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Boron diffusion and activation in polycrystalline $Si_{1-x}Ge_x$ films for CMOS gate electrodes

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INTRODUCTION

We have studied the B diffusion process in polycrystalline $Si_{1-x}Ge_x$ films fabricated by means of molecular beam epitaxy (MBE) on top of thermally grown SiO_2 dielectric films. The diffusion parameters: diffusion length $L(T_A, t_A)$, diffusion coefficient $D(T)$, diffusion constant D_0, and activation energy W_A were investigated as functions of Ge mole fraction x in the grown films and of MBE deposition temperature T_D for achieving different poly grain sizes. The stochiometry of the grown polycrystalline $Si_{1-x}Ge_x$ films was determined by Rutherford-backscattering spectrometry (RBS).

For an accurate determination of $L(T_A, \tau)$ for different annealing temperatures T_A and annealing process times τ we used the delta doping technique to obtain a well defined initial B depth and concentration profile $c_B(z, T_A = 0, \tau = 0)$ in the fabricated $Si_{1-x}Ge_x$ films. The annealing process time τ consists of the temperature ramping time t_R and the annealing time t_A at T_A. Rapid thermal annealing (RTA) was used to minimize B diffusion during ramping times t_R. The B and the $Si_{1-x}Ge_x$ concentration profiles were measured by means of secondary ion mass spectrometry (SIMS).

SAMPLE PREPARATION

By using MBE an undoped homogeneous $Si_{1-x}Ge_x$ film ($0 \leq x \leq 1$) with a thickness of 150nm was grown at a temperature T_D ($T_D = 200/500/700°C$) on top of a 10nm thermally grown SiO_2 film. In a second step pure B with a dose of $\varphi_0 = 5e12cm^{-2}$ was deposited at $T_D = 200°C$. Finally an undoped 50nm Si cap was deposited also at $T_D = 200°C$. This cap is needed to form an ultra-sharp and well defined buried B delta doping spike with a thickness smaller 3nm [1] and for an accurate SIMS analysis.

After MBE pieces of a grown sample were annealed by means of RTA each at an individual annealing time t_A and temperature T_A ($T_A = 750/800/850/900/950/1050°C$). To determine the influence of the RTA ramping phases pieces were annealed at the chosen annealing temperatures T_A for $t_A = 0$. The resulting diffusion profiles $c_B(z, T_A, \tau)$ were measured by SIMS.

DIFFUSION MODELLING

Time and temperature dependent impurity diffusion processes are described by the second Fick´s law:

$$d/dt[c(z, T, t)] = D(T)*d^2/dz^2[c(z, T, t)]. \qquad [1]$$

For an initial ultra-sharp impurity concentration $c(z = 0, T < T_{crit}, t = 0) = \varphi_0$ the solution of eq.1 is given by:

$$c(z, T, t) = 2*\varphi_0/(\pi^{0.5}*L(T, t))*exp(-z^2/L(T, t)^2). \qquad [2]$$

Below the critical temperature T_{crit} diffusion is negligible. The diffusion length $L(T, t)$ is given by :

$$L(T, t) = 2*(D(T)*t)^{0.5}. \qquad [3]$$

The diffusion coefficient $D(T)$ is given by :

$$D(T) = D_0*exp(-W_A/(k_B*T)). \qquad [4]$$

RESULTS

To calculate the diffusion coefficient $D(T_A)$ as function of Ge mole fraction x, MBE deposition temperature T_D, and annealing temperature T_A the diffusion length $L(T_A, \tau = t_A)$ was calculated by:

$$L(T_A, \tau = t_A) = L(T_A, \tau = t_R + t_A) - L(T_A, \tau = t_R). \qquad [5]$$

The diffusion lengthes $L(T_A, \tau = t_R + t_A)$ and $L(T_A, \tau = t_R)$ were extracted from the individual SIMS profiles (see fig.1).

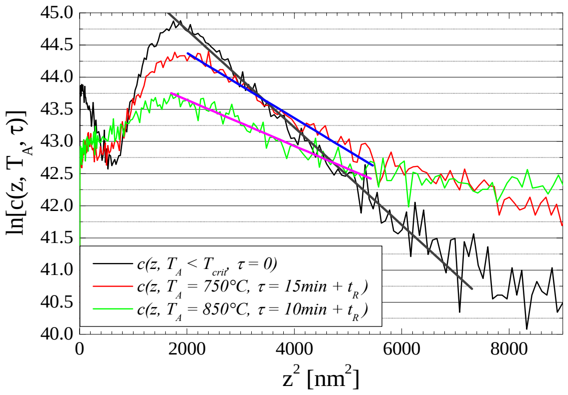

Fig.1: $ln[c(z, T_A, \tau)]$ vs. z^2 for Ge mole fraction $x = 0.2$ and $T_D = 500°C$

The individual activation energy W_A and diffusion constant D_0 as functions of Ge mole fraction x and MBE deposition temperature T_D were extracted from an Arrhenius plot $ln[D(T_A)]$ vs. $1/T_A$ (see fig.2).

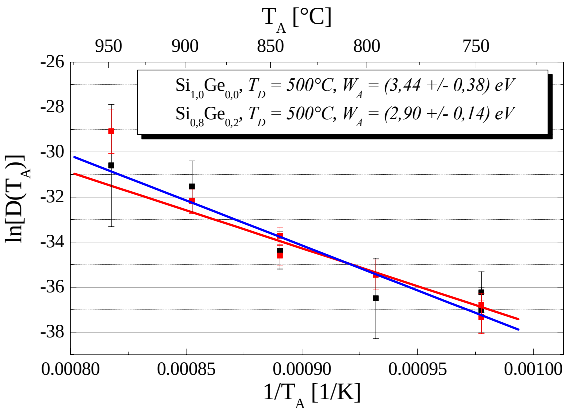

Fig.2: Arrhenius plot $ln[D(T_A)]$ vs. $1/T_A$ for Ge mole fraction $x = 0.2$ and $T_D = 500°C$

As known from literature the activation energy W_A of B in Si is $W_A = 3.46\ eV$. This is in accordance to our experimental results for polycrystalline Si. With increasing Ge mole fraction x the B activation energy decreases. This allows a lower thermal budget for CMOS processing. Experimental results of the whole process parameter matrix given by deposition temperature T_D, Ge mole fraction x, annealing temperatures T_A, and annealing times t_A are presented. In addition the poly grain size dependence will be discussed.

REFERENCES

[1] Zeindl, Wegehaupt, Eisele, Oppolzer, Reisinger, Tempel, Koch, Appl. Phys. Lett. 50 (1987) 1165