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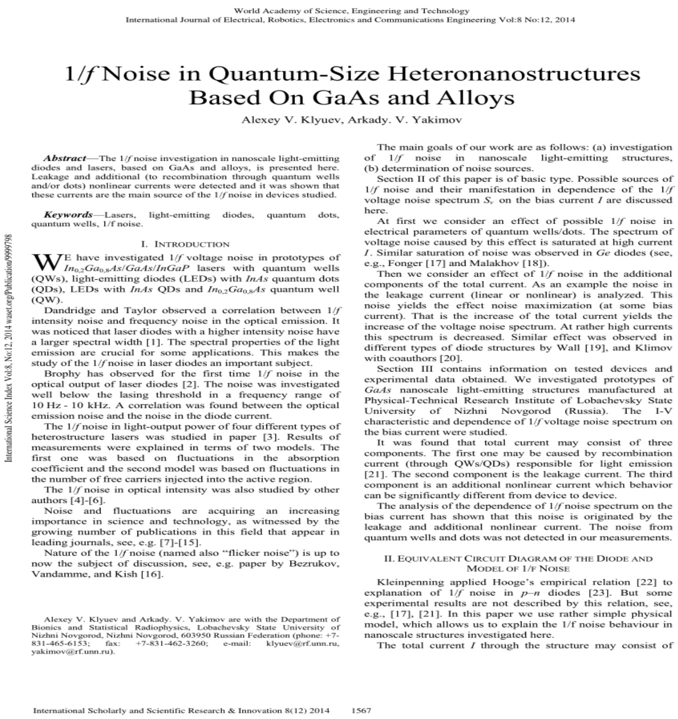

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$1/f$ Noise in Quantum-Size Heteronanostructures Based On GaAs and Alloys

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Abstract—The $1/f$ noise investigation in nanoscale light-emitting diodes and lasers, based on GaAs and alloys, is presented here. Leakage and additional (to recombination through quantum wells and/or dots) nonlinear currents were detected and it was shown that these currents are the main source of the $1/f$ noise in devices studied.

Keywords—Lasers, light-emitting diodes, quantum dots, quantum wells, 1/f noise.

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I. Introduction

We have investigated $1/f$ voltage noise in prototypes of $In_{0,2}Ga_{0,8}As/GaAs/InGaP$ lasers with quantum wells (QWs), light-emitting diodes (LEDs) with $InAs$ quantum dots (QDs), LEDs with $InAs$ QDs and $In_{0,2}Ga_{0,8}As$ quantum well (QW).

Dandridge and Taylor observed a correlation between $1/f$ intensity noise and frequency noise in the optical emission. It was noticed that laser diodes with a higher intensity noise have a larger spectral width [1]. The spectral properties of the light emission are crucial for some applications. This makes the study of the $1/f$ noise in laser diodes an important subject.

Brophy has observed for the first time $1/f$ noise in the optical output of laser diodes [2]. The noise was investigated well below the lasing threshold in a frequency range of 10 Hz - 10 kHz. A correlation was found between the optical emission noise and the noise in the diode current.

The $1/f$ noise in light-output power of four different types of heterostructure lasers was studied in paper [3]. Results of measurements were explained in terms of two models. The first one was based on fluctuations in the absorption coefficient and the second model was based on fluctuations in the number of free carriers injected into the active region.

The $1/f$ noise in optical intensity was also studied by other authors [4]-[6].

Noise and fluctuations are acquiring an increasing importance in science and technology, as witnessed by the growing number of publications in this field that appear in leading journals, see, e.g. [7]-[15].

Nature of the $1/f$ noise (named also "flicker noise") is up to now the subject of discussion, see, e.g. paper by Bezrukov, Vandamme, and Kish [16].

The main goals of our work are as follows: (a) investigation of $1/f$ noise in nanoscale light-emitting structures, (b) determination of noise sources.

Section II of this paper is of basic type. Possible sources of $1/f$ noise and their manifestation in dependence of the $1/f$ voltage noise spectrum S_v on the bias current I are discussed here.

At first we consider an effect of possible $1/f$ noise in electrical parameters of quantum wells/dots. The spectrum of voltage noise caused by this effect is saturated at high current I. Similar saturation of noise was observed in Ge diodes (see, e.g., Fonger [17] and Malakhov [18]).

Then we consider an effect of $1/f$ noise in the additional components of the total current. As an example the noise in the leakage current (linear or nonlinear) is analyzed. This noise yields the effect noise maximization (at some bias current). That is the increase of the total current yields the increase of the voltage noise spectrum. At rather high currents this spectrum is decreased. Similar effect was observed in different types of diode structures by Wall [19], and Klimov with coauthors [20].

Section III contains information on tested devices and experimental data obtained. We investigated prototypes of $GaAs$ nanoscale light-emitting structures manufactured at Physical-Technical Research Institute of Lobachevsky State University of Nizhni Novgorod (Russia). The I-V characteristic and dependence of $1/f$ voltage noise spectrum on the bias current were studied.

It was found that total current may consist of three components. The first one may be caused by recombination current (through QWs/QDs) responsible for light emission [21]. The second component is the leakage current. The third component is an additional nonlinear current which behavior can be significantly different from device to device.

The analysis of the dependence of $1/f$ noise spectrum on the bias current has shown that this noise is originated by the leakage and additional nonlinear current. The noise from quantum wells and dots was not detected in our measurements.

II. Equivalent Circuit Diagram of the Diode and Model of 1/f Noise

Kleinpenning applied Hooge's empirical relation [22] to explanation of $1/f$ noise in p–n diodes [23]. But some experimental results are not described by this relation, see, e.g., [17], [21]. In this paper we use rather simple physical model, which allows us to explain the 1/f noise behaviour in nanoscale structures investigated here.

The total current I through the structure may consist of

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