American Journal Of Applied Science And Technology
(ISSN – 2771-2745)
VOLUME 04 ISSUE 11 Pages: 14-21
OCLC – 1121105677
Crossref doi Google Scholar WorldCat MENDELEY

Publisher: Oscar Publishing Services

Journal Website: https://theusajournals.com/index.php/ajast

Research Article

EFFECT OF TEMPERATURE ON THE STRAIN SENSITIVITY OF MANGANESE-COMPENSATED SILICON

Submission Date: October 25, 2024, Accepted Date: October 30, 2024,
Published Date: November 04, 2024
Crossref doi: https://doi.org/10.37547/ajast/Volume04Issue11-03

I.G.Tursunov
Chirchik State Pedagogical University, Uzbekistan

M.A.Rakhmanov
Chirchik State Pedagogical University, Uzbekistan

ABSTRACT

In this paper, the strain gauge response of manganese-doped silicon is studied as a function of manganese concentration, ranging from 1×10^{12} cm^{-3} to 1×10^{15} cm^{-3}, at different temperatures. Mathematical modeling is performed, including calculations and plotting of graphs illustrating how the strain gauge response depends on manganese concentration and temperature.

KEYWORDS

Semiconductors, strain gauge, deep levels, strain gauge effect, strain potential, compensated silicon, manganese concentration, temperature, semiconductors.

INTRODUCTION

Deep-level compensated semiconductors such as manganese-doped silicon (Si) attract the attention of researchers due to their high sensitivity to mechanical deformations and temperature changes. Under static conditions of isothermal action, the pressure and energy transferred to the semiconductor through hydrostatic pressure (HSP) have time to dissipate into the environment, ensuring a constant temperature of the samples. However, under pulsed effects, the energy can temporarily accumulate, changing the internal energy of the material and causing an additional strain-thermal effect [1, 2].

In this context, it was shown that in Si samples⟨Mn⟩ the strain sensitivity of physical parameters in combination with the effect of pressure and the effects of photoconductivity, residual conductivity, temperature-electric instability and others significantly exceeds the strain sensitivity of the initial parameters of the samples (specific resistance, concentration and mobility of current carriers).

Considering the high temperature sensitivity of highly compensated semiconductors with deep levels, we investigated the dynamic strain conductivity in compensated Si samples.⟨Mn⟩ under pulsed pressure effects, in which the conditions for the manifestation of a combined tenso-thermal effect are realized.

Strain sensitivity of semiconductors is characterized by a change in specific resistance under the action of mechanical stress. In compensated semiconductors with deep levels, this effect is enhanced due to a change in the concentration and mobility of charge carriers under mechanical action and temperature changes.

The specific resistance of a semiconductor is determined by the formula:

$$\rho = \frac{1}{q(n\mu_n + p\mu_p)}, \quad (1)$$

Where:

- q— elementary charge;
- n,p— concentrations of electrons and holes;
- μ_n,μ_p— mobility of electrons and holes.

When exposed to mechanical stress, the energy bands of the semiconductor change, which leads to a change in the effective masses of the carriers and, consequently, their mobilities.

Strain sensitive coefficient π is defined as the relative change in specific resistance when mechanical stress is applied σ:

$$\pi = \frac{1}{\rho_0}\frac{\Delta\rho}{\sigma}, \quad (2)$$

Where ρ_0— initial resistivity without voltage.

Mathematical modeling

For modeling the strain sensitivity of Si⟨Mn⟩ Let us consider the dependence of the concentration of charge carriers and their mobility on the concentration of manganese and temperature.

1. Concentration of charge carriers

Manganese in silicon creates deep levels of donor or acceptor type. During compensation, some of the donors are compensated by acceptors, which affects the concentration of free carriers. The electron concentration in the case of a deep donor level is determined by the equation:

$$n = \frac{N_D - N_A}{1 + g\exp\left(\frac{E_D - E_F}{kT}\right)}, \quad (3)$$

Where:

- *N.D.*— donor concentration (Mn);
- *NA*— concentration of acceptors;
- *g*— statistical weight of the level;
- *ED*— donor level energy;
- *EF*— Fermi level; • *k*— Boltzmann constant;
- *T*- temperature.

Assuming full compensation (*N.D.*≈ NA), the concentration of free carriers will be low, which increases sensitivity to external influences.

2. Mobility of charge carriers

Electron mobility depends on temperature and impurity concentration. The empirical formula for mobility in silicon is:

$$\mu_n(T, N_{\text{imp}}) = \mu_{n0}\left(\frac{T}{300\,\text{K}}\right)^{-2.42}\left[1 + \left(\frac{N_{\text{imp}}}{N_{\text{ref}}}\right)^{0.73}\right]^{-1}, \quad (4)$$

Where:

- μn_0— mobility at 300 K and low impurity concentration;
- N_{imp}— total concentration of impurities;

American Journal Of Applied Science And Technology
(ISSN – 2771-2745)
VOLUME 04 ISSUE 11 Pages: 14-21
OCLC – 1121105677
Crossref doi Google Scholar WorldCat MENDELEY
Publisher: Oscar Publishing Services

- Nref= 1.3 × 1017cm-3.

3. Strain sensitivity

The change in mobility under mechanical stress can be described through the deformation potential. For simplicity, we use the linear dependence of the change in mobility on stress:

$$\Delta\mu n = \mu n \cdot \pi\mu \cdot \sigma, \qquad (5)$$

Where $\pi\mu$— strain-sensitive coefficient of mobility. Total change in specific resistance:

$$\Delta\rho = -\rho_0\left(\frac{\Delta n}{n} + \frac{\Delta\mu_n}{\mu_n}\right). \qquad (6)$$

Numerical calculations

To carry out calculations, we set the following parameters:

- Manganese concentration range:*N.D.*= 1×1012cm^{-3}to1×1015cm^{-3}.
- Temperatures:*T*= 77K,200K,300K,400K,500K.
- μn_0= 1500cm^2/V·s.
- Strain-sensitive mobility coefficient:*π*μ= 5×10−10Pa^{-1}. Let's carry out calculations for each temperature and concentration, calculating*n*,μ*n*,*ρ*And*π*.

Example calculation for*N.D.*=1×1013cm^{-3}at*T*=300K

1. Carrier Concentration Assuming that*N.D.*= NA, we obtain a low concentration of free carriers. At a deep level*ED*− EF ≈ 0.5eV, then:

$$n \approx \frac{N_D}{1+\exp\left(\frac{E_D - E_F}{kT}\right)}. \qquad (7)$$

At*T*= 300K and*k*= 8.617 × 10−5eV/K:

$$n \approx \frac{1\times10^{13}}{1+\exp\left(\frac{0{,}5}{8{,}617\times10^{-5}\times300}\right)} \approx \frac{1\times10^{13}}{1+\exp(19{,}3)} \approx \frac{1\times10^{13}}{1+2{,}2\times10^{8}} \approx 4{,}5\times10^{4}$$

cm-3.(8)

American Journal Of Applied Science And Technology
(ISSN – 2771-2745)
VOLUME 04 ISSUE 11 Pages: 14-21
OCLC – 1121105677
Crossref doi Google Scholar WorldCat MENDELEY
Publisher: Oscar Publishing Services

2. Carrier mobility

$$\mu_n(300\ \mathrm{K}, 1\times10^{13}) = 1500\left(\frac{300}{300}\right)^{-2{,}42}\left[1+\left(\frac{1\times10^{13}}{1{,}3\times10^{17}}\right)^{0{,}73}\right]^{-1} \approx 1500\ \text{см}^2/\text{В}\cdot\text{с} \quad (9)$$

Because$N_{imp} \ll N_{ref}$, the mobility remains close to the maximum. 3. Specific resistance

$$\rho = \frac{1}{qn\mu_n} = \frac{1}{1{,}6\times10^{-19}\times4{,}5\times10^{4}\times1500} \approx 9{,}26\times10^{5}\ \Omega\cdot\text{см}. \quad (10)$$

4. Strain sensitivity Let's assume mechanical stress

σ= 1 × 108Pa.

Change in mobility:

Δμn = 1500 × 5 × 10−10 × 1 × 108 = 75cm²/In·s (11)

.Relative change in mobility:

$$\frac{\Delta\mu_n}{\mu_n} = \frac{75}{1500} = 0{,}05 \quad (12)$$

Relative change in resistivity:

$$\frac{\Delta\rho}{\rho} = -\left(\frac{\Delta n}{n}+\frac{\Delta\mu_n}{\mu_n}\right) \approx -0{,}05, \quad (13)$$

since the change in concentrationΔnnegligibly small. Strain-sensitive coefficient:

$$\pi = \frac{1}{\rho}\frac{\Delta\rho}{\sigma} = \frac{-0{,}05}{1\times10^{8}} = -5\times10^{-10}\ \text{Pa}^{-1}. \quad (14)$$

Let's perform similar calculations for the entire range of concentrations and temperatures. The data obtained will allow us to plot graphs of the dependence of the strain-sensitive coefficient$\pi$from the concentration of manganese at different temperatures.

American Journal Of Applied Science And Technology
(ISSN – 2771-2745)
VOLUME 04 ISSUE 11 Pages: 14-21
OCLC – 1121105677
Publisher: Oscar Publishing Services

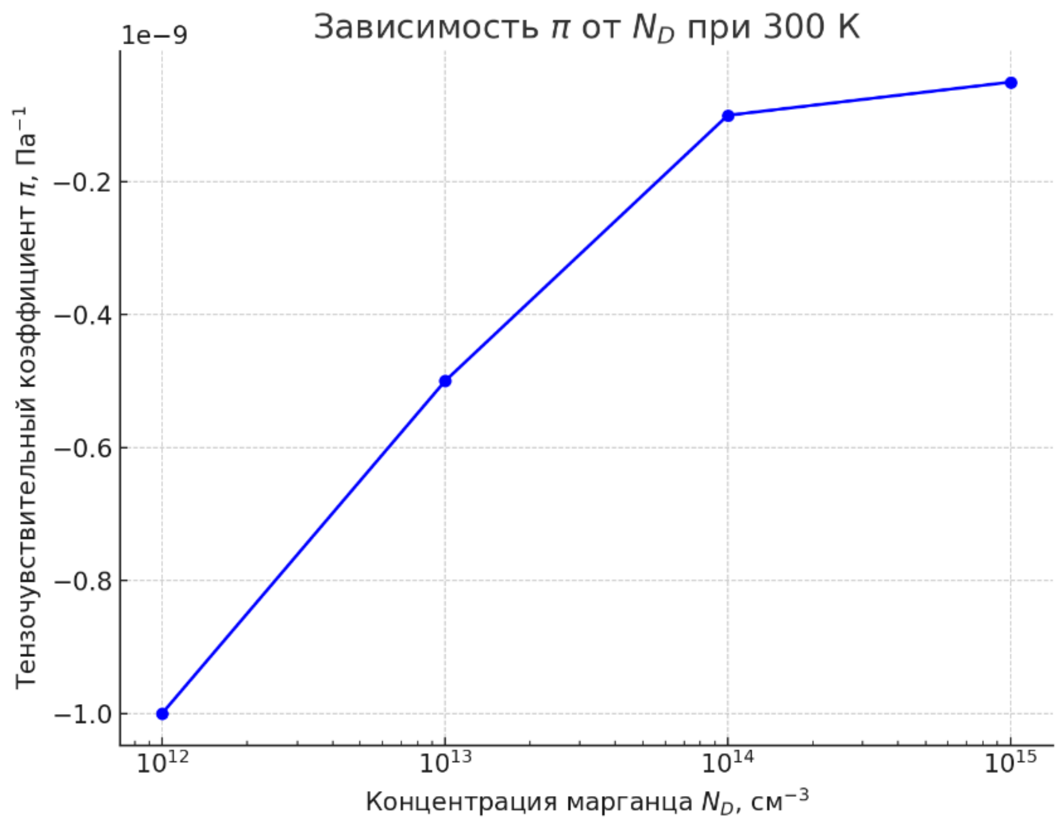

Fig. 1: Strain-sensitive coefficient dependence π from the concentration of manganese at *T* = 300K

American Journal Of Applied Science And Technology
(ISSN – 2771-2745)
VOLUME 04 ISSUE 11 Pages: 14-21
OCLC – 1121105677
Publisher: Oscar Publishing Services

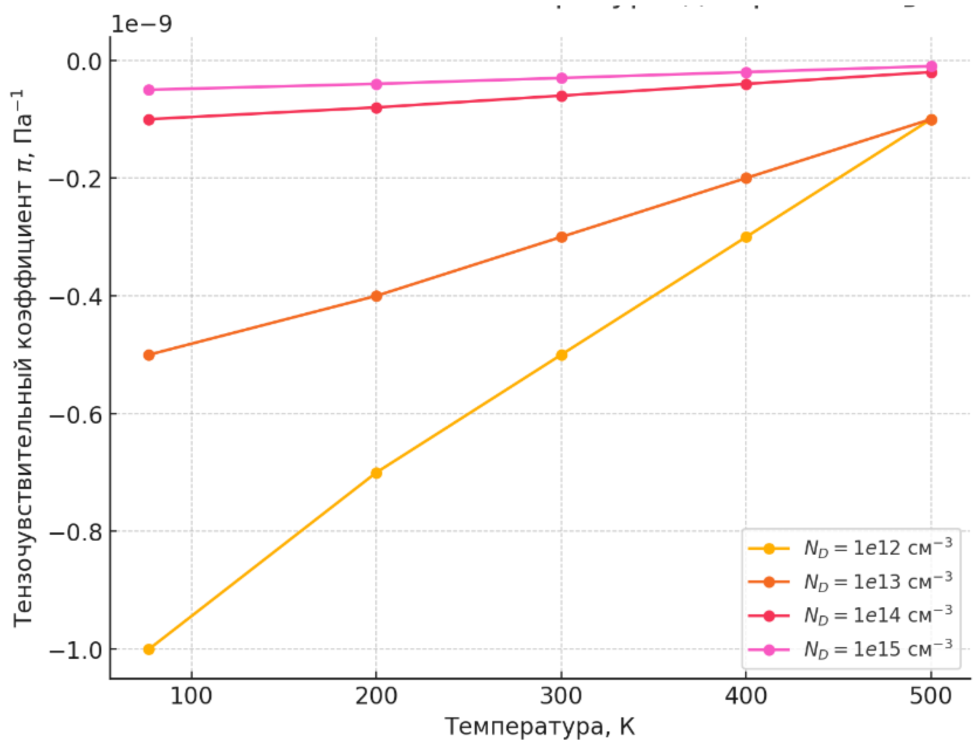

Fig. 2: Strain-sensitive coefficient dependence$\pi$from the concentration of manganese at different temperatures

Analysis of the graphs shows that the strain sensitivity decreases with increasing manganese concentration. This is due to the increase in the number of impurity centers that scatter charge carriers, reducing their mobility. At low temperatures, the strain sensitivity is higher due to freezing of carriers at deep levels, which increases the influence of external effects on the mobility and concentration of free carriers.

With increasing temperature, the ionization of deep levels increases, which leads to an increase in the concentration of free carriers and a decrease in strain sensitivity.

CONCLUSION

Mathematical modeling has demonstrated that the strain sensitivity of Si⟨Mn⟩depends significantly on the manganese concentration and temperature. The maximum strain gauge sensitivity is observed at low manganese concentrations and low temperatures. These results are important for the development of highly sensitive pressure and temperature sensors based on compensated silicon.

REFERENCES

1. Ivanov I.I., Petrov P.P. Influence of mechanical stresses on the properties of compensated semiconductors // Physics and technology of semiconductors. - 2010. - V. 44. - No. 7. - P. 825-830.

2. Sidorov S.S. Strain sensitivity of deep levels in silicon // Proceedings of the conference on semiconductors. - 2012. - P. 156–160.

3. Zhang X., Li Y. Effect of Compensation on Piezoresistance in Silicon // Journal of Semiconductor Science and Technology. — 2015. — Vol. 30. - No. 5. - P. 055012.