Proc. Natl. Conf. Theor. Phys. **37** (2012), pp. 163-167

BACKWARD DIFFUSION PROCESS AND THE METHOD OF CONTROL OF POLLUTED ATMOSPHERE BY DUST AND INDUSTRIAL EXHAUST

VU BA DUNG, DINH VAN THIEN
Hanoi University of Mining and Geology
TA THI DUNG, HOANG DINH CHIEU
Ha Noi National University of Education

Abstract. *The diffusion is a general process in nature. According diffusion law the diffusion fluxes are opposite to the direction of concentration gradient (forward diffusion). However, in some cases the backward diffusion could happen, so diffusion fluxes are in the same direction of concentration gradient. Based on irreversible thermodynamic theory the backward diffusion is presented and discussed, and a method of control of polluted atmosphere by dust and industrial exhaust is suggested.*

I. INTRODUCTION

Based on experimental observations and the irreversible thermodynamics theory, diffusion processes have been described by Fick laws and Onsager laws. Both laws assumed that diffusivities are positive and diffusion fluxes are opposite to the direction of concentration gradient (forward diffusion process). But it may be not true in some cases. If temperature of low concentration region is higher than temperature of higher concentration region, diffusion process may be in opposite direction of forward diffusion process, i.e. the diffusion fluxes are in the same direction of concentration gradient this diffusion is called backward diffusion or reverse diffusion. In the backward diffusion process, molecule concentration of the high concentration regions are increase and molecule concentration of the low concentration regions are reduce. In other words, there is a flux molecules going from low concentration region to high concentration region. The backward diffusion and negative diffusivity have been studied by some authors and by us. Based on properties of the backward diffusion, a method of control of polluted atmosphere by dust and industrial exhaust is suggested.

II. FORWARD DIFFUSION PROCESS

Most of the diffusion process are forward diffusion. Diffusion laws (Fick law and Onsager law) stated that diffusion currents are opposite to the direction of concentration gradient [1,2]. The fick law is expressed by the following equation:

$$J = -D\frac{\partial C}{\partial x} \tag{1}$$

where C(cm^3) is doping concentration, D(cm^2s^{-1}) is diffusivity. The onsager low is given by:

$$J = -L\frac{\partial \mu}{\partial x} \tag{2}$$

where μ is chemical potential, L is Onsager coefficient. L and D are related as follows:

$$L = \frac{DC}{kT} \tag{3}$$

where k is Boltzmann constant, T is absolute temperature. However, thermodynamics prove that equations of Fick law (1) and Onsager law (2) are true solution only in low chemical potential condition. In general, Fick and Onsager lows are nonlinear:

$$J = -\frac{D}{kT}exp\frac{\mu - \mu_0}{kT}\frac{\partial \mu}{\partial x} \tag{4}$$

where μ_0 is constant. Fick and Osager diffusion laws indicate the diffusivities are always positive. The diffusion flows in the direction of decreasing concentration.

III. NEGATIVE DIFFUSIVITY AND BACKWARD DIFFUSION PROCESS

When the diffusion flows in the direction of increasing concentration, the diffusion is called backward. Backward diffusion occurs when diffusivity is negative. There are some calculations and experiments showed that backward and negative diffusivity could happen. In the simultaneous diffusion of boron, silicon-self interstitial and vacancy in silicon, the silicon-self interstitial diffusion is described by the following equation [5-9]:

$$\begin{gathered} J_I = -\frac{1}{2}(2D_I + D_V + \frac{D_IC_I - D_BC_B}{C_V})\frac{\partial C_I}{\partial x} - \\ -\frac{1}{2}(D_V - D_B + \frac{D_VC_V - D_IC_I}{C_B} + \frac{D_IC_I - D_BC_B}{C_V})\frac{\partial C_B}{\partial x} \end{gathered} \tag{5}$$

The previous studies show that the effective diffusivity D_{eff} of silicon-self interstitial could be positive or zero, or negative. The fig.1 is the graph of the effective diffusivity of silicon-self interstitial dependent on diffusion depth, that show that D_{eff} is negative near silicon surface. So the diffusion process of silicon-self interstitial is backward, i.e. the diffusion flux of silicon-self interstitial is from the region of low concentration to the region of high concentration [5-9] :

$$D_{eff} = -\frac{1}{2}(2D_I + D_V + \frac{D_IC_I - D_BC_B}{C_V}) \tag{6}$$

Some experiment results on diffusion in silicon have showed the backward diffusion of point defects. The anomal diffusion phenomena in silicon may be related to backward diffusion like Lateral Diffusion Effect, Stacking Faults (SF) and ring Stacking Faults (ring-SF) [10].

Fig.2 is the ring Stacking Faults in silicon, that is studied by H.Yoshida etal[9].

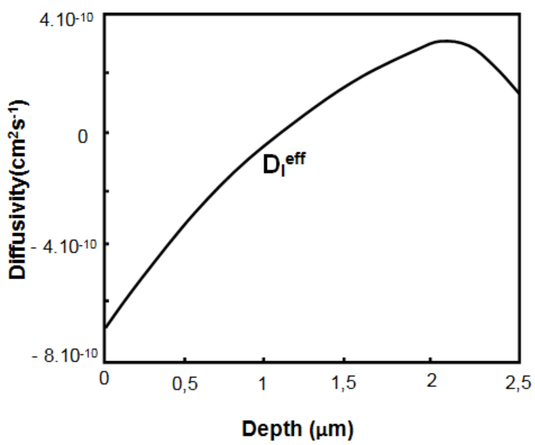

Fig. 1. The effective diffusivity of interstitial in silicon

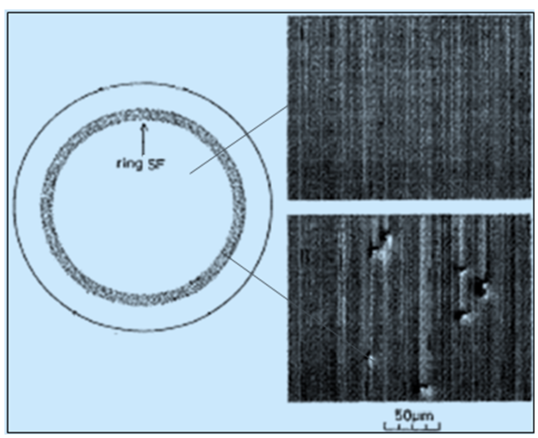

Fig. 2. The ring Stacking Faults in silicon [9].

IV. FORWARD DIFFUSION AND BACKWARD DIFFUSION EQUATION

The negative diffusivity and backward diffusion process are explained by thermodynamics theory of transport processes.

Consider the two equal thickness slices of a solid illustrated in fig.3, where slice I and slice II have different impurities concentration ($C_1 < C_2$). Thermal agitation velocities of molecules in slice I and slice II are not identical ($u_1 > u_2$). We denote :

$$u_1 = u; u_2 = u + V \tag{7}$$

$$C_1 = C; C_2 = C + \Delta C \tag{8}$$

The molecule flux from slice I to slice II is:

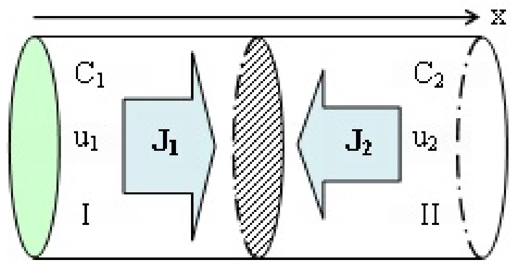

Fig. 3. The diffusion modeling

$$J_1 = \frac{u_1 C_1}{6} = \frac{uC}{6} \tag{9}$$

and flux from slice II to slice I is :

$$J_2 = \frac{u_2 C_2}{6} = \frac{uC + VC + u\Delta C - V\Delta C}{6} \tag{10}$$

The flux diffusion is :

$$J = J_1 - J_2 = -(\frac{u-V}{6})\Delta C - \frac{V}{6}C \tag{11}$$

For macroscopic description, we can use an approximate :

$$\Delta C \approx \lambda \frac{\partial C}{\partial x} \tag{12}$$

Using approximate (12) from equation (11) the flux diffusion is determined by :

$$J = -(\frac{u-V}{6})\frac{\partial C}{\partial x} - VC \tag{13}$$

Applying Fick law from equation (13) we have general diffusion equation :

$$\frac{\partial C}{\partial t} = D_{dif}\frac{\partial^2 C}{\partial x^2} + u_{dri}\frac{\partial C}{\partial x} \tag{14}$$

Equation (14) is transmission-diffusion parabolic form, where D_{dif} and u_{dri} are called diffusivity and drift term and given by:

$$D_{dif} = \frac{u-V}{6}; u_{dri} = \frac{V}{6} \tag{15}$$

The equation (14) and (15) show that :

i) If $V < u$ the diffusivity D_{dif} is positive and the diffusion process is forward.

ii) If $V = u$ the diffusivity D_{dif} is vanished and there is not diffusion process.

iii) If $V > u$ the diffusivity D_{dif} is negative and the diffusion process is backward.

Backward diffusion and forward diffusion are described by the same equation form, but the sign of diffusivity is different.

V. POSSIBLE APPLICATION IN POLLUTED EARTH'S ATMOSPHERE CONTROL

Main mechanism of air pollution in earth's atmosphere is the forward diffusion. The dust and industrial exhaust are generated on earth's surface get up in the sky, so the dust and industrial exhaust concentration increases in earth's atmosphere. Based on the interesting properties of the backward diffusion, we propose a method of control of polluted atmosphere, that is called "backward diffusion method". In this method, the conditions for backward diffusion of dust and industrial exhaust are made somehow by human. Then in the backward diffusion, dust and industrial exhaust transport from the atmosphere back to earth's surface.

VI. CONCLUSION

When the thermal agitation velocity of molecules in the low concentration region is faster than in the high concentration region, the diffusivity could be negative and diffusion process could be backward. In the backward diffusion, the diffusion flux is from the region of lower concentration to the region of higher concentration. The backward diffusion process could be occurred in simultaneous of boron, silicon-self interstitial and vacancy in silicon. The backward diffusion could be applied as a new method for the control of polluted earth atmosphere by dust and industrial exhaust.

REFERENCES

[1] A.Fick, *Phil. Mag* **10**(1855)30.
[2] ,J. Philibert *Diffusion fundamentals* **2** (2006) 1-10.
[3] ,G.D.C.Kuiken, *Thermodynamics of Irreversible Processes*, Wiley, London (1994).
[4] P.Garbaczewski, *Acta. Phys. Pol.* **E39** (2008) 1087-1101.
[5] V.B.Dung, D.K. An and N.N.Long, *Proceedings of the* 1^{st} *Academic Conference on Natural Science for Master Electronics, Pergamum Press* **13** (1970) 165-172.
[6] V.B.Dung and Dao Khac An, *Defect and Diffusion Forum* **94** (2001) 6470-652.
[7] V.B.Dung and D.K.An,P.A.Tuan and N.N.Long, *Proceedings of The Osaka University-Asia Pacific-Vietnam National University Forum* (2005) 92.
[8] V.B.Dung, D.K.An and P.A.Tuan and N.V. Truong, *Defect and Diffusion Forum* **258** (2007) 32-38.
[9] H.Yoshida, M.Ohmori (1992), *Applied Physics Letters*, **60**, p. 2389.
[10] G.Gilboa, N. Sochen and Y.Zeevi, *IEEE Transaction in Image Processing* **11**(2002) 698-703.
[11] A.Visintin, *Calculus of Variations and PDE* **15** (2002) 115-132.
[12] ,L.C.Evans, *American Math Society*, third printing (2002).
[13] L.C.Evans and M. Portilheiro, *Math. Models Method Appl. Sci.***14** (2009) 341-351.
[14] B.H.Gilding and A.Tesei, *Phys.* D. **239** (2010) 291-311.
[15] , A.Terracina and A.Tesei,Arch.National Mech. Anal. **194** (2009) 887-925.
[16] D. Pelinovsky and M.Chugunova, J.math.Appl. **243** (2008) 970-988.
[17] M.Slemrod, J.Dyn. Differential Equations **3** (1991) 614-622.
[18] L.C.Evans and M.Portilheiro, Math. Models Method Appl. Sci.**14** (2009) 341-351.

Received 30-09-2012.