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Investigation of a GaN-Based SAW Oscillator with respect to UV Illumination and Temperature

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Oscillation frequency of a GaN-based surface acoustic wave delay-line oscillator is investigated in the temperature range from −20 °C to +38 °C, with and without UV illumination. The results imply that such an oscillator may be used for temperature sensing with the resolution of up to 1 mK. On the other hand, as the frequency downshift due to UV illumination does not exhibit a significant dependence on temperature, it may be expected that such a system, when used as a UV sensor, would not require applying a correction for temperature.

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1. Introduction

Gallium nitride (GaN) as well as related semiconducting substances is of interest for possibility of applications to devices which employ both semiconducting and piezoelectric properties of the structure. One of them is a surface acoustic wave (SAW) oscillator which uses a SAW delay line as its feedback circuit. The oscillation frequency of such a device is determined by the geometry of its SAW delay line and the velocity of SAW propagation. The velocity, on the other hand, is generally dependent on factors such as temperature and illumination, which offers a possibility for designing sensors of appropriate kind.

Frequency response of a GaN-based SAW delay-line oscillator to ultraviolet (UV) illumination has been demonstrated for the first time in [1, 2]. The effect has been found to be selective with respect to the wavelength of the incident light — it nearly vanishes when the wavelength exceeds 400 nm [2]. Later on, investigation of SAW interaction with UV light was extended to other types of materials: ZnO [3], AlN [4], AlGaN [5].

Here we continue our previous work [6], further investigating the influence of temperature and UV illumination on the oscillation frequency of a GaN-based SAW delay-line oscillator. Now, we focus on room and lower temperatures which can be attained by using a conventional refrigerator or freezer as well as elevated temperatures.

2. Experimental

The experimental setup of our oscillator, which consists of a wide-band amplifier and a SAW delay line serving as a feedback loop, is shown in Fig. 1. The SAW delay line is made up by a GaN layer grown by means of low-pressure metal-organic chemical vapor deposition on a (0001) sapphire substrate with a pair of aluminum interdigital transducers deposited on the surface of the GaN layer. Dispersion properties of SAW propagating on a GaN layer deposited over sapphire are described in [7]. We use a Rayleigh mode of SAW propagation with velocity v of about 5137 m/s.

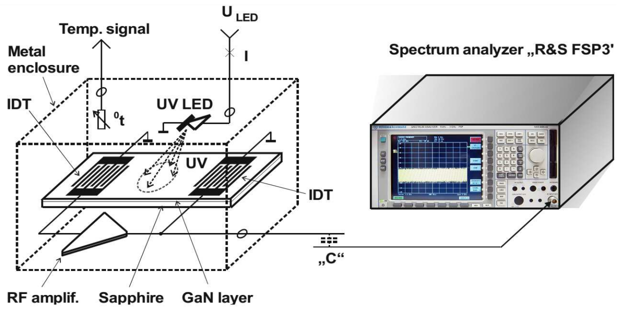

Fig. 1. Experimental setup.

Fabrication parameters of the delay line are the following: the period of the transducers is $\Lambda = 24$ μm, their central frequency $\nu_0 = v/\Lambda = 214.04$ MHz. Each transducer consists of 100 pairs of electrodes and thus is 2.4 mm long. The aperture of the transducers is 1.38 mm. The distance between their central points $L = 11.1$ mm. Thickness of GaN layer is 2.5 μm.

The oscillator itself is confined in a metal enclosure, protecting the device from external EM fields. Two more devices reside inside: a temperature sensor and a T5H36 light emitting diode (LED) of the UV band with radiation maximum at 365 nm. The LED, along with its lens, is installed at the distance of 2–3 mm from the SAW delay line.

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The signal of the oscillator is fed to a Rohde & Schwartz FSP3 spectrum analyzer by means of extremely weak capacitive coupling. The device sends the frequency value to a PC. Such a solution enables us to make wireless measurements of frequency in a medium physically separated from the environment (e.g., in a thermostat), in a way which neither disturbs the condition of the media nor influences the operation of the oscillator itself.

If necessary, voltage is applied to the LED to obtain the current necessary, which defines the power of the UV radiation incident on the SAW travelling area of the SAW delay line.

Resonance frequency of the oscillator obeys the usual relation implying that the round-trip change in phase of the signal passing through the delay line and the amplifier shall be a multiple of 2π:

$$\frac{2\pi f_n L}{v} + \varphi = 2\pi n, \tag{1}$$

where f_n is the frequency of the n-th mode, and φ is the phase shift undergone by the signal in the amplifier.

We have made several experiments with our oscillator: (a) a measurement of oscillation frequency in the dark at stabilized temperatures: room (20 °C and 22 °C), at 0 °C, and −20 °C; (b) a measurement of oscillation frequency versus time in the dark when the system is thermostabilized at different temperatures; (c) a measurement of the change of frequency versus incident power of UV radiation at three different temperatures.

We have operated the oscillator at frequencies exceeding 200 MHz, i.e., at modes as high as almost 500. Thus, the intermodal frequency difference is little compared to the frequency itself, and, therefore, the difference between temperature coefficient of frequency and related magnitudes for adjacent modes is insignificant.

3. Results

Figure 2 shows the variation of oscillation frequency versus temperature in the dark. The curves denoted by circles and rectangles correspond to different measurements with the same structure; one measurement has been done using a commercial refrigerator, and the other — a commercial freezer. Each curve features two points only because freezing devices of such a kind do not allow achieving stable enough intermediate temperatures. Both curves reveal the same slope, which implies the same temperature coefficient of frequency. The shift in the frequency axis of 377 kHz is due to the fact that the oscillator has operated in two different (adjacent) oscillation modes. The temperature coefficient of the frequency derived from the graph is about −14.5 kHz/K.

The curve denoted by triangles represents a measurement made with another similar structure which may have had a little bit different effective length. It is why its slope is a little different.

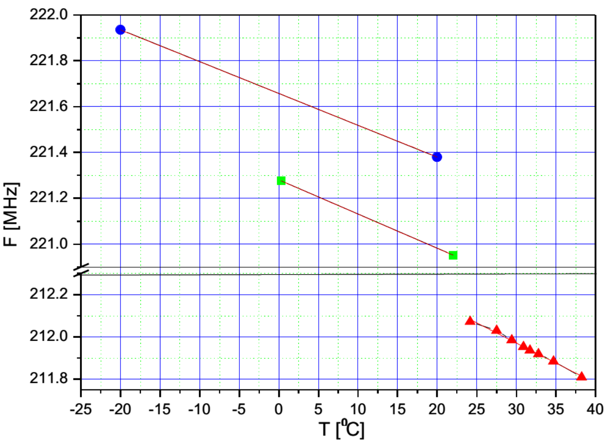

Fig. 2. Oscillation frequency versus temperature in the dark.

Figure 3a reveals the oscillation frequency and calculated temperature versus time in the dark. During the time of the experiment, we have used a thermostat and applied different heating regimes. Thus, we see several areas on the graph — the time when a new temperature is set, then the temperature stabilizes, etc. Figure 3b shows the area limited by the square in Fig. 3a in detail. Even long time after a new temperature is set, it still slightly oscillates quasiperiodically. However, chaotic change, or jitter, of frequency (and corresponding temperature) gives us an estimate of the uncertainty with which the value of constant temperature can be estimated using such a system. It is seen that the value of uncertainty is about 1 mK.

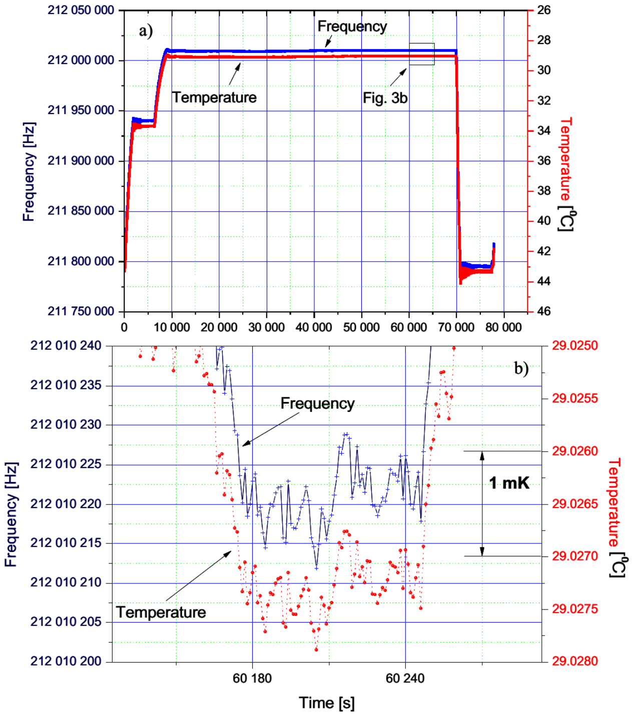

Fig. 3. Oscillation frequency and calculated temperature versus time: (a) all the data obtained; (b) the area limited by the square on in (a) in detail.

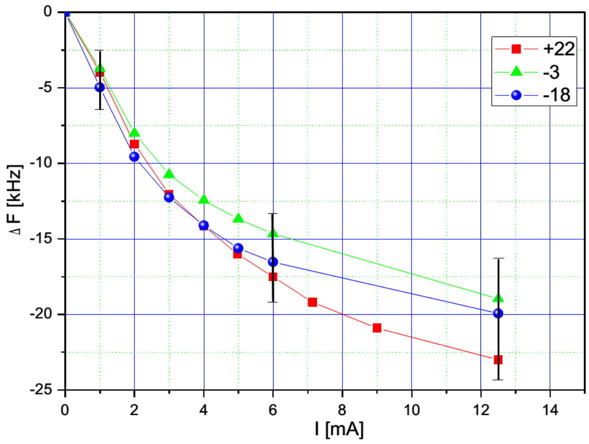

Fig. 4. The change of frequency, ΔF, versus the current flowing through the light emitting diode at three different temperatures.

Figure 4 describes the effect that UV illumination has on the oscillation frequency at three different temperatures. The change of frequency, ΔF, at each point is the difference between the oscillation frequency at the particular incident power of UV radiation and the oscillation frequency in the dark at the specified temperature. The power of the UV radiation can be estimated from the current I, following the manufacturer's specification stating that illumination power can be described as

$$P = GI, \tag{2}$$

where G is the efficiency coefficient, which, for a LED of this kind, is in the range of 0.04–0.1 mW per mA.

The geometry of the setup implies that the SAW travelling area of the delay line receives about 35% of the energy emitted by the LED. Negative values of ΔF are consistent with the theory outlined in [2], according to which the photoelectrons generated upon UV illumination screen the electric field of the acoustic wave, thus reducing the influence of piezoelectric effect and, therefore, reducing the phase velocity of SAW and the resonance frequency of the oscillator. The difference between the curves pertaining to different temperatures does not exceed the measurement uncertainty. Thus, our results do not imply the dependence of the temperature coefficient of frequency on UV illumination power, at least in the range of power applied.

4. Conclusion

Oscillation frequency of a GaN-based SAW delay-line oscillator has been investigated in the temperature range from −20 °C to +38 °C. The dependence of frequency downshift versus power of the incident UV radiation has been measured at three different temperatures. The results imply that such an oscillator may be used for temperature sensing with the resolution of up to 1 mK. On the other hand, the frequency downshift due to UV illumination does not exhibit a significant dependence on temperature in the range of temperatures investigated. Therefore, it may be expected that such a system, when used as a UV sensor, would not require making a correction for temperature.

Acknowledgments

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