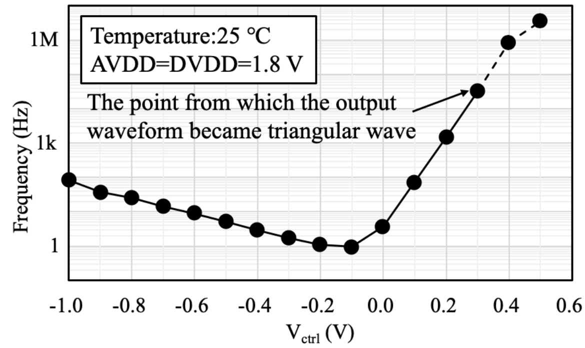

Fig. 5. Output frequency characteristics of the fabricated ring-oscillator.

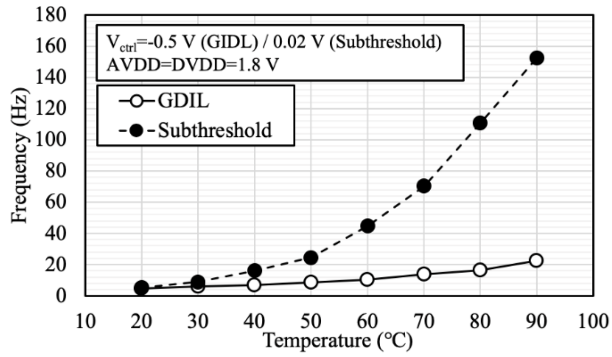

Fig. 6. Relationships between oscillation frequency and temperature of the GIDL-RO and the subthreshold-RO.

Table. 1 Ring-oscillator summary.

	This work	Ref. [1]	Ref. [2]
Process (μm)	0.18	0.13	0.6
Active area (mm^2)	0.0062	0.45	0.07
Integrated capacitor	No	Yes	Yes
Integrated resistor	No	Yes	N/A
Min Frequency (Hz)	0.94	0.03	7.5
Max Frequency (Hz)	83	185	20

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