

# Homework #20

20221059 정상목

## 1. 과제 목표

Potential, electron, hole에서 Greenfunction을 이용하여 G값을 구하자.

## 2. Mesh

이번 과제에서 사용할 mesh는 다음과 같습니다.

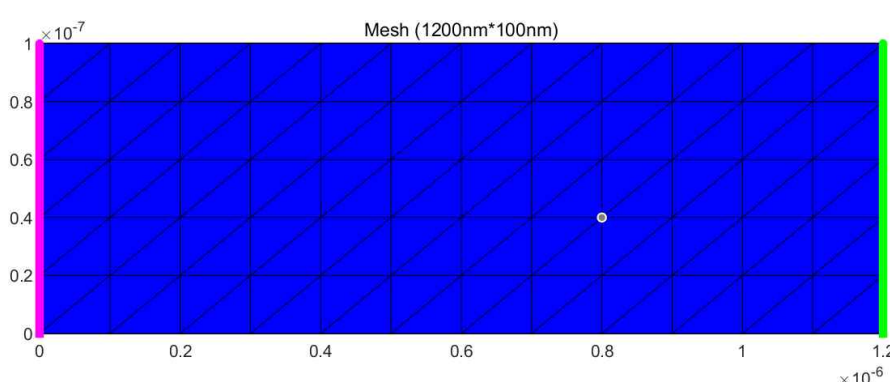
Mesh	Vertex information
	<p>Total vertex: 275</p> <p>dx: 50nm</p> <p>dy: 10nm</p> <p>Jaco matrix: 25*11</p>

Fig 1. N-type bar

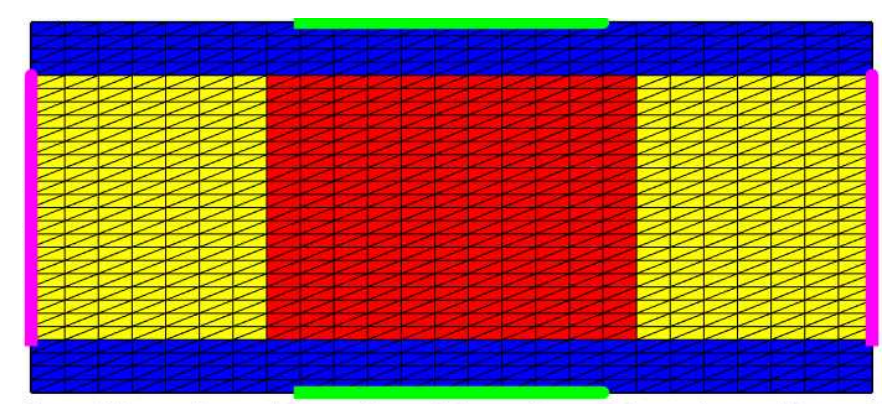
Double gate MOSFET	Region information
	<p>Oxide: blue, <math>t_{ox}=2nm</math></p> <p>Source/Darin: yellow, <math>L=15nm</math></p> <p>Channel: red, <math>L=20nm</math></p> <p>Gate contact: green</p> <p>Source/Drain contact: magenta</p>
	<p>Doping density</p> <p>N-type: <math>5e26 m^{-3}</math></p> <p>p-type: <math>2e21 m^{-3}</math></p> <p>Oxide workfunction: 4.3eV</p>
	<p>Vertex information</p> <p>Total veretx: 754</p> <p>Jaco matrix: 2024*2024</p>

Fig 2. Double\_gate\_MOSFET

다음과 같이 2가지 경우에 대한 mesh를 계산했습니다. N\_type bar의 경우  $r_0$ 를 모든 지점에서 측정하여 G값을 구해주었습니다. Doublegate MOSFET의 경우 결과가 정상적으로 나오지 않아 수정이 필요합니다.

### 3. Result

#### 3.1. N\_type bar

N\_type bar에서 모든 지점  $r_0$ 에 대해 excitation 되었을 때의 G값을 구해주기 위해 b vector를 다음과 같이 구성했습니다.

$$b \text{ vector} = \begin{bmatrix} 1 & 0 & \dots & 0 & 0 \\ 0 & 1 & & & \\ \dots & \dots & & & \\ 0 & & & 1 & \\ 0 & & & & 1 \end{bmatrix}$$

물론 다음과 같이 b vector를 구성한 후 Boundary condition을 모두 고려해주었습니다. 다음과 같이 b vector를 구성함으로써 한번의 계산으로 G값을 모두 구할 수 있었습니다. 구해진 결과는 다음과 같습니다.

$$\begin{bmatrix} G_{\phi\phi} \\ G_{n\phi} \\ G_{p\phi} \end{bmatrix}$$

solution_vector_phi_AC x solution_vector_elec_AC x solution_vector_hole_AC x					
78x234 complex double					
1	2	3	4	5	6
0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i
-6.5809e-41 + 8.3333e-05i	1.3705e-26 + 3.9459e-49i	-1.4624e-27 + 4.1912e-49i	0.0032 - 0.0000i	-3.5371e-04 - 1.0194e-25i	-3.8656e-04 + 1.1079e-25i
-2.3654e-41 + 1.6667e-04i	1.7905e-26 + 5.0671e-49i	-2.0990e-28 + 5.3761e-49i	1.1179e-05 - 2.4121e-25i	-4.6211e-04 - 1.3076e-25i	-5.5484e-05 + 1.4211e-25i
8.8217e-41 + 2.5000e-04i	2.2891e-26 + 4.1649e-49i	5.6520e-28 + 4.4163e-49i	-3.4522e-04 - 2.0691e-25i	-5.9081e-04 - 1.0749e-25i	1.4940e-04 + 1.1674e-25i
2.2158e-40 + 3.3333e-04i	2.6589e-26 + 1.9669e-49i	1.1671e-27 + 2.0828e-49i	-6.0952e-04 - 1.0740e-25i	-6.8622e-04 - 5.0766e-26i	3.0850e-04 + 5.5057e-26i
3.3482e-40 + 4.1667e-04i	2.8749e-26 + 8.7396e-49i	1.6032e-27 + 9.3201e-50i	-7.9944e-04 + 2.5399e-26i	-7.4200e-04 + 2.2556e-26i	4.2378e-04 + 2.4637e-26i
4.1001e-40 + 5.0000e-04i	2.9349e-26 + 3.7816e-49i	1.8731e-27 + 4.0170e-49i	-9.1451e-04 + 1.6341e-25i	-7.5740e-04 + 9.7600e-26i	4.9513e-04 + 1.0619e-25i
4.3569e-40 + 5.8333e-04i	2.8375e-26 + 6.2562e-49i	1.9767e-27 + 6.6422e-49i	-9.5284e-04 + 2.8233e-25i	-7.3255e-04 + 1.6147e-25i	5.2252e-04 + 1.7558e-25i
4.1782e-40 + 6.6667e-04i	2.5836e-26 + 7.8745e-49i	1.9140e-27 + 8.3586e-49i	-9.1487e-04 + 3.6156e-25i	-6.6681e-04 + 2.0324e-25i	5.0594e-04 + 2.2095e-25i
3.6211e-40 + 7.5000e-04i	2.1729e-26 + 8.2899e-49i	1.6849e-27 + 8.7894e-49i	-8.0058e-04 + 3.8421e-25i	-5.6081e-04 + 2.1369e-25i	4.4539e-04 + 2.3258e-25i
2.5863e-40 + 8.3333e-04i	1.6053e-26 + 7.2320e-49i	1.2895e-27 + 7.6750e-49i	-6.0999e-04 + 3.3715e-25i	-4.1433e-04 + 1.8695e-25i	3.4087e-04 + 2.0286e-25i
1.3963e-40 + 9.1667e-04i	8.8069e-27 + 4.5069e-49i	7.2782e-28 + 4.7629e-49i	-3.4310e-04 + 2.1094e-25i	-2.2737e-04 + 1.1632e-25i	1.9239e-04 + 1.2642e-25i
0.0000e-00 + 1.0000e-03i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i
0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i
-6.5804e-41 + 8.3333e-05i	1.2107e-26 + 3.9459e-49i	-1.2906e-27 + 4.1907e-49i	4.4990e-04 - 1.7350e-25i	-3.1247e-04 - 1.0184e-25i	-3.4116e-04 + 1.1078e-25i
-2.3636e-41 + 1.6667e-04i	1.7803e-26 + 5.0673e-49i	-2.0820e-28 + 5.3762e-49i	2.4460e-06 - 2.4129e-25i	-4.5949e-04 - 1.3078e-25i	-5.5034e-05 + 1.4211e-25i
8.8218e-41 + 2.5000e-04i	2.2892e-26 + 4.1649e-49i	5.6501e-28 + 4.4164e-49i	-3.4430e-04 - 2.0692e-25i	-5.9058e-04 - 1.0749e-25i	1.4935e-04 + 1.1674e-25i
2.2157e-40 + 3.3333e-04i	2.6587e-26 + 1.9670e-49i	1.1670e-27 + 2.0828e-49i	-6.0940e-04 - 1.0740e-25i	-6.8619e-04 + 5.0766e-26i	3.0840e-04 + 5.5059e-26i
3.3483e-40 + 4.1667e-04i	2.8749e-26 + 8.7396e-49i	1.6032e-27 + 9.3201e-50i	-7.9993e-04 + 2.5399e-26i	-7.4200e-04 + 2.2556e-26i	4.2378e-04 + 2.4637e-26i
4.1001e-40 + 5.0000e-04i	2.9349e-26 + 3.7816e-49i	1.8731e-27 + 4.0170e-49i	-9.1451e-04 + 1.6341e-25i	-7.5740e-04 + 9.7600e-26i	4.9513e-04 + 1.0619e-25i
4.3569e-40 + 5.8333e-04i	2.8375e-26 + 6.2562e-49i	1.9767e-27 + 6.6422e-49i	-9.5284e-04 + 2.8233e-25i	-7.3255e-04 + 1.6147e-25i	5.2252e-04 + 1.7558e-25i

$$\begin{bmatrix} G_{\phi n} \\ G_{nn} \\ G_{pn} \end{bmatrix}$$

solution_vector_phi_AC x solution_vector_elec_AC x solution_vector_hole_AC x					
78x234 complex double					
1	2	3	4	5	6
0.0000 + 0.0000i	-1.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i
-5.8878e-16 - 3.0622e-06i	-0.1119 + 0.0000i	-0.0113 + 0.0000i	2.4890e-22 - 6.5165e-01i	2.8879e-21 - 4.0168e-01i	-2.9862e+21 + 4.3771e-01i
-1.0330e-15 - 4.8103e-06i	-0.0771 + 0.0000i	-0.0082 - 0.0000i	4.3189e-21 - 1.2187e+00i	1.9902e+21 - 6.9600e-01i	-2.1576e+21 + 1.9479e-01i
-1.2538e-16 - 4.0544e-06i	-0.0680 + 0.0000i	-0.0072 + 0.0000i	3.3419e-21 - 1.6059e+00i	1.7545e+21 - 8.9688e-01i	-1.9056e+21 + 9.7497e-01i
-1.2268e-15 - 3.2900e-06i	-0.0603 + 0.0000i	-0.0064 + 0.0000i	2.9380e-21 - 1.8334e+00i	1.5569e+21 - 1.0272e+00i	-1.6913e+21 + 1.1007e+00i
-1.0521e-15 - 7.5128e-06i	-0.0528 + 0.0000i	-0.0056 + 0.0000i	2.5676e-21 - 1.9181e+00i	1.3623e+21 - 1.0526e+00i	-1.4799e+21 + 1.1442e+00i
-8.6356e-16 - 2.4391e-06i	-0.0453 + 0.0000i	-0.0048 + 0.0000i	2.2023e-21 - 1.8776e+00i	1.1680e+21 - 1.0261e+00i	-1.2698e+21 + 1.1151e+00i
-5.7023e-16 - 3.4871e-06i	-0.0377 + 0.0000i	-0.0040 + 0.0000i	1.8359e-21 - 1.7297e+00i	9.7375e+20 - 9.4263e-01i	-1.0578e+21 + 1.0244e+00i
-5.6833e-16 - 3.1106e-06i	-0.0302 + 0.0000i	-0.0032 + 0.0000i	1.4696e-21 - 1.4924e+00i	7.7947e+20 - 8.1171e-01i	-8.4676e+20 + 8.8207e-01i
-0.0080e-16 - 8.6238e-05i	-0.0227 + 0.0000i	-0.0024 + 0.0000i	1.1033e-21 - 1.1834e+00i	5.8520e+20 - 6.4278e-01i	-6.8571e+20 + 9.9802e-01i
-1.9121e-16 - 2.0296e-06i	-0.0151 + 0.0000i	-0.0016 + 0.0000i	7.3702e+20 - 8.2058e-01i	3.9092e+20 - 4.4534e-01i	-4.2467e+20 + 8.8393e-01i
1.9221e-17 - 1.2255e-05i	-0.0076 + 0.0000i	-8.0811e-04 + 9.4070e-25i	3.7073e+20 - 4.2185e-01i	1.9664e+20 - 2.2683e-01i	-1.6913e+21 + 1.4866e-01i
0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i
0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i
-5.8871e-16 - 3.0192e-06i	-0.0938 + 0.0000i	-0.0100 + 0.0000i	3.8325e-21 - 6.4916e-01i	2.4205e+21 - 4.0108e-01i	-2.6351e+21 + 3.3653e-01i
-1.0327e-15 - 4.9486e-06i	-0.0766 + 0.0000i	-0.0081 + 0.0000i	3.9460e-21 - 1.2181e+00i	1.9759e+21 - 6.9592e-01i	-2.1447e+21 + 7.5673e-01i
-1.2529e-15 - 6.0209e-06i	-0.0679 + 0.0000i	-0.0072 + 0.0000i	3.3296e-21 - 1.6058e+00i	1.7537e+21 - 8.9688e-01i	-1.9049e+21 + 9.7496e-01i
-1.2267e-15 - 3.2856e-06i	-0.0603 + 0.0000i	-0.0064 + 0.0000i	2.9373e-21 - 1.8334e+00i	1.5568e+21 - 1.0127e+00i	-1.6912e+21 + 1.1007e+00i
-1.0524e-15 - 8.7480e-06i	-0.0528 + 0.0000i	-0.0056 + 0.0000i	2.5686e-21 - 1.9181e+00i	1.3623e+21 - 1.0526e+00i	-1.4799e+21 + 1.1440e+00i
-8.6336e-16 - 2.6214e-06i	-0.0453 + 0.0000i	-0.0048 + 0.0000i	2.2021e-21 - 1.8776e+00i	1.1680e+21 - 1.0261e+00i	-1.2698e+21 + 1.1151e+00i
-5.7009e-16 - 3.7584e-06i	-0.0377 + 0.0000i	-0.0040 + 0.0000i	1.8359e-21 - 1.7297e+00i	9.7375e+20 - 9.4263e-01i	-1.0578e+21 + 1.0244e+00i

$$\begin{bmatrix} G_{\phi p} \\ G_{np} \\ G_{pp} \end{bmatrix}$$

solution_vector_phi_AC x solution_vector_elec_AC x solution_vector_hole_AC x					
78x234 complex double					
1	2	3	4	5	6
0.0000 + 0.0000i	0.0000 + 0.0000i	-1.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i
-5.9378e-16 - 3.0600e-06i	-0.1081 + 0.0000i	-0.0120 + 0.0000i	-2.1165e-22 - 6.5185e-01i	2.7387e+21 - 4.0638e-01i	-3.1794e+21 + 4.4235e-01i
-1.0376e-15 - 4.9696e-06i	-0.0768 + 0.0000i	-0.0081 + 0.0000i	4.1658e-21 - 1.2251e+00i	1.9630e+21 - 6.9939e-01i	-2.1509e+21 + 7.6046e-01i
-1.2525e-15 - 6.0083e-06i	-0.0679 + 0.0000i	-0.0072 + 0.0000i	3.3330e-21 - 1.6101e+00i	1.7516e+21 - 8.9904e-01i	-1.9025e+21 + 9.7731e-01i
-1.2255e-15 - 3.1538e-06i	-0.0602 + 0.0000i	-0.0064 + 0.0000i	2.9326e-21 - 1.8356e+00i	1.5543e+21 - 1.0137e+00i	-1.6884e+21 + 1.1018e+00i
-1.0497e-15 - 1.5228e-05i	-0.0527 + 0.0000i	-0.0056 + 0.0000i	2.5676e-21 - 1.9184e+00i	1.3597e+21 - 1.0527e+00i	-1.4771e+21 + 1.1441e+00i
-8.6034e-16 - 2.5363e-06i	-0.0452 + 0.0000i	-0.0048 + 0.0000i	2.1972e-21 - 1.8764e+00i	1.1654e+21 - 1.0253e+00i	-1.2660e+21 + 1.1143e+00i
-5.6742e-16 - 3.4961e-06i	-0.0376 + 0.0000i	-0.0040 + 0.0000i	1.8309e-21 - 1.7272e+00i	9.7113e+20 - 9.4120e-01i	-1.0550e+21 + 1.0228e+00i
-4.5838e-16 - 2.7660e-06i	-0.0301 + 0.0000i	-0.0032 + 0.0000i	1.4646e-21 - 1.4887e+00i	7.7686e+20 - 8.0970e-01i	-8.4392e+20 + 8.7989e-01i
-1.9766e-16 - 1.5950e-06i	-0.0228 + 0.0000i	-0.0024 + 0.0000i	1.0984e-21 - 1.1789e+00i	5.8250e+20 - 6.4033e-01i	-6.8337e+20 + 9.9533e-01i
-1.7524e-17 - 2.4243e-06i	-0.0150 + 0.0000i	-0.0016 + 0.0000i	7.3208e+20 - 8.1546e-01i	3.8830e+20 - 4.4256e-01i	-4.2182e+20 + 8.8091e-01i
1.9553e-17 - 9.5090e-05i	-0.0075 + 0.0000i	-7.9737e-04 + 9.2848e-25i	3.6581e-20 - 4.1637e-01i	1.9403e+20 - 2.2586e-01i	-2.1078e+20 + 2.4543e-01i
0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i
0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i	0.0000 + 0.0000i
-5.9371e-16 - 3.0231e-06i	-0.0937 + 0.0000i	-0.0101 + 0.0000i	-1.2564e-20 - 6.5601e-01i	2.4196e+21 - 4.0580e-01i	-2.6648e+21 + 4.4167e-01i
-1.0373e-15 - 4.8371e-06i	-0.0764 + 0.0000i	-0.0081 + 0.0000i	3.9279e-21 - 1.2248e+00i	1.9719e+21 - 6.9929e-01i	-2.1398e+21 + 7.6036e-01i
-1.2543e-15 - 5.8458e-06i	-0.0678 + 0.0000i	-0.0072 + 0.0000i	3.3228e-21 - 1.6100e+00i	1.7520e+21 - 8.9903e-01i	-1.9019e+21 + 9.7731e-01i
-1.2255e-15 - 3.0141e-06i	-0.0602 + 0.0000i	-0.0064 + 0.0000i	2.9322e-21 - 1.8355e+00i	1.5542e+21 - 1.0137e+00i	-1.6883e+21 + 1.1018e+00i
-1.0499e-15 - 4.7942e-06i	-0.0527 + 0.0000i	-0.0056 + 0.0000i	2.5676e-21 - 1.9184e+00i	1.3597e+21 - 1.0527e+00i	-1.4771e+21 + 1.1441e+00i
-8.6004e-16 - 2.2374e-06i	-0.0452 + 0.0000i	-0.0048 + 0.0000i	2.1972e-21 - 1.8764e+00i	1.1654e+21 - 1.0253e+00i	-1.2660e+21 + 1.1143e+00i
-5.6726e-16 + 3.7941e-06i	-0.0376 + 0.0000i	-0.0040 + 0.0000i	1.8309e-21 - 1.7272e+00i	9.7113e+20 - 9.4120e-01i	-1.0550e+21 + 1.0228e+00i

G 값은 계산으로 값이 나왔으나, 이것이 의미하는 것은 더 공부해야할 것 같습니다. 특히  $n, p$  또한 복소수로 나오게 되는데, 이것이 어떤 것을 의미하는지 더 확인해야합니다. 또한 지금 Doublegate에서 smallsignal를 주었을 때 수렴하지 않는 현상이 있습니다. 코드상의 문제인 것으로 생각되어 이를 수정중에 있습니다. 코드가 정확한 것을 확인하기 위해서 PN접합인 구조를 만들어 확인해볼 예정입니다.