EECE5606 Laboratory Template

Student Name: Pavan Umesh **NUID:** 002831632 **Date: 03/14/2024**

Title: Metrology and Dicing **Lab week: 6**

1. Lab Description (10 points) *(What is this lab about?)*

In this lab lesson, the students were introduced to the process of measuring wafer and thin film resistivity with DC probes, RF characterization of MEMS resonators using a vector network analyzer (VNA). The following were discussed: measuring RF admittance (magnitude) of a sample resonator as a function of frequency, setting up and calibrating the VNA, and using one-port and two-port probes for data acquisition.

2. Lab Objective (10 points) (*Why are you doing this lab?)*

This laboratory class was aimed at training the students to use the DC probes, VNA to measure the RF characteristics of sample resonators in the MEMS research lab (ISEC 4th floor).

3. Methods (20 points)

1. Measuring the resistivity of thin-film aluminum on a silicon wafer using the DC probe:

The SÜSS MicroTec PM5 is an instrumentation tool used to measure the resistivity of semiconductor wafers and thin films. The one used in the ISEC research lab is equipped with the Motic PSM-1000 Probe Station Microscope that enables one to probe the sample correctly. A camera mounted on the microscope provides a live feed via a monitor screen of the sample and probes. A metal wire connected to a variable DC voltage source provides a DC current through the sample for voltages via two metal probes. A multimeter is used to measure the current that flows out of the first probe and into the second probe. The resistance can be calculated easily using Ohm’s Law ($R = V/I$) or can be read out using the multimeter too.

For this laboratory class, the sample had a thin-film aluminum layer with a long zig-zag pattern of “rods” connected to square patches at regular intervals of every 4 rods.

The various steps involved in resistivity measurement using the 4-point probe are as follows:

1. The sample is placed on the probe station sample holder.
2. The variable DC voltage source is switched on and adjusted to a set value.
3. Using the optical microscope the height of the DC probes is adjusted such that it contacts the sample.
4. Further resolution for adjustment of the two probes is obtained using the camera mounted on the microscope with live feed from the monitor screen.
5. Initially the probes are adjusted such that the DC current only passes through the initial patches. The resistance measured using the multimeter gives the contact resistance value.
6. Next, one of the probes is kept stationary while the other is moved to the next patch. The resistance value is again measured.

7. The process is repeated until the resistance value has been measured for every patch.
8. Once the measurements have been taken, the DC voltage source is switched off and the heights of the probes are adjusted so they do not contact the sample.
9. The sample is then removed from the probe station sample holder.

Initially the sample was tested using the Wentworth 6-inch Probe Station equipped with the Accu Tech Optical Microscope in the Kostas cleanroom. Due to difficulty in adjusting the DC voltage source connected to it, the SÜSS MicroTec PM5 was used.

2. Silicon wafer dicing:

1. Performing the lift-off process on the aluminum coated silicon wafer:

The lift-off process in micro-fabrication is the method of patterning structures on the surface of a substrate. It is an additive process as opposed to a subtracting process like etching. In the process of lift-off, the photoresist (PR) layer, which acts as a sacrificial stencil, is initially patterned in an inverse manner during lift-off by creating etched openings that allow the target material to reach specific regions of the substrate. The target material is then deposited over the entire wafer surface, adhering to the substrate in the etched regions and remaining on top of the PR layer in the unetched regions. Upon washing away the PR layer with a solvent, the material on top is lifted-off and removed with the PR layer underneath. As a result, the target material is left only in the areas where it had direct contact with the substrate after the lift-off process. In this laboratory class, the following steps were used to perform the lift-off process:

a. A previously produced aluminum coated (100 nm Al thickness) silicon wafer was cleaved into small pieces (samples) and then subjected to the lift-off process. For the lift-off process, the samples were placed in beakers with acetone for 20 minutes. This dissolves the PR layer along with the aluminum coated on top, while preserving the aluminum coated on the silicon wafer, producing microstructures or micro-scale devices. For lift-off, it is preferable to place the wafer face down such that the PR and the aluminum coated on it dissolve away with gravity assist. However, the disadvantage of this method is that while removing the sample from the beaker it is likely to get scratched, but this can be prevented with the use of plastic holders. The beakers must be covered to prevent the acetone from evaporating.

b. Once the lift-off process is complete, the sample must be washed with isopropyl alcohol (IPA). Then the sample is immersed in a solution of deionized (DI) water and sonicated in an ultrasonic cleaner for a few minutes. The sample is then dried front and back using a nitrogen gun.

2. Calibrating the VNA:

The vector network analyzer (VNA) used was the Keysight N5221A PNA Network Analyzer. It is an instrument that is used to measure electrical network parameters such as sparameters, y-parameters, z-parameters, and h-parameters.

Network analyzers are used to characterize two-port networks such as amplifiers and filters, but they can be used on networks with an arbitrary number of ports. Network analyzers can be divided into two categories: scalar (SNA), which measures only amplitude, and vector (VNA), which measures both amplitude and phase properties. The VNA used in the laboratory class works from

10 MHz to 13.5 GHz, and the cables used to probe the sample device supported frequencies up to 10 GHz. The highly sensitive RF probe tips are available in two types: three-tipped ground-source-ground (GSG) or two-tipped ground-source (GS). GSG probes are more sensitive than GS probes as they have two ground tips to isolate signals whereas GS has only one. Furthermore, GSG probes are used for two-port networks whereas GS probes are used for one-port networks. In the laboratory class, a two-tipped GS probe was used as GSG probes are more expensive. The GS probe has G and S tips placed 150 μm apart. Everything was matched to 50 Ω.

The sample is fastened on the vacuum chuck on the SÜSS MicroTec PM5 Probe Station. The probe station is equipped with the Motic PSM-1000 Probe Station Microscope, which was used to observe the alignment of the RF probe tips on the sample device. The complete setup involves the probe cables going from the sample on the probe station to the VNA which displays the RF characteristics.

The various steps involved in the calibration of the VNA are as follows:

1. The number of ports is set to 2.
2. The power of the signal is set to 20 dBm.
3. Frequency range is set as 100 MHz to 300 MHz.
4. Sampling frequency is set to 8000 samples (for the frequency range).
5. The Analysis option is selected and under equation order, Y12 is set.
6. Input is set at port 1 and output at port 2.
7. The intermediate frequency (IF) bandwidth is set to 1000 Hz so that an averaging is done for every 1000 Hz and one sample is acquired.
8. Measurement is set to only magnitude.
9. Start the calibration process.
10. Use a calibration sample to test placement of probes and stage.
11. The sample is tested in two conditions: an input signal of 20 dBm power is sent with the probes not touching the sample, producing zero output, and then with the S and G tips of the probe connected to the same metal structure, essentially creating an S-G short, and again producing zero output.
12. The admittance of a resonator as a function of frequency for a 50 Ω resistive load is plotted. The curve is flat since the admittance is frequency-independent for a purely resistive load.
13. There are three "Trigger" options available: "Continuous", "Single", and "Hold". The Continuous Trigger option is selected.
14. Once calibration is done, the settings are saved and selected when performing RF characterization.

2. Outcomes and Measurements (15 points)

The outcome of this laboratory class was that the students were introduced to the process of RF characterization of resonators using VNAs.

Comments (5 points)

The following were observed in this laboratory class:

- RF probes are very expensive, around USD 500 per probe.
- Acoustic resonators can be modeled as an electrical two-port network.

- Probes are supposed to get scratched with use.

1. **Analysis Questions (30 points)**
   Based on the measurements performed in the lab

   a. Extract the resistivity of the Aluminum using the resistance measurements performed on the test structure.

   The resistivity of aluminum is given by,
   Rho= (Resistance*thickness*width)/length
   Given details about the circuit parameters.
   length = 500X 10^{-6} meters width = 10X 10^{-6} meters thickness = 100 X10^{-9} meters
   1 st pad with second with 4 rods in between them = 0.828kohm
   Rho1 = 0.828X10^{3} *(t*w)/l*4
   Rho1=6.63X10^{-9} ohm/m
   1 st pad with third with 8 rods in between them = 1.509kohm
   Rho2 = 1.509X10^{3} *(t*w)/l*8
   Rho2=2.42X10^{-8} ohm/m
   1 st pad with fourth with 12rods in between them = 2.213kohm
   Rho3 = 2.213X10^{3} *(t*w)/l*12
   Rho3=5.36e-08 ohm/m
   1 st pad with fifth with 16 rods in between them = 2.950kohm
   Rho4 = 2.950X10^{3} *(t*w)/l*16
   Rho4 = 9.41X10^{-8} ohm/m
   1 st pad with sixth with 20 rods in between them = 3.682kohm
   Rho5 = 3.682X10^{3} *(t*w)/l*20
   Rho5 = 1.47X10^{-7} ohm/m

   b. Calculate C0 , kt2 , and 3 dB Q of the measured resonator. (You may use the shared Matlab code)

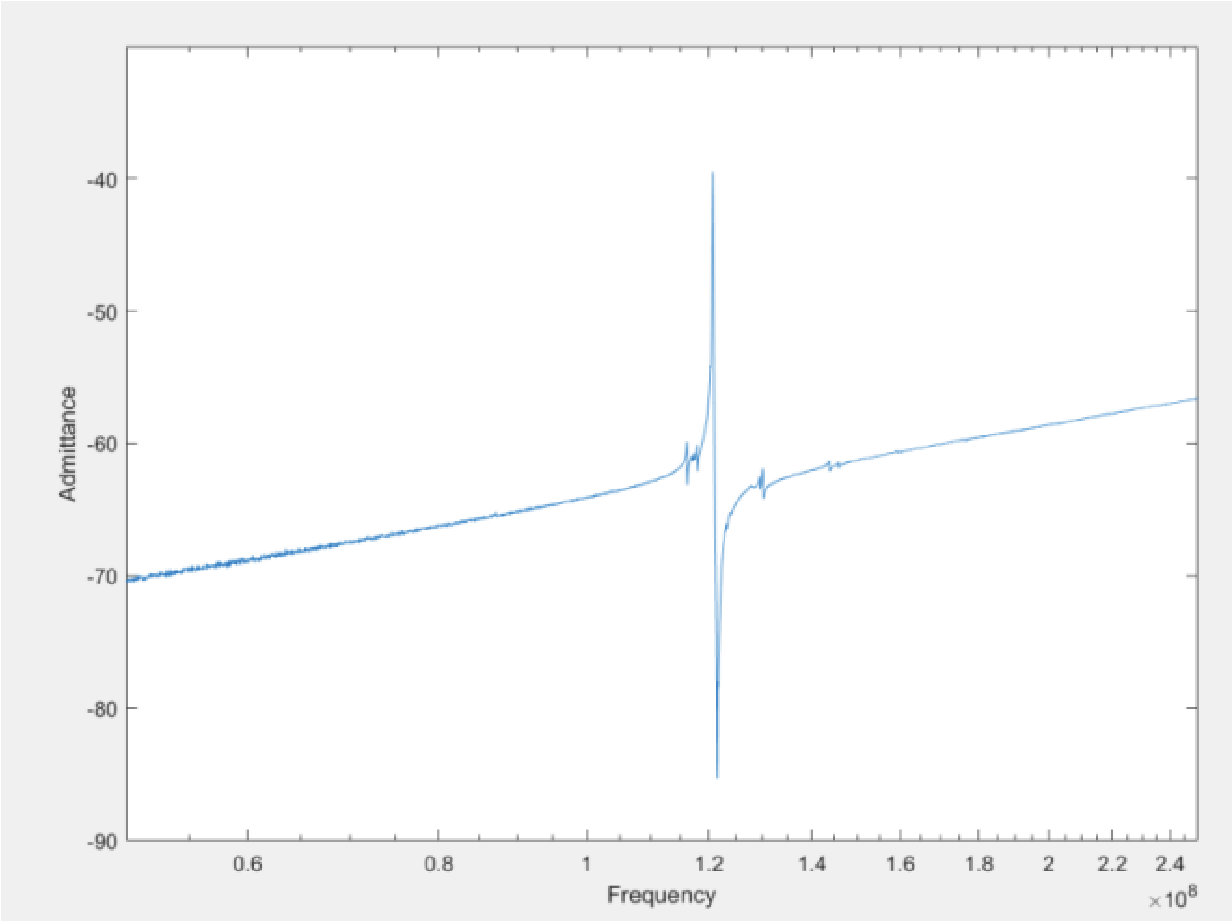
$$k_t^2 = \frac{\pi^2}{8}\left(\frac{f_p^2 - f_s^2}{f_s^2}\right)$$

$$C_o = \frac{\text{imag}(Y_{11}(f_o))}{2\pi f_o}$$

   For Co calculation you should pick frequency (fo) that is before and far away from the fs.

```
clc
clear all
close all
[filename, folder_path]=uigetfile('*.s1p');
file_path=[folder_path,filename];
Y=yparameters(file_path);
freq=Y.Frequencies;
y11=rfparam(Y,1,1);
ydb=20*log10(y11);
semilogx(freq,ydb);
Fo=0.9*10^8;
F0_index=1594;
xlabel('Frequency');
ylabel('Admittance');
Fpx=interp1(freq,ydb,Fo);
fprintf('Fpx=%.2f\n',Fpx);
%%F0=interp1(real(ydb),freq,real(Fpx));
fprintf('F0=%.2f\n',Fo);
C0=imag(y11(1594))/2*pi*Fo;
fprintf('C0=%.2f\n',C0);
Fs=interp1(real(ydb),freq,max(real(ydb)));
Fp=interp1(real(ydb),freq,min(real(ydb)));
FSX=interp1(freq,ydb,Fs);
Fa=FSX-3;
tolerance = 0.1;
[~, index1] = min(abs(ydb - Fa));
F1 = freq(index1);
if index1 < length(freq)
 index2 = index1 + find(freq(index1+1:end) ~= freq(index1), 1);
 F2 = freq(index2);
else
 F2 = [];
end
Kt2 = (pi^2/8)*(((Fp)^2-(Fs)^2)/(Fs)^2);
Q3db = Fs/(F2-F1);
fprintf('FSX=%.2f\n',FSX);
fprintf('Fs=%.2f\n',Fs);
fprintf('Fp=%.2f\n',Fp);
fprintf('Fa=%.2f\n',Fa);
fprintf('F1=%.2f\n',F1);
fprintf('F2=%.2f\n',F2);
fprintf('Kt2=%.2f\n',Kt2);
fprintf('Q3db=%.2f\n',Q3db);
```

Output Fpx=-65.15mho, F0=90000000.00 Hz, C0=78063.91 Farad, FSX=-39.45mho, Fs=120750000.00Hz, Fp=121550000.00Hz, Fa=-42.45mho, F1=120750000.00Hz, F2=120775000.00Hz, Kt2=0.02, Q3db=4830.00,



2. Attendance (10 points)

Leave this answer blank – to be used by TAs.