# 1/f noise modeling of InAs/GaSb superlattice mid-wavelength infrared detectors

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***Abstract***— **The model of 1/f noise of $p^+$-p-n detector made of type-II InAs/GaSb superlattice material (designed for a mid-wavelength infrared detection) is described. It is shown that 1/f noise magnitude can be reasonably estimated if dark current contributions are determined and respective (empirical) noise coefficients are known.**

***Keywords— InAs/GaSb superlattice; 1/f noise modeling; dark current modeling.***

## I. Introduction

The detectivity of the *biased* photovoltaic detector is influenced not only by common shot and thermal noises but also by the 1/f noise. As still the general theory of this phenomenon is lacking, evaluation of the *real* detectivity calls for experimental estimation of the device's noise. This should be done for any bias and temperature if optimal operation conditions are to be found. Any attempt which aims at the prediction of 1/f noise level is then valuable because it can save experimental effort. This paper adds to this issue: a model of 1/f noise is presented which enables estimation of 1/f noise intensity in InAs/GaSb superlattice (SL) detectors in the wide range of voltage bias and temperature. The model is formulated and adjusted for the real device fabricated in the Institute of Electron Technology, Warsaw, Poland. This device (detector) has $p^+$-p-n architecture. All layers are made of InAs/GaSb SL. The basic period of SL contains 10/10 monolayers of InAs and GaSb. The cut-off wavelength $\lambda_{\text{cut-off50\%}}$ of the detector is about 4.3 µm at temperature $T = 77$ K.

## II. Current And 1/f noise Modeling

Although the general theory of 1/f noise is missing, it is commonly argued that total 1/f noise power spectral density (p.s.d.) $S_i$ can be calculated as the sum of the contributions introduced by each component of the detector's dark current [1]:

$$S_i(f = 1\,\text{Hz}) = (\alpha_{sh} I_{sh}^2 + \alpha_{g-r} I_{g-r}^2 + \alpha_{tat} I_{tat}) / 1\,\text{Hz}\,, \qquad (1)$$

where $I_{sh}$, $I_{g-r}$, and $I_{tat}$ are shunt, bulk generation-recombination (g-r) and trap-assisted tunneling (tat) current magnitudes, respectively, and symbol $\alpha_x$ is 1/f noise coefficient associated with current component $x$. Making use of (1) requires resolving dark current into its components, which can be done employing current modeling. Several current components are taken into account, namely: diffusion $I_{dif}$, bulk g-r $I_{g-r}$, band-to-band tunneling $I_{btb}$, trap-assisted tunneling $I_{tat}$, and ohmic shunt $I_{sh}$ currents. These currents were calculated with the equations developed for bulk semiconductor devices. Such bulk-like approach has already been used and good agreement with experiment was found [2]–[4]. The details of current modeling, i.e., the equations and the material parameters of InAs/GaSb SL were reported in ref. [1].

In Fig. 1, the results of current modeling at $T = 77$ K are shown for the case of I-V characteristic. The total current is constituted by the shunt current, the trap-assisted and the band-to-band tunneling currents. The diffusion and the bulk g-r currents can be neglected at this temperature. The effective tunneling masses $m_{btb}$ and $m_{tat}$, trap concentration $N_t$, and the shunt resistance $R_{sh}$ are the fitting parameters. Their values are provided in Fig. 1. As can be seen, the shunt current, the trap-assisted tunneling current and the band-to-band tunneling current dominate in the low, medium and high bias range, respectively.

The results of 1/f noise modeling are shown in Fig. 2: The p.s.d. at 1 Hz is plotted versus total detector's current. This modeling relies on fitting (1) to the experimental data with the coefficients $\alpha_x$ as the *only* fitting parameters - detector's dark current components are taken as in Fig. 1. The 1/f noise p.s.d. follows squared total current $S_i \sim I^2$ at low current range ($I < 10^{-6}$ A). In this range, the 1/f noise is essentially associated with the shunt current $S_i = \alpha_{sh}(I_{sh})^2$, the *shunt 1/f noise coefficient* $\alpha_{sh} = 8\times10^{-7}$. For the large current ($I > 10^{-6}$ A), 1/f noise is associated with the trap-assisted tunneling current $S_i = \alpha_{tat} I_{tat}$, the *tat 1/f noise coefficient* $\alpha_{tat} = 1.3\times10^{-12}$ A. No 1/f noise associated with the band-to-band tunneling is observed. The prediction of 1/f noise at arbitrary bias and temperature requires the knowledge of the remaining coefficients $\alpha_{dif}$, $\alpha_{g-r}$. The modeling of the diffusion and the bulk g-r current and the estimation of their noise coefficients should be done at higher temperatures where these currents become dominant. In ref. [1], such modeling has been performed for current-temperature dependence measured at constant bias voltage. According to this modeling, the *diffusion 1/f noise coefficient* $\alpha_{dif} < 10^{-11}$, whereas the *bulk g-r 1/f noise coefficient* $\alpha_{g-r} = 2\times10^{-8}$ and is hardly temperature dependent.

The work was supported by the National Science Centre project: UMO-2014/13/N/ST7/03074 (Ł. Ciura) and the Ministry of Science and Higher Education of the Republic of Poland grant for statutory activity (A. Kolek).

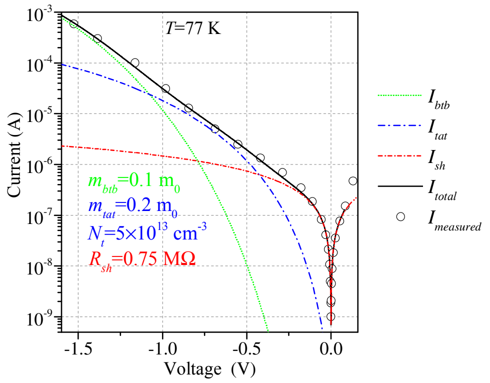


Fig. 1. Detector's dark current and its components vs. bias voltage at the temperature $T = 77$ K.

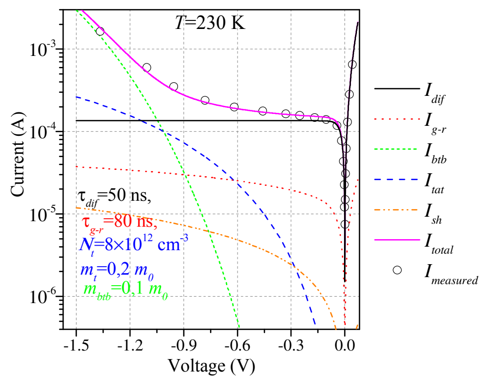


Fig. 3. Detector's dark current and its components vs. bias voltage at temperature $T = 230$ K.

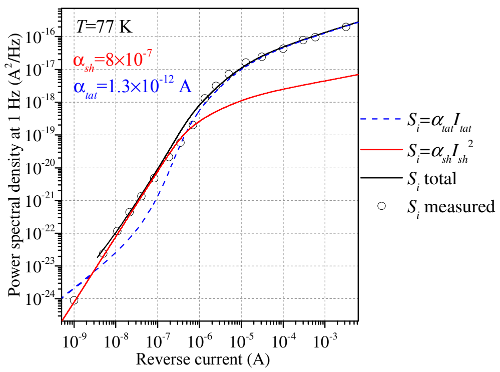


Fig. 2. The measured 1/f noise and its modeled contributions vs. total current at temperature $T = 77$ K.

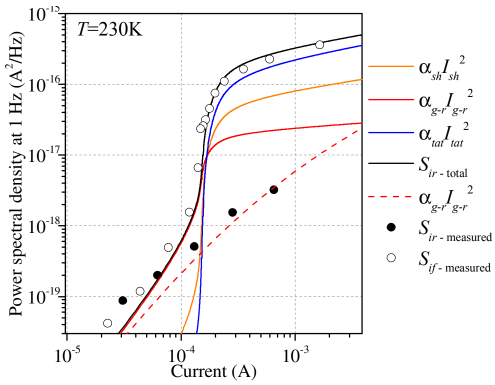


Fig. 4. Predicted and measured 1/f noise p.s.d. at 1 Hz and its contributions vs. total current at temperature $T = 230$ K. The "r" and "f" indexes refer to reverse and forward bias, respectively.

To validate the model and check its usefulness as a noise-predictive tool, the calculations were done for $T = 230$ K. In Fig. 3, the modeling of current vs. voltage characteristic at this temperature is shown. The g-r and the shunt currents are modeled using the parameters from ref. [1]. The diffusion current dominates in the low and mid voltage range (both for forward and reverse bias), while tunneling currents become significant in the high voltage (reverse) bias. The main result of the paper is presented in Fig. 4, where the 1/f noise p.s.d. at 1 Hz calculated with (1) is plotted vs. dark current. In this equation, the dark current contributions are taken as in Fig. 3, whereas 1/f noise coefficients were taken from independent experiments described above. Then, *no fitting* was used in this step. The agreement with the experiment is very good. The interpretation of our noise vs. bias dependence can be as follows: Diffusion current does not contribute to 1/f noise in any direction. For the entire forward, as well as low-reverse bias, the 1/f noise comes exclusively from bulk g-r current (despite its small participations in the total current!). For the high-reverse bias, the 1/f noise originates mainly from trap-assisted tunneling and shunt currents. In the mid-current region ($I \approx 1.5\times10^{-4}$ A), all three contributions have the same participation in the total 1/f noise.

## SUMMARY

In InAs/GaSb superlattice p$^+$-p-n MWIR photodiode, the 1/f noise magnitude can be calculated for arbitrary bias and temperature with empirical 1/f noise model described by (1). This model requires modeling of dark current components and the knowledge of 1/f noise coefficients associated with these components. The simple bulk-like modeling of the current gives good agreement with experimental data.

## REFERENCES


[1] L. Ciura, A. Kolek, J. Jurenczyk, K. Czuba, A. Jasik, I. Sankowska, E. Papis-Polakowska, and J. Kaniewski, "Noise-Current Correlations in InAs/GaSb Type-II Superlattice Midwavelength Infrared Detectors," *IEEE Trans. Electron Devices*, vol. 63, pp. 4907–4912, 2016.

[2] V. Gopal, E. Plis, J. B. Rodriguez, C. E. Jones, L. Faraone, and S. Krishna, "Modeling of electrical characteristics of midwave type II InAs/GaSb strain layer superlattice diodes," *J. Appl. Phys.*, vol. 104, 2008.

[3] P. Martyniuk, J. Wróbel, E. Plis, P. Madejczyk, A. Kowalewski, W. Gawron, S. Krishna, and A. Rogalski, "Performance modeling of MWIR InAs/GaSb/B–Al 0.2 Ga 0.8 Sb type-II superlattice nBn detector," *Semicond. Sci. Technol.*, vol. 27, p. 55002, 2012.

[4] J. Nguyen, A. Soibel, D. Z. Y. Ting, C. J. Hill, M. C. Lee, and S. D. Gunapala, "Low dark current long-wave infrared InAs/GaSb superlattice detectors," *Appl. Phys. Lett.*, vol. 97, pp. 30–32, 2010.