Low Frequency Noise in Boron Doped Poly-SiGe Resistors

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Abstract — **Low frequency noise in moderately and heavily boron doped poly-SiGe resistors was studied. The poly-SiGe films were grown using ultra-high vacuum chemical molecular epitaxy system. The Ge content is in the range of 0 ~ 36%. The low frequency noise was measured at room temperature. We find that the low frequency noise in poly-SiGe was almost independent of Ge content for heavily doped sample. However, for moderately doped sample, the noise decreases with the increase of Ge incorporation. This is due to the lower barrier height of grain boundary for high Ge content sample. The carrier mobility fluctuation model can explain this phenomenon.**

I. INTRODUCTION

In analog and RF circuits, the polycrystalline Si (poly-Si) film is frequently used for resistor, gate material of MOSFET, and emitter contact of BJT. Electrical and physical properties of poly-Si films have been extensively studied in the literature [1]-[3]. Recently, polycrystalline silicon-germanium (poly-$Si_{1-x}Ge_x$) has been shown to be an attractive alternative to the conventional poly-Si material for various integrated circuits applications [4]-[6]. Poly-$Si_{1-x}Ge_x$ film is known to be compatible with the conventional Si technology processing. In addition, the deposition, crystallization and dopant activation of $Si_{1-x}Ge_x$ film can be performed at a lower temperature, compared to pure Si film, due to its lower melting point. Therefore, poly-$Si_{1-x}Ge_x$ films have been applied to low temperature thin film transistor (TFT) fabrication with processing temperature not exceeding 550°C [4]. Moreover, with its lower resistivity and variable work function, the heavily doped p-type poly-$Si_{1-x}Ge_x$ film is a very promising gate-electrode material for sub-quarter-micron CMOS technologies [5].

Because the low frequency noise in transistors and resistors may contribute to the phase noise of a circuit or system, it is important to predict the amount of noise in them. Carrier number fluctuation and mobility [8]. Several researchers have studied the noise properties of poly-Si film [9]-[12]. Few investigations of noise in poly-Si can be found in the literature, by which both carrier number fluctuations [10], and mobility fluctuations [11], [12] were supported. However, the low frequency noise in poly-$Si_{1-x}Ge_x$ resistor was less studied [13], [14]. Although Chen et al. [14] has reported the Ge effect on low frequency noise in poly-$Si_{1-x}Ge_x$ films, however, their polycrystalline films were formed on imperfect gate oxide, which may contribute additional noise. In this paper, the low frequency noise in boron doped poly-$Si_{1x}Ge_x$ with various Ge content was investigated. The results will be presented in term of Ge contents with moderate and high boron dose. By using the mobility fluctuation model, the relationship of noise and Ge content in poly-$Si_{1-x}Ge_x$ resistors can be well predicted.

II. EXPERIMENT

Poly-$Si_{1-x}Ge_x$ films were grown by ultra-high vacuum chemical molecular epitaxy (UHVCME) system to a thickness of approximately 0.2μm at 580°C onto thermally grown silicon nitride. Pure disilane and germane were used as the source gas. The Ge content x in polycrystalline film was varied from 0 to 0.36. Boron atoms were implanted into the films by BF_2^+ at an energy of 20 KeV. After the ion implantation, a furnace annealing of 800°C for 20 min and a RTA annealing of 1050°C for 10 sec were performed for dopant activation and uniform doping distribution. In order to measure resistivity accurately, the Kelvin resistor structures were fabricated. The dimension of all samples under study is 500×10 μm^2.

The current-voltage characteristics of these poly-$Si_{1-x}Ge_x$ resistors were measured using HP4156A semiconductor parameter analyzer at various temperatures. The noise measurements were performed at room temperature using a BTA9812B noise analyzer in

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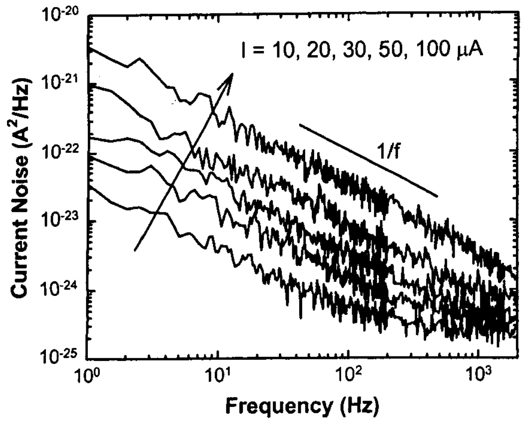

Fig. 1. Current noise spectrum versus frequency of a moderately doped ($B = 6\times10^{18}cm^{-3}$) poly-$Si_{0.64}Ge_{0.36}$ resistor.

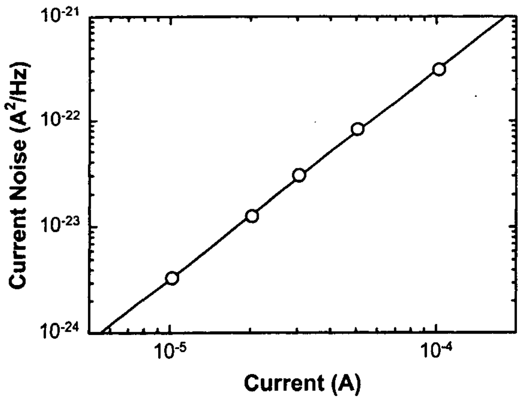

Fig. 2. Current noise spectrum versus applied current at 10 Hz for the resistor used in Fig. 1.

The measurement system was fully automated using a personal computer via HP-IB.

III. Results and Discussion

Fig. 1 shows a typical result of the measured spectral density of the noise current in poly-$Si_{1-x}Ge_x$ resistor at room temperature for various applied currents. The spectral reveal the presence of large pure $1/f$ excess noise. As can be seen in Fig. 1 the noise decreases approximately inversely proportional to frequency. The exponent of the frequency slope of the noise exhibited value between –0.95 and –1 slightly increasing toward higher applied currents. Fig. 2 shows the noise current as a function of the applied current. As a result, variation of

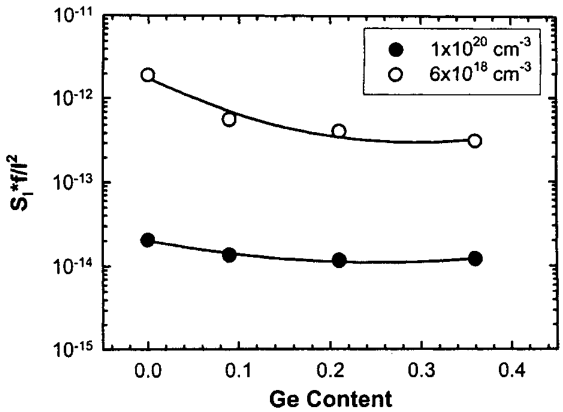

Fig. 3. Normalized current noise spectrum as a function of Ge content at different boron doping level.

noise to the square of current is observed, as reported in Ref. [11]. From these observations, the current noise can be normalized with frequency and the squares of current for clear comparison at different Ge contents. Fig. 3 shows the normalized current noise in poly-$Si_{1-x}Ge_x$ resistors as a function of the Ge content. The low frequency noise is almost independent of Ge content in heavily doped ($B = 1\times10^{20}cm^{-3}$) poly-$Si_{1-x}Ge_x$ resistors. However, the noise decreases with the increase of Ge content in moderately doped samples ($B = 6\times10^{18}cm^{-3}$). As seen in Fig. 3, the poly-$Si_{0.64}Ge_{0.36}$ exhibits a significantly lower noise level than the poly-Si. It makes poly-$Si_{1-x}Ge_x$ films the preferred choice for analog resistors.

In the generally accepted model of poly-Si, the material is viewed as composed of small crystallites joined together by grain boundaries. Inside each crystallite, the atoms are arranged in a periodic manner forming small single crystals, while the grain boundaries are composed of disordered atoms and contain large numbers of defects due to incomplete bonding. From the literature, the grain boundary contains trapping states that are capable of trapping mobile carriers and contributing to the creation of space-charge potential barrier [2]. The potential barrier will block the transport of free carriers between the grains, thus reduce the carrier mobility [2]. For low and moderately doped poly-Si, the sheet resistance R_s can be expressed as [1]:

$$R_S = \text{const.}\sqrt{T}\exp\left(\frac{q\phi_B}{kT}\right), \quad (1)$$

where T is the temperature, ϕ_B is the potential barrier height, k is the Boltzmann's constant. To determine the

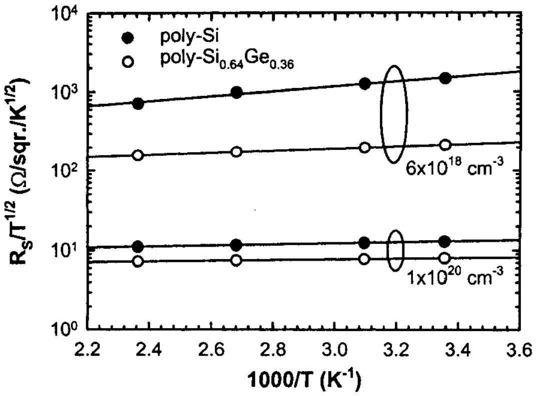

Fig. 4. Normalized sheet resistance of poly-Si and poly-$Si_{0.64}Ge_{0.36}$ for two boron concentrations at varying temperatures.

barrier heights of the grain boundary, the sheet resistance has been determined as a function of the measurement temperature for poly-Si and poly-$Si_{0.64}Ge_{0.36}$ samples. In Fig. 4, the logarithm of the normalized sheet resistance is plotted as a function of reciprocal temperature. For heavily doped samples, the sheet resistance contains barrier and bulk grain components, so the bulk resistance must be subtracted from (1). The obtained values for ϕ_B are listed in Table I. It is shown that the barrier height is lower for the $Si_{1-x}Ge_{1-x}$ samples compared to the Si samples at equal dose. In the case of poly-Si both p-type and n-type doped material will show a similar trapping behavior. In the case of poly-Ge the traps at the grain boundaries are p-type, the energy levels of the traps shift toward the valence band. Hence, the $Si_{1-x}Ge_x$ has lower potential barrier for the boron doped samples [3].

It is believed that the observed 1/f noise in poly-Si is attributed to carrier mobility fluctuations occurring in the space charge regions near the grain boundary. From the model proposed by Luo, the normalized current noise can be expressed as [11]:

$$\frac{S_I \times f}{I^2} = \frac{1}{N_{eff}} \left(\frac{v_r}{v_d} \right)^2 \frac{q^2 d\alpha}{3\varepsilon kTA} \exp\left(\frac{q\phi_B}{kT} \right), \quad (2)$$

where S_I is the measured current noise spectral density, I is the bias current, f is the frequency, N_{eff} is the effective number of large-barrier grains in the conduction path, v_r is the recombination velocity, v_d is the diffusion velocity, ε is the dielectric constant, A is the cross section of the resistor, d is the width of a one-sided space charge region, and α is the noise parameter for the grains. Substituting $d = (2\varepsilon\phi_B/qn)^{1/2}$ in (2), we have

TABLE I
Grain boundary energy barriers of boron doped poly-Si and poly-$Si_{0.64}Ge_{0.36}$ samples for two boron concentrations.

Sample	$q\phi_B$ (meV) B, 6×10^{18} cm^{-3}	B, 1×10^{20} cm^{-3}
Poly-Si	61	14
Poly-SiGe	27	9

$$\frac{S_I \times f}{I^2} \propto \sqrt{\phi_B} \exp\left(\frac{q\phi_B}{kT} \right), \quad (3)$$

Hence, the noise will depend on the barrier height according to (3). For moderately doped samples, the difference in the barrier height can lead to a factor 6 difference in noise between Si and $Si_{0.64}Ge_{0.36}$. For both materials the potential barriers are lower with increasing dopant concentration and the relative difference becomes smaller, so that the effect of the potential barriers becomes less important. For heavily doped samples, the potential barrier height only contributes to approximately a factor 1.5 difference in noise.

IV. CONCLUSION

The low frequency noise in poly-$Si_{1-x}Ge_x$ resistors has been studied versus Ge content for two boron concentrations. The noise in the heavily boron doped resistors is independent of the Ge content. The noise properties of poly-$Si_{1-x}Ge_x$ are comparable with that of poly-Si. On the other hand, the noise in moderately doped resistors decrease with increasing Ge content, which means the poly-$Si_{1-x}Ge_x$ resistors are the preferred choice for analog circuit. These results can be described by using the carrier mobility fluctuation model. It has been shown that it is possible to explain the lower noise in poly-$Si_{1-x}Ge_x$ from consideration of the lower potential barrier of grain boundaries.

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