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MECHANISM FOR DETECTING CONTAMINANTS IN THE TRACK SENSORS

Abstract. Track sensors are created on the basis of track structures, which are obtained as a result of ion implantation of thin dielectric and semiconductor films. The passage of ion currents through such structures has specific features that are studied for a long time. The entry of various types of impurities into the ion current changes the density of the current, which makes it possible to detect the small concentrations of impurities. In this work the possible mechanism of detection of foreign impurities in the environment using such sensor is considered. The effect of the characteristics of foreign particles entering the flow, as well as the structural and geometric features of the track, on the density of the "carriers flow" (CF), has been investigated. The measured dependences of the CF density on the charge of model particles in the CF and foreign particles, as well as on the defective structure of the track walls and its diameter, have made it possible to propose a mechanism for identifying various contaminants in such a track system.

In the sensor, as a result of the interaction of a foreign particle with CF particles, an excited region arises, the size of which depends on the nature of this interaction. The appearance of such a region leads to the observed negative peak in the CF kinetics. The lifetime of such an excited region determines the resolution of the sensor. This lifetime depends on the diameter of the track and the defect structure of its walls. This implies the possibility of influencing the resolution of the sensor. This parameter of the device can be influenced at all stages of its manufacture. When creating a track structure, it is important to ensure a certain ion implantation mode. Accordingly, it is necessary to select the track diameter. It is important to select the charge and geometric characteristics of the particles in the CF.

Key words: track sensors, model particles, relaxation time of the carriers flow, sensor resolution ability.

INTRODUCTION

The migration of particles in porous materials has been studied for a long time (see, for example [1, 2]). It was established that migration and diffusion in porous materials are characterized by specific laws, which differ from the peculiarities of corresponding processes in solids. The latest [3–5] research showed that the interaction of migrating particles with pore walls plays a decisive role in the mechanisms of nanoparticles passage in such materials.

Special conditions arise during migration and diffusion of charged particles in artificial porous materials, so called track materials, which are created during ion implantation of thin films. When creating tracks by ion implantation, the inner surfaces of the tracks have a complex defective structure [6] and a set of local centers that significantly affect the mechanism of particles movement inside tracks. An important role in these processes is played by the charge states of migrating particles and local centers on the track walls.

When creating a track biosensor, it is necessary to know the regularities of the passage of ion streams through tracks, since the violation of these regularities indicates the presence of certain impurities in the carrier stream. Optimal parameters of the track structure, on the basis of which the biosensor is created, give the ohmic dependence of the ion current through the track.

The passage of ion flows through nanotracks is effectively studied by the computer simulation method. This paper discusses a possible mechanism for detecting various types of contaminants in track sensors. A computer experiment has shown that in the simplest case, a track sensor allows the detection of foreign particles if at least one parameter (for example, the charge) of the foreign particle differs from the corresponding parameter of the model particle in the carrier flow [7]. A corresponding change in the kinetics of the "carrier flow" (CF) is observed. In this work, we conducted a computer simulation study of the mechanism for detecting a foreign particle in a flow of ionic liquid passing through a track sensor.

DISTURBING INFLUENCE OF A FOREIGN PARTICLE ON THE FLOW

The methodology described in [7] was used. The model particles in the ion flow had a charge of +1. A foreign particle was introduced step by step with a charge of +2, +3 and +4. In all cases, the change in the usual current kinetics (Fig. 1) was of the same type, similar to that observed in the [7] (Fig. 2). However, the diameter of the well (Δt~τ) increased in proportion to the charge of the foreign particle (Fig. 3) and decrease with the diameter increasing (Fig. 4).

Based on the results of computer experiment obtained, the concept of sensor resolution (SR) can be introduced. This characteristic of the device is determined by the lifetime of the corresponding negative peak τ ~ Δt. Since Δt ~ Z*, it is clear, that SR of the sensor decreases with increasing foreign particle charge. In the work [9], a characteristic dependence of the flux density on the diameter was established for fixed charges of model particles. As the track diameter decreases, an area of sharp decrease in current density appears. In Fig. 5 this region was investigated and it was found that the slope of the curve in this region is determined by the charges of the model particles.

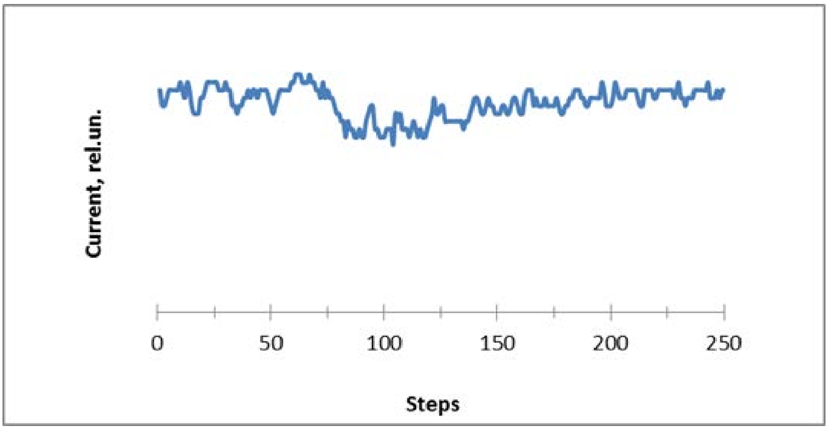

Fig. 1. Usual kinetics of the clean flow of model particles

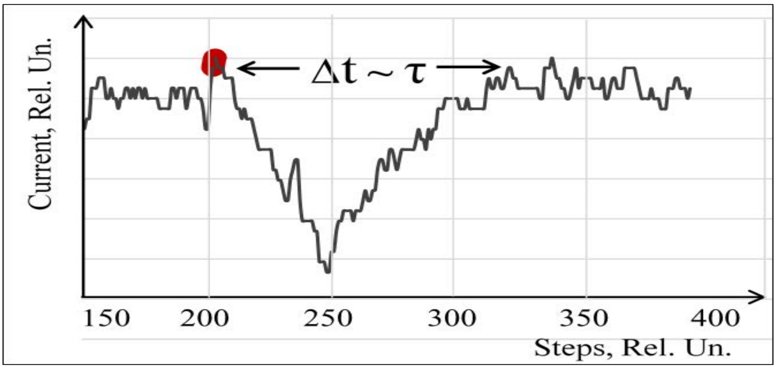

Fig. 2. Characteristic kinetics of the flow of model particles when introducing a foreign particle, see explanations in the text

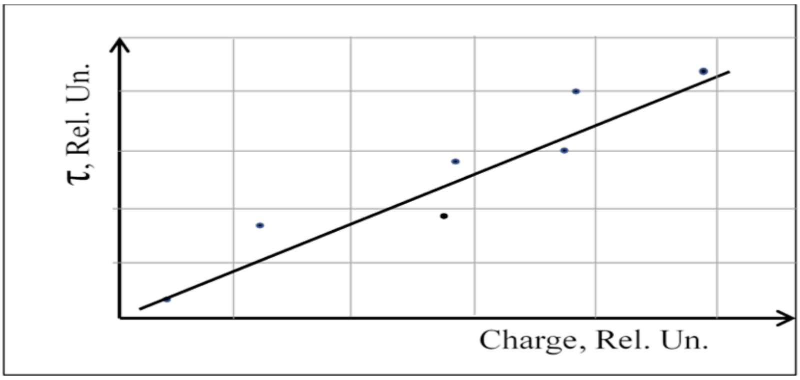

Fig. 3. Dependence of relaxation time τ on the charge of a foreign particle

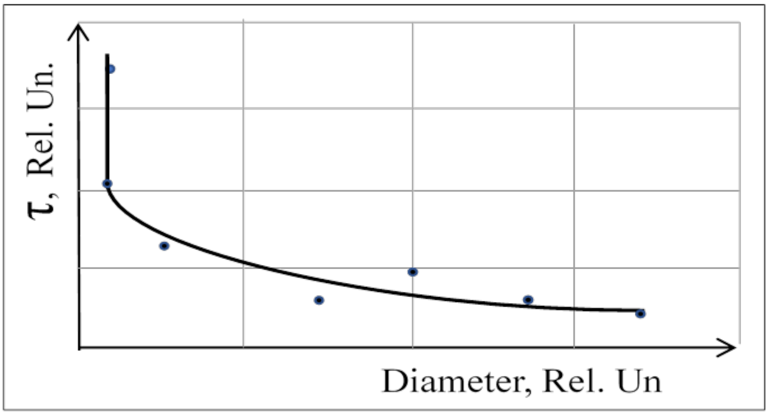

Fig. 4. Dependence of relaxation time τ on the track diameter

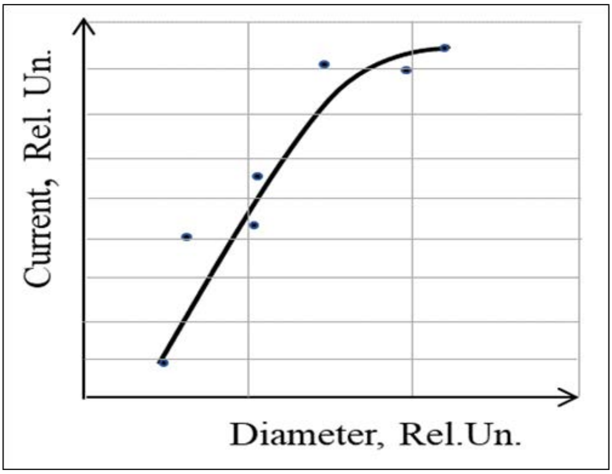

Fig. 5. Dependence of the current density of model particles on the track diameter in the region of a sharp drop in current

DISCUSSION AND CONCLUSION

The results obtained in this work and related works show that even in the simplest track sensors (including biosensors), the quality of the device depends on a large number of parameters of the track structure. Moreover, there are correlations between them, which complicate the accounting of each parameter separately. Therefore, conducting experimental research in the laboratory poses serious difficulties, which can be overcome by computer modeling. But in this case, new problems arise that require new approaches. The use of classical molecular dynamics makes it possible to obtain important information about the features of various processes in track structures, in particular about the mechanisms of migration and diffusion in such materials.

ACKNOWLEDGMENTS

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BIBLIOGRAPHY

1. Fundamentals of Ion-Irradiated Polymers. Ed. Fink, D., Springer. 2004. 406 p.

2. Renkin E.M. Filtration, diffusion, and molecular sieving through porous cellulose membranes. *J. Gen. Physiol.* 1954. Vol. 38. P. 225–243.
3. Donchev I.I., Kavetskyy T.S., Mushynska O.R., Zubrytska O.V., Briukhovetska I.V., Pryima A.M., Kovalchuk H.Y., Hoivanovych N.K., Kropyvnytska L.M., Pavlyshak Y.Y., Skrobach T.B., Kossak G.M., Stakhiv V.I., Monastyrska S.S., Kiv A.E. Computer model of track biosensor. *Semicond. Phys. Quant. Electron. Optoelectron.* 2022. Vol. 25 (4). P. 441–445.
4. Bondaruk Y., Fink D., Kiv A., Donchev I. Simulation of the passage of ion flows through nanotracks. *International Journal of Advanced Computer Technology (IJACT).* 2020. Vol. 9. P. 1–4.
5. Donchev I., Bondaruk Y., Fink D., Kavetskyy T., Kushniyazova M., Pan’kiv L., Kukhazh Y., Mushynska O., Zubrytska O., Vinkovskaya A., Dyachok D., Kiv A. Optimization of ion track characteristics in a track biosensor. *Acta Carpathica*. 2022. Vol. 2 (38). P. 31–37.
6. Vinkovskaya A., Bondaruk Y., Fink D., Kavetskyy T., Dyachok D., Donchev I., Pankiv L., Kukhazh Y., Zubrytska O., Matskiv O., Kravtsiv M., Leshko R., Hoivanovych N., Kiv A. Features of chemical etching of track structures. *Acta Carpathica.* 2023. Vol. 2 (40). P. 107–113.
7. Garcia Arellano H., Munoz Hernandez G., Fink D., Vacik J., Hnatowicz V., Alfonta L., Kiv A. Dependence of yield of nuclear track-biosensors on track radius and analyte concentration. *Nucl. Instrum. Methods Phys. Res. B.* 2018. Vol. 420. P. 69–75.
8. Bondaruk Y.V., Kavetskyy T.S., Vinkovskaya A.O., Kushniyazova M., Dyachok D.O., Pankiv L.I., Klepach H.M., Mushynska O.R., Zubrytska O.V., Matskiv O.I., Pavlovskyy Y.V., Voloshanska,S.Y., Monastyrska S.S., Bodnar L.V., Kiv A.E. Improvement of new electronic materials using computer modeling. *Semicond. Phys. Quant. Electron. Optoelectron.* 2023. Vol. 26 (4). P. 470–474.
9. Donchev I., Fink D., Vinkovskaya A., Kavetskyy T., Kushniyazova M., Dyachok D., Bondaruk Y., Pan’kiv L., Kukhazh Y., Mushynska O., Zubrytska O., Matskiv O., Soloviev V., Kiv A. Simulation of track structures as the basis of biosensors. *Acta Carpathica.* 2023. Vol. 1 (39). P. 66–72.

REFERENCES

1. Fundamentals of Ion-Irradiated Polymers (2004). Ed. Fink, D., Springer. 406 p.
2. Renkin, E.M. (1954). Filtration, diffusion, and molecular sieving through porous cellulose membranes. *J. Gen. Physiol.* Vol. 38. P. 225–243.
3. Donchev, I.I., Kavetskyy, T.S., Mushynska, O.R., Zubrytska, O.V., Briukhovetska, I.V., Pryima, A.M., Kovalchuk, H.Y., Hoivanovych, N.K., Kropyvnytska, L.M., Pavlyshak, Y.Y., Skrobach, T.B., Kossak, G.M., Stakhiv, V.I., Monastyrska, S.S., & Kiv, A.E. (2022). Computer model of track biosensor. *Semicond. Phys. Quant. Electron. Optoelectron.* Vol. 25 (4). P. 441–445.
4. Bondaruk, Y., Fink, D., Kiv, A., & Donchev, I. (2020). Simulation of the passage of ion flows through nanotracks. *International Journal of Advanced Computer Technology (IJACT).* Vol. 9. P. 1–4.
5. Donchev, I., Bondaruk, Y., Fink, D., Kavetskyy, T., Kushniyazova, M., Pan’kiv, L., Kukhazh, Y., Mushynska, O., Zubrytska, O., Vinkovskaya, A., Dyachok, D., & Kiv, A. (2022). Optimization of ion track characteristics in a track biosensor. *Acta Carpathica*. Vol. 2 (38). P. 31–37.
6. Vinkovskaya, A., Bondaruk, Y., Fink, D., Kavetskyy, T., Dyachok, D., Donchev, I., Pankiv, L., Kukhazh, Y., Zubrytska, O., Matskiv, O., Kravtsiv, M., Leshko, R., Hoivanovych, N., & Kiv, A. (2023). Features of chemical etching of track structures. *Acta Carpathica.* Vol. 2 (40). P. 107–113.

7. Garcia Arellano, H., Munoz Hernandez, G., Fink, D., Vacik, J., Hnatowicz, V., Alfonta, L., & Kiv, A. (2018). Dependence of yield of nuclear track-biosensors on track radius and analyte concentration. *Nucl. Instrum. Methods Phys. Res. B.* Vol. 420. P. 69–75.
8. Bondaruk, Y.V., Kavetskyy, T.S., Vinkovskaya, A.O., Kushniyazova, M., Dyachok, D.O., Pankiv, L.I., Klepach, H.M., Mushynska, O.R., Zubrytska, O.V., Matskiv, O.I., Pavlovskyy, Y.V., Voloshanska, S.Y., Monastyrska, S.S., Bodnar, L.V., & Kiv, A.E. (2023). Improvement of new electronic materials using computer modeling. *Semicond. Phys. Quant. Electron. Optoelectron.* Vol. 26 (4). P. 470–474.
9. Donchev, I., Fink, D., Vinkovskaya, A., Kavetskyy, T., Kushniyazova, M., Dyachok, D., Bondaruk, Y., Pan'kiv, L., Kukhazh, Y., Mushynska, O., Zubrytska, O., Matskiv, O., Soloviev, V., & Kiv, A. (2023). Simulation of track structures as the basis of biosensors. *Acta Carpathica.* Vol. 1 (39). P. 66–72.

АНОТАЦІЯ

МЕХАНІЗМ ДЛЯ ВИЯВЛЕННЯ ЗАБРУДНЮЮЧИХ РЕЧОВИН У ТРЕКОВИХ СЕНСОРАХ

Трекові сенсори створюють на основі трекових структур, які отримують унаслідок іонної імплантації тонких діелектричних і напівпровідникових плівок. Проходження іонних струмів через такі структури має особливості, які давно вивчаються. Входження різних видів домішок в іонний струм змінює густину струму, що дає змогу виявляти малі концентрації домішок. У цій роботі розглянуто можливий механізм виявлення сторонніх домішок у середовищі за допомогою такого сенсора. Досліджено вплив характеристик сторонніх частинок, що потрапляють у потік, а також структурно-геометричних особливостей треку на густину «потоку носіїв» (ПН). Виміряні залежності густини ПН від заряду модельних частинок у ПН та сторонніх частинок, а також від дефектної структури стінок треку та її діаметра дали змогу запропонувати механізм ідентифікації різноманітних забруднень у такій трековій системі.

У сенсорі внаслідок взаємодії сторонньої частинки із частинками ПН виникає збуджена область, розмір якої залежить від характеру цієї взаємодії. Поява такої області призводить до спостережуваного негативного піку кінетики ПН. Час життя такої збудженої області визначає роздільну здатність сенсора. Цей час життя залежить від діаметра треку та дефектної структури її стінок. Це передбачає можливість впливу на роздільну здатність сенсора. На цей параметр пристрою можна впливати на всіх етапах його виготовлення. Під час створення трекової структури важливо забезпечити певний режим іонної імплантації. Відповідно до цього потрібно підбирати діаметр треку. Важливо підібрати заряд і геометричні характеристики частинок в ПН.

Ключові слова: трекові сенсори, модель частинок, час релаксації потоку носіїв, роздільна здатність сенсора.