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Fabrication and Characterization of Micromachined Cantilever Loaded with a Resonant Tunneling Diode for Delta-Sigma Type Strain Sensor Applications

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Abstract

We proposed a Delta-Sigma type strain sensor using an RTD oscillator. To realize this, micromachined cantilevers loaded with RTDs and oscillators based on them were fabricated and characterized. It was demonstrated that the oscillation frequency can be controlled by the strain, which is a basis for our proposal.

1. Introduction

Resonant tunneling diodes (RTDs) have been attracting much attention for ultrahigh speed applications. Oscillations higher than 1 THz have been already reported [1]. The RTD consists of thin heterostructures, so that the current-voltage characteristics are sensitive to strain [2]. Based on these features we propose a novel strain sensor. A most important feature of this proposal is to employ the Frequency Modulation Delta-Sigma Analog Digital Conversion (FMDSADC) technique [3], which is advantageous for high dynamic range and wide frequency range.

In this paper we report on the fabrication and characterization of micromachined cantilevers loaded with RTDs and oscillators based on them. These oscillators convert the strain to frequency, which is a key to realize high performance FM Delta-Sigma strain sensors.

2. FMDSADC and Its Application to the Strain Sensor

A key component of the Delta-Sigma ADC is a Delta-Sigma modulator (DSM), which converts the input analog signal to the pulse density modulated 1-bit digital signal at much higher frequency (sampling frequency, *f*s) than the Nyquist rate (*f*n). Here, we concentrate on a novel DSM called Frequency Modulation DSM (FMDSM). A key part of this is an oscillator that converts the input analog signal to FM signal. The FM signal can be easily converted to the pulse density digital signal using a DFF and an XOR [2]. Therefore, if the frequency of the oscillator is controlled by strain, it can be used for the Delta Sigma strain sensor. An oscillator based on the cantilever loaded with an RTD can be used for this purpose. Since the performance of the FMDSM depends strongly on the carrier frequency of the FM signal, RTD oscillators have a great advantage. Figure 1 shows the block diagram of our proposal.

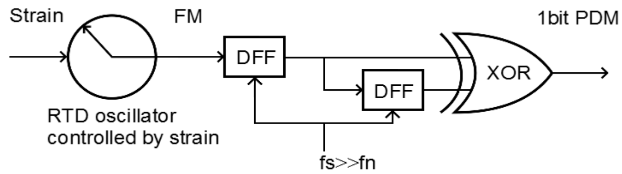

Figure 1. Block diagram of the strain sensor based on FM Delta-Sigma modulator.

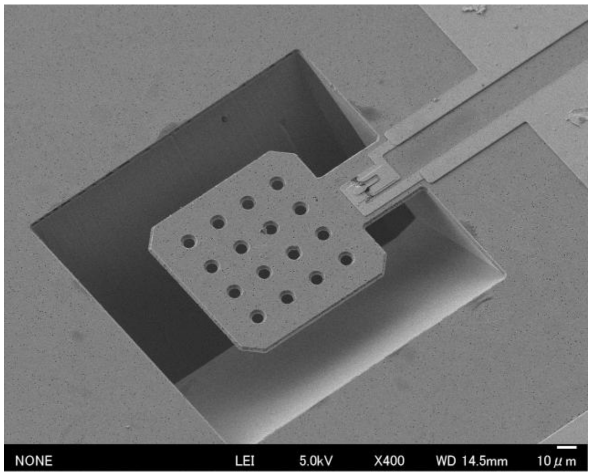

Figure 2. The SEM photograph of the cantilever.

$In_{0.53}Ga_{0.47}As$	$1\times10^{19}cm^{-3}$	25nm	
$In_{0.53}Ga_{0.47}As$	$1\times10^{18}cm^{-3}$	80nm	
$In_{0.53}Ga_{0.47}As$	Undoped(UD)	1.5nm	
AlAs	UD	1.6nm	
$In_{0.53}Ga_{0.47}As$	UD	1.3nm	
InAs	UD	1.8nm	RTD layers
$In_{0.53}Ga_{0.47}As$	UD	1.3nm	
AlAs	UD	1.6nm	
$In_{0.53}Ga_{0.47}As$	UD	1.5nm	
$In_{0.53}Ga_{0.47}As$	$1\times10^{18}cm^{-3}$	80nm	
$In_{0.53}Ga_{0.47}As$	$1\times10^{19}cm^{-3}$	400nm	
InP	UD	6nm	
$In_{0.52}Al_{0.52}Ga_{0.48}As$	UD	2000nm	
$In_{0.53}Ga_{0.47}As$	UD	2nm	Used for the cantilever
$In_{0.52}Al_{0.48}As$	UD	2nm	
InP substrate			Super-lattice

Figure 3. Epitaxial structure.

3. Cantilever loaded with an RTD

An example of the fabricated cantilever is shown in Fig. 2. It consists of a flat plane with a beam, and an RTD is placed on the beam. This can be a basis for various sensors including pressure, acceleration, and ultrasonic sensors. We fabricated the cantilever with an RTD by using conventional photolithography and lift off process. Figure 3 shows the epitaxial structure used in this experiment. It consists of an RTD structure on a thick InAlGaAs buffer layer, which is used for the cantilever. A point is to fabricate the hollow under the cantilever. It is done by selective wet etching of InP using hydrochloric acid based etchant. We found the form of the hollow strongly depends on the crystal axis. Good results were obtained when the cantilever extended along the $[0\ \bar{1}\ 1]$ direction.

Figure 4 shows the current-voltage characteristics of the fabricated RTD on the sensor beam, when the flat plane of the sensor is pushed down by a microprobe. This pressure makes the cantilever bend downward, so that tensile strain is induced on the surface of the beam. The peak voltage shifts to higher voltages when the strain increases. This peak voltage shifts can be used for Delta-Sigma strain sensor.

4. Oscillators based on RTD strain sensor

We further fabricated oscillators based on RTDs on the strain sensor beam. An example of the fabricated circuits is shown in Fig. 5. It consists of an RTD and a coplanar wave guide (CPW) resonator. The one end of the CPW is grounded, and the other end is grounded through a small resistor. The signal was observed at this small resistor node. This configuration permits us to observe oscillation signal without disturbance from the measurement system, though the output power is small.

We measured the strain dependence of the oscillation frequency. An example of the results is shown in Fig. 6. The oscillation frequency decreases with increasing the stress. The frequency variation range was 70MHz. This result indicates the promise of the RTD Delta-Sigma strain sensors.

Acknowledgements

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References

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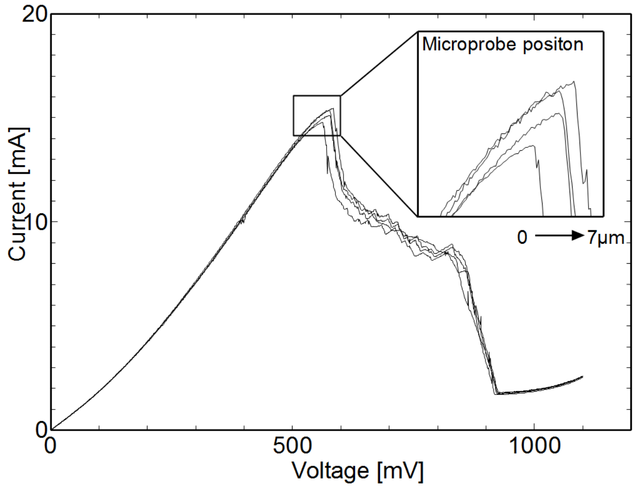

Figure 4. *I-V* characteristics of the fabricated RTD on the sensor beam under stress. The stress is applied by the microprobe.

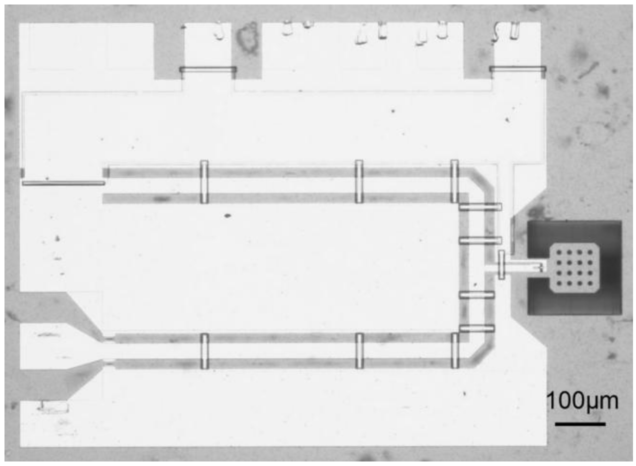

Figure 5. The microphotograph of the fabricated circuit consisting of the cantilever, RTD and coplanar wave guide resonator.

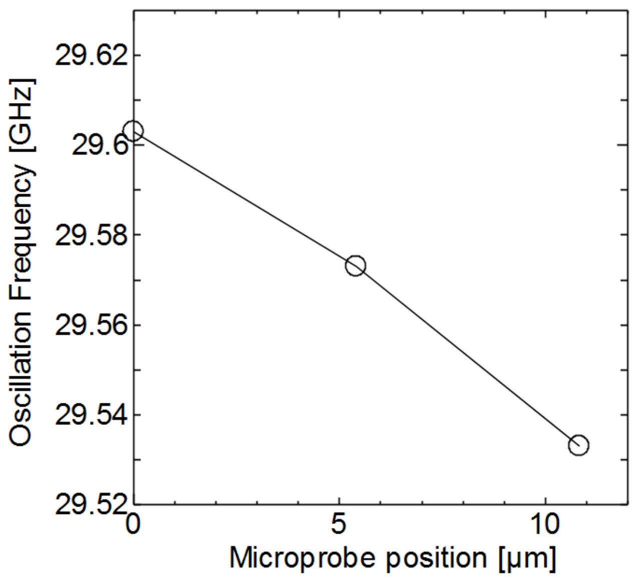

Figure 6. The oscillation frequency under stress. The stress is applied by the microprobe.