Based on the results that follow I suggest a diffusion time of 30 minutes at 1000°C with an oxide thickness of at least 500Å. The poly variation can be from 1500Å to 2500Å. What follows is the design process and verification of this process. This process will work for oxide thicknesses from

First, let's start with the hand calculations. (Jaeger Vol. V, Table 1 page 74)
300 to1000Å, diffusion times of 20-30 minutes. (This includes 129 like ramp rates), and temperatures from 995 to 1005 °C.

$D_0 := 10.5$ $\quad E_A := 3.69$ $\quad T := 1000 + 273$ $\quad U_T := \frac{1.38 \cdot 10^{-23} \cdot T}{1.6 \cdot 10^{-19}}$

$U_T = 0.11$

$D := D_0 \cdot e^{\frac{-E_A}{U_T}}$ $\quad D = 2.664 \times 10^{-14}$

The solid solubility will control the surface concentration. (Jaeger Vol. V, Fig 4.6 page 75)

$N_S := 4 \cdot 10^{20}$

Since the P from the P SOG will not run out during our diffusion we use the erfc for junction depth. A standard PN junction is not required in this case. It is designed to have the doping be around 10^19 at the Si/Poly interface

$N_B := 10^{19}$ $\quad x_j := .2 \cdot 10^{-4}$

$Z := 1 - \frac{N_B}{N_S}$ $\quad Z = 0.975$ $\quad x := 2$

In MathCAD the inverse erfc function is not built in.

Given

$$Z = \frac{2}{\sqrt{\pi}} \cdot \int_0^x e^{-t^2}\, dt$$

$X := \mathrm{Find}(x)$ $\quad X = 1.585$

$t := \left(\frac{x_j}{2 \cdot X}\right)^2 \frac{1}{D}$ $\quad t = 1.494 \times 10^3$

$\mathrm{Time} := \frac{t}{60}$ $\quad \mathrm{Time} = 24.905$

24 minutes is reasonable, but the HC for P diffusion can be off, and we the thickness if the poly is only .2um on top of oxide. This requires TCAD!

To verify the process with TCǺD a run deck was created in which the P substrate doping (NǺ), Oxide Thickness (Ox_T), Poly Thickness (Poly_T), Diffusion Time (SD_Time), and Diffusion Temperate (SD_Tmp) were all variables. The process sequence was modified from standard 129 procedures. The run deck (Figure 1) was set up to extract the phosphorus doping near the oxide substrate interface in order to tell if the phosphorus has diffused through the gate.

NǺ is in cm^-3
Ox_T is in Ǻ
Poly_T is in Ǻ
SD_time is in minutes
SD_Tmp is in degrees C

The First experiment varied the diffusion time from 5 to 50 minutes while the temperature was held at a constant 1000oC, while the other variables were held constant (Figure 2). Ǻ sample plot of the structure shows that the ND in the poly is within specification and that the phosphorus never appreciably enters into the substrate.

```
set sim_left 0
set sim_right 5.6
set sim_bottom .5
set sim_top 0
line y loc=0 spa=1.12 tag=left
line y loc=5.6 spa=1.12 tag=right
line x loc=0 spa=0.025 tag=top
line x loc=.5 tag=bottom
region Silicon xlo=top xhi=bottom ylo=left yhi=right
init concentration=1e+16 field=Boron wafer.orient=100  slice.angle=[CutLine2D 0 0 5.6 0.0
deposit material = {Oxide} type = isotropic  rate = {1.0} time=0.1
deposit material = {Poly} type = isotropic  rate = {1.0} time=0.2
deposit material = {Oxide} type = isotropic  Phosphorus conc=5e21 rate = {1.0} time=0.3
temp_ramp name=tempramp_4_2 time=15 temp=400 ramprate=0.5556
diffuse temp_ramp=tempramp_4_2
temp_ramp name=tempramp_4_3 time=15 temp=900 ramprate=0.1111
diffuse temp_ramp=tempramp_4_3
temp_ramp name=tempramp_4_4 time=5 temp=1000
diffuse temp_ramp=tempramp_4_4
temp_ramp name=tempramp_4_5 time=5 temp=1000
diffuse temp_ramp=tempramp_4_5
temp_ramp name=tempramp_4_6 time=20 temp=1000 ramprate=-0.5000
diffuse temp_ramp=tempramp_4_6
struct dfise=s_d_doping
strip Oxide
set Ygox [interface oxide /silicon  ]
set Ytmp [expr $Ygox + 0.005]
sel z = Phosphorus
set Ygoxtmp [expr $Ygox + 0.005 ]
set ND_SUB [format %.3e [lindex [lsort -real [interpolate x = $Ygoxtmp  silicon ]] 0]]
puts "DOE: ND_SUB  [format %.3e $ND_SUB]"
struct dfise=n4
struct smesh=n4
exit
```

**Figure 1: Sample Run Deck.**

| | NA | Ox_T | Poly_T | SD_Time | SD_Tmp | ND_SUB |
|---|---|---|---|---|---|---|
| -- | 1e16 | 1000 | 2000 | 5 | 1000 | 1.643e+10 |
| | | | | 10 | 1000 | 1.644e+10 |
| | | | | 15 | 1000 | 1.643e+10 |
| | | | | 20 | 1000 | 1.641e+10 |
| | | | | 25 | 1000 | 1.639e+10 |
| | | | | 30 | 1000 | 1.637e+10 |
| | | | | 35 | 1000 | 1.634e+10 |
| | | | | 40 | 1000 | 1.633e+10 |
| | | | | 45 | 1000 | 1.631e+10 |
| | | | | 50 | 1000 | 1.630e+10 |

**Figure 2: Results.**

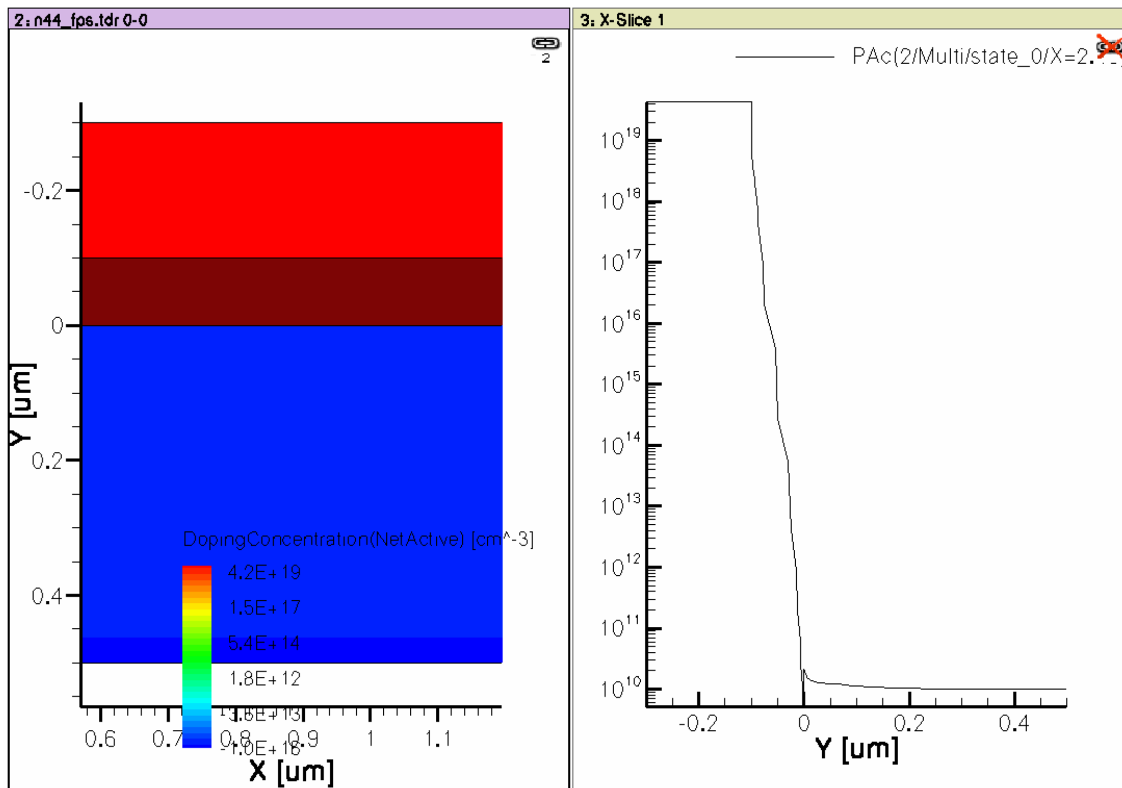


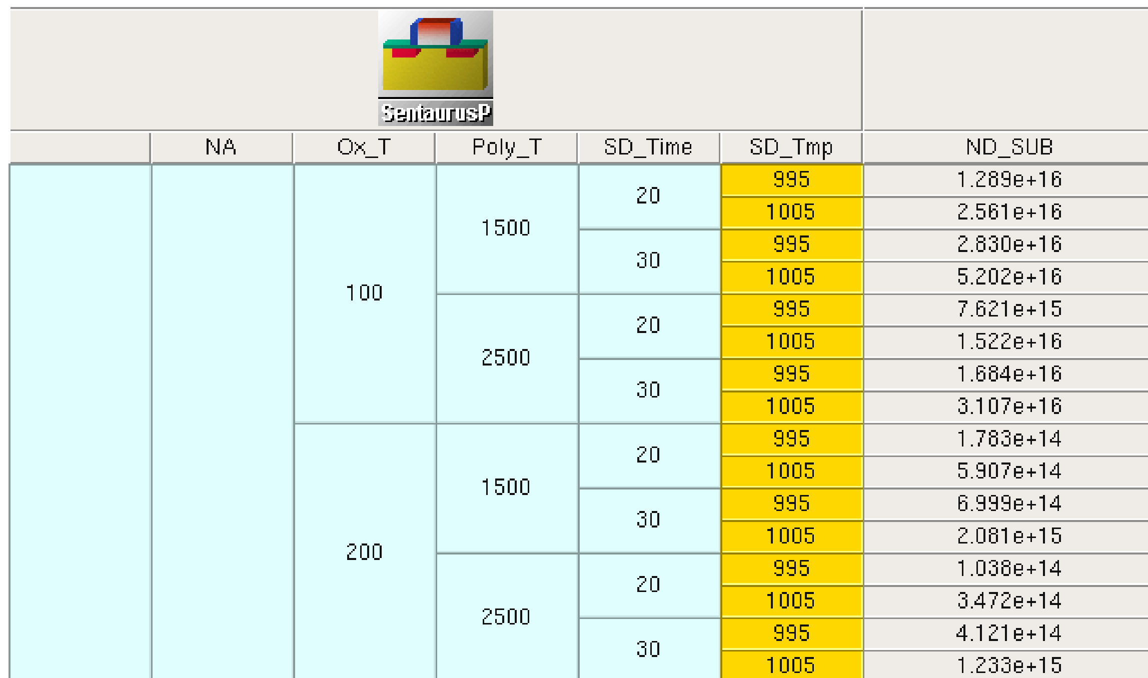

**Figure 3: Plotted Results of Sample Structure**

The process seems quite robust for 1000Å of Si02 and the times and temperatures investigated. To see the limits of the process the oxide thickness was varied from 100Å to 900Å in steps of 100Å. For every Oxide thickness the ploy thickness was varied from 1500Å to 2500Å in steps of 1000Å. For every Oxide thickness, Plot thickness pair the SD time was evaluated at 20 and 30

minutes. For every SD time the SD temp was evaluated at 995oC and 1005oC. Å successful iteration will have the phosphorus concentration in the gate about 10^19 thought the gate, and the phosphorus concentration in the substrate 100 times less than 10^16.

As can be seen in Figure 4, an oxide thickness of 200Å and below results in phosphorus being introduced into the substrate. Another fear is that the poly will not be completely doped if it too thick or the temperature and diffusion time are too small. Looking at the results of at poly thickness of 2500Å and diffusion time and temperature of 20 minutes and 995oc respectively showed that the poly was completely doped.

Based on these results I suggest a diffusion time of 30 minutes at 1000oC with an oxide thickness of at least 500Å. The poly variation can be from 1500Å to 2500Å.




| | NA | Ox_T | Poly_T | SD_Time | SD_Tmp | ND_SUB |
|---|---|---|---|---|---|---|
| | | 100 | 1500 | 20 | 995 | 1.289e+16 |
| | | | | | 1005 | 2.561e+16 |
| | | | | 30 | 995 | 2.830e+16 |
| | | | | | 1005 | 5.202e+16 |
| | | | 2500 | 20 | 995 | 7.621e+15 |
| | | | | | 1005 | 1.522e+16 |
| | | | | 30 | 995 | 1.684e+16 |
| | | | | | 1005 | 3.107e+16 |
| | | 200 | 1500 | 20 | 995 | 1.783e+14 |
| | | | | | 1005 | 5.907e+14 |
| | | | | 30 | 995 | 6.999e+14 |
| | | | | | 1005 | 2.081e+15 |
| | | | 2500 | 20 | 995 | 1.038e+14 |
| | | | | | 1005 | 3.472e+14 |
| | | | | 30 | 995 | 4.121e+14 |
| | | | | | 1005 | 1.233e+15 |

**Figure 4: Sensitivity Analysis.**