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Introduction: 1/f noise is notorious for its ubiquity in electronic devices and electrode contacts. Experimental studies on 1/f noise in semiconductor GaAs have focused on n-type GaAs. There are only two publications about 1/f noise in p-type GaAs [1, 2]. The two values of a reported in these papers differed by two orders of magnitude. Therefore, we further investigated the 1/f noise in p-type GaAs.

We used a new procedure for making contacts. We grew an epitaxial layer of p-type GaAs and immediately deposited a 0.2-um thick aluminum layer on it in the MBE chamber at +20 (sample W214) and -25°C (sample W249 and 243), respectively [3]. Noise-free contacts of low resistance were obtained.

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Low frequency noise in p'-GaAs with non-alloyed contacts

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Measurements of 1/f noise were performed including and excluding the influence of the contacts formed by metallic aluminum layers (MBE) deposited on the p'-type GaAs (MBE). The results show that the MBE process can produce non-alloyed ohmic contacts free of noise. The 1/f noise of bulk p'-GaAs is characterized by $f_{\text{cut-off}} = 5 \times 10^4$ Hz.

Fig. 1 Geometry of sample

a, is spatial distance between adjacent contacts, h, = 200 um is width of contacts

Experiments: The structures of the samples are a bridge-shape Hall bar (BSHB) or a transmission line model (TLM) (Fig. 1). Their preparation was described in detail elsewhere [3]. The acceptor concentration in p-type GaAs and the contact resistivity $\rho_c$ are as follows: W214, 3.3 x 10^{18} cm^{-3}, 1.5 x 10^4 \Omega \cdot cm; W249, 3.4 x 10^{18} cm^{-3}, 5.7 x 10^4 \Omega \cdot cm; W243, 1.1 x 10^{18} cm^{-3}, 2.5 x 10^4 \Omega \cdot cm [3]. The noise measurements were performed at room temperature, in the 1 Hz – 20kHz frequency range, at different bias currents. The transverse noise (measured at the 3–6, 4–7, or 5–8 pair of terminals) and the longitudinal noise (measured at the 1–2, 3–4, or 6–8 pair of terminals, and so on) were obtained using BSHB samples with the current always flowing through contacts 1 and 2. Using a TLM sample, we could only measure the longitudinal noise. In four-point measurements, the sensors used to measure the noise power densities are not the same as the drivers that carry the current; in two-point measurements the sensors and the drivers are the same.

Results and discussion: In this Letter, we express the spectral density of the noise voltage by $S$, which is the measured result minus the thermal noise and the noise of the preamplifier.

(i) In the two-point measurements, the longitudinal noise is the sum of the bulk noise and the contact noise:

$$S = \frac{S(1/j) + S(g-r)_{\text{bulk}} + S_{\text{contacts}}}{1/j}$$ (1)

Here, $S(g-r)$ is the spectral density of the generation and recombination noise with a Lorentzian shape, $S(1/j)$ is the 1/f noise spectral density given by the empirical relation $S(1/j) = a f^x$ with $a$ the Hooge parameter [4].

(ii) In the four-point measurements, the longitudinal noise is

$$S = \frac{R_{\text{MBE}}}{R_{\text{MBE}} + R} S(1/j) + S(g-r)_{\text{bulk}} + S_{\text{contacts}}$$ (2)

with $R$, the series resistance in the measurement circuit and $R$ the resistance of the measured sample element.

Fig. 2 shows that the noise spectra have a pure 1/j shape with $y = 1$ for the samples W249 and W243, with $y = 1.1$ for W214. We do not observe a g-r noise bump in the noise spectra. Therefore, there are no traps that can cause g-r noise in the bulk of the sample and the contact regions. Here the sample W214 is an exception, in which we observe very strong noise.
In four-point measurement, the contact noise of drivers can be removed from the results by selecting $R_2 > R_1$. The linear dependence of $S$ on $L$ (Fig. 3b) for W243 and W249 with the TLM structure is proof of the fact that the contact noise does not contribute to the result. Hence the noise we measured is purely from the bulk. The $\alpha$ values from the empirical equation are $2 \times 10^{-3}$ and $2.2 \times 10^{-3}$, respectively, for W243 and W249. The meaning of $L$ is explained in Fig. 3c which suggests a model for the current through these samples. The contact resistivity is so small here that the contacts short-circuit the parts of the sample directly beneath them. This model is proved by the linear dependence of $S$ and the resistance on the length $L$ as it is defined here. Furthermore, the results of these samples, that include the contact noise in two-point measurements and exclude contact noise in four-point measurements, are the same for a chosen pair of terminals. Clearly, the contacts on the samples W243 and W249 are free of noise.

Another proof for this conclusion is that for W249 with the BSBH structure, the ratio of the longitudinal noise $S_{Lc}$ to the transverse noise $S_{Tc}$ at the same current through contacts 1 and 2 is $\approx 0.1$ in accordance with calculations given in [5], where the contacts were considered as ideal.

As for sample W214 with TLM structure, the model for current through the sample is also presented in Fig. 3a. It is proved by the linear dependence of resistance on $L$, where in this case we define $L$ as the centre-to-centre distance between the two contacts. The contact resistance is so high here that the current only passes through the GaAs layer. The process of contacting at the high temperature of $+25^\circ C$ influences the quality of the parts of the sample located directly under the contact, which is the source of the high $1/f$ noise shown in Fig. 3c. We cannot be sure that this process does not create traps in the sample, even if we do not observe the $g$-$r$ noise spectrum. Maybe the $1/f$ noise is so high that it dominates a possible $g$-$r$ noise spectrum.

Both lattice scattering and impurity scattering contribute to the measured mobility $\mu_{\text{meas}}$ and to its fluctuations characterised by $\alpha_{\text{meas}}$. The relationship between $\alpha_{\text{meas}}$ and $\alpha_{\text{true}}$ is given by $\alpha_{\text{true}} = (\mu_{\text{true}}/\mu_{\text{meas}})^{2} \times \alpha_{\text{meas}}$ as explained in [4]. The results for $\alpha_{\text{true}}$ are presented in Fig. 4, where we use $\mu_{\text{meas}} = 400 \text{cm}^2/\text{Vs}$ and $\mu_{\text{true}}$ is $120 \text{ cm}^2/\text{Vs}$ for our samples.

Conclusion: Noise-free contacts of low resistance can be prepared by an MBE process at $-25^\circ C$. There are no traps in the bulk or the contact area that cause $g$-$r$ noise in the measuring frequency range. However, depositions at $+25^\circ C$ produce very noisy contacts of higher resistance.

The $1/f$ noise we measured in $p$-GaAs is bulk noise caused by mobility fluctuations, related to the scattering by the crystal lattice. The value of $\alpha_{\text{true}}$ for our samples is $\approx 5 \times 10^{-4}$.

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