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Temperature cross-sensitivity of Hall plate in submicron CMOS technology

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Abstract

The temperature coefficient of the current-related sensitivity of a Hall plate in submicron CMOS technology was measured. A zero-temperature-coefficient region was observed. A model of the temperature coefficient based on the freeze-out effect and the temperature dependence of the Hall scattering factor was developed. Using a Hall sensor in the observed zero-temperature-coefficient region may significantly improve its measurement accuracy. The additional, very high influence of mechanical stress, due to the piezo-Hall effect, on the temperature coefficient has been analyzed for two packaging techniques. © 2000 Elsevier Science S.A. All rights reserved.

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1. Introduction

CMOS Hall plates are simple and cost-effective magnetic sensors. The integration of the read-out electronics with sensor is important advantage. Since magnetic sensitivity of Hall plates depends inversely on the area density of charge carriers and directly on carrier mobility, they are normally fabricated in an n-well layer (low doping concentration) [1]. With the scaling-down of CMOS technologies and devices, the doping level of the n-well region is increasing, and this ultimately leads to a lower sensitivity. But if we would like to benefit from CMOS electronics with the Hall plate on the same chip then we have to accept the disadvantages of a non-optimized sensor technology.

The freeze-out effect becomes important for high doping concentrations. Not all donor atoms are ionized for low temperatures due to the insufficient thermal agitations [2]. The electron density in the conduction band is not saturated. With concentrations higher than 10^{16} cm^{-3}, the freeze-out range comes near to the room temperatures and influences temperature dependence of the current-related sensitivity.

In this paper, we study the temperature behavior of a Hall plate made in an 0.8-μm CMOS technology. Temperature coefficient of the current-related sensitivity is measured. Calculation of the temperature coefficients based on freeze-out effect and temperature dependence of the Hall scattering factor [3] are performed. Also, the influence of two sensor packaging techniques on temperature behavior of the Hall plate have been analyzed. Sensor packaging induces the temperature-dependent mechanical stress in the sensor chip. The current-related sensitivity is affected by the stress due to the piezo-Hall effect [4].

2. Measurement setup

All measurements were carried out at the magnetic field of $B = 1$ T (homogeneity better than 5 ppm) measured near to the Hall sample by Nuclear Magnetic Resonance (NMR) teslameter. The connection–commutation technique has been applied for offset reduction [1]. Since the

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Hall voltage rotates with the bias current and the offset voltage does not, the voltage can be cancelled from the output voltage. The whole measurement system control and data acquisition was controlled by a computer.

A bias current of 1 mA was utilized. The measured residual offsets of the devices were less than 10 μV at all temperatures, which limited the measurement accuracy to 100 ppm.

The supply–current-related sensitivity as a function of temperature was measured over a temperature range of 230–400 K using an air–stream system.

3. Current-related sensitivity

Supply–current-related sensitivity of the Hall device is defined as [1]:

$$S_I = G\frac{r_{\mathrm{H}}}{qnt}, \tag{1}$$

where n is the electron density in the conduction band, r_{H} is the Hall scattering factor, G is the geometrical correction factor, q is the elementary charge and t is the effective plate thickness.

Assuming the G, q and t do not depend on the temperature, we can formulate the expression of the temperature coefficient of sensitivity as:

$$\alpha_{S_I} = \alpha_{r_{\mathrm{H}}} - \alpha_n. \tag{2}$$

The temperature coefficient α_X of a value $X(S_I,\ r_{\mathrm{H}},\ n,\ldots)$ is defined as:

$$\alpha_X = \frac{1}{X_0}\cdot\frac{\mathrm{d}X}{\mathrm{d}T}, \tag{3}$$

where X_0 is $X(T = 308\ \mathrm{K})$.

4. Freeze-out effect

To preserve electrical neutrality, the total negative charges must equal to the total positive charges. For the case of donor impurities added to the silicon crystal, from the electrical neutrality, we obtain:

$$n \approx N_{\mathrm{D}}^{+}, \tag{4}$$

where $N_{\mathrm{D}}^{+}$is the number of ionized donors given by:

$$N_{\mathrm{D}}^{+} = N_{\mathrm{D}}\left[1 - \frac{1}{1 + \frac{1}{2}\exp\left(\frac{E_{\mathrm{D}} - E_{\mathrm{F}}}{kT}\right)}\right]. \tag{5}$$

E_{D} is the ionization energy of donor impurities, E_{F} is the Fermi level, T is the absolute temperature and k is the Boltzmann constant. The value of the ionization energy for phosphorus impurities in silicon is 0.045 eV [2].

The electron density in the conduction band n is given by:

$$n \approx N_{\mathrm{C}}\exp\left(\frac{E_{\mathrm{C}} - E_{\mathrm{F}}}{kT}\right), \tag{6}$$

where N_{C} is the effective density of states in the conduction band and E_{C} is the bottom of conduction band.

The effective density of states in the conduction band is defined by:

$$N_{\mathrm{C}} = 2\left(\frac{2\pi m_n kT}{h^2}\right)^{3/2}, \tag{7}$$

where m_n is the electron effective mass and h the Planck constant.

Applying Eqs. (5) and (6) in Eq. (4), we obtain the approximate expression for the electron density:

$$n \approx N_{\mathrm{C}}\exp\left(\frac{E_{\mathrm{C}} - E_{\mathrm{F}}}{kT}\right). \tag{8}$$

Using Eq. (8), we calculated the electron density for four different donor (phosphorus) concentrations and temperatures ranging from 50 K to 1000 K. The obtained results are presented in Fig. 1, from which we see that the freeze-out region approaches room temperature ($T = 308$ K) for higher donor concentrations, i.e. the electron density is not constant (horizontal) for higher donor concentrations.

From the results presented in Fig. 1, the temperature coefficient α_n of the electron density n was calculated. The temperature coefficient of the electron density as a function of temperature for different doping levels is presented in Fig. 2.

The temperature coefficient of the electron density is close to zero for low donor impurity concentrations ($N_{\mathrm{D}} <$

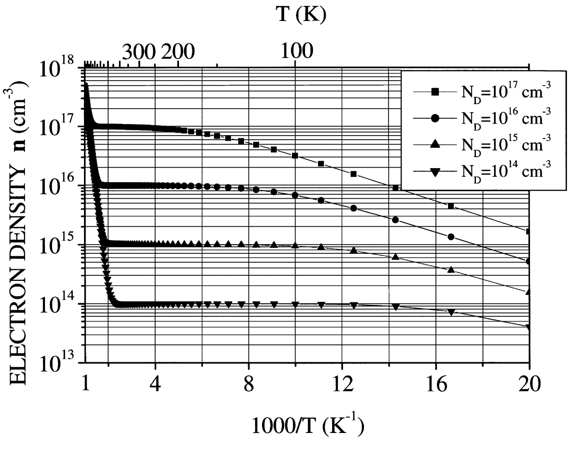

Fig. 1. Calculated electron density as a function of temperature for four different donor impurity concentrations.