Graphical User Interface in MATLAB for Lithography in MICROSCALE Devices

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Abstract

Micro-photolithography consists of patterning the substrate using a source of light for micro and nano scale devices. Process parameters play a vital role in the designing of any process for Microlithography. Process engineers pre-calculate these parameters in order to refine and make the process more accurate. Graphical user interface created in Matlab – memspro – enables its users to simulate the process flow for Lithography operations and calculate process parameters for their designed process. It acts as a supporting tool for better understanding of the process with photomask and device visualization. The interface consists of options for generating plots and saving reports for the processes simulated. The entire code can be executed as an application and run on any system with an installed MATLAB runtime engine.

1. Introduction to the Interface

The Graphical user interface (GUI) is built in the Matlab GUIDE- Graphical User Interface Development Environment and .exe file is deployed by creating the application embedding all the required files. The interface provides options for calculating various parameters individually and plotting graphs and analyzing them. It also provides for an integrated option of entering the complete process parameters and generating the fabricated device along with its reports.

The tool consists of (A) Single Process Simulations in which user can calculate and plot a particular process from a group of drop down menus and (B) Multiple Process Simulations which consists of step wise procedure for entering process values and finally obtaining results in a separate 'Fabrication Report Analysis (FRA)' window that can be saved for further reference.

2. Architecture of the tool

Creating a GUI in Matlab IDE essentially consists of two main tasks- Designing the window that will serve as the interface for its users and linking it to the backend .m code for execution. For the embedded '*newpro*' tool of multiple processes simulation 'Database referral and revision' approach is used. Figure 1. Shows the opening window of the tool with options available for Single Process and Multiple Process simulations.

2.1 Creating a figure for the User Interface

The .fig file consists of the source code with opening and closing functions present in the .m code. Every object within the .fig file consists of a unique tag that links it to the 'callback' function and performs the task. There are overall 16 .fig files in the project excluding dialog boxes and the progress bar.

2.2 Linking the figure with .m code

Each of the figures is linked by a unique .m code. There is an individual 'callback' and 'Create' function for each object along with the main opening and closing function. All the data entered by the user is stored as the metricdata and is referred to as *variable.handles.metricdata* in the entire code.

2.3 Functionalities and database approach

A database consisting of device dimensions, material properties, photomask coordinates, etchant types, flag variables for verifying successful report generation, calculated process values is utilised and

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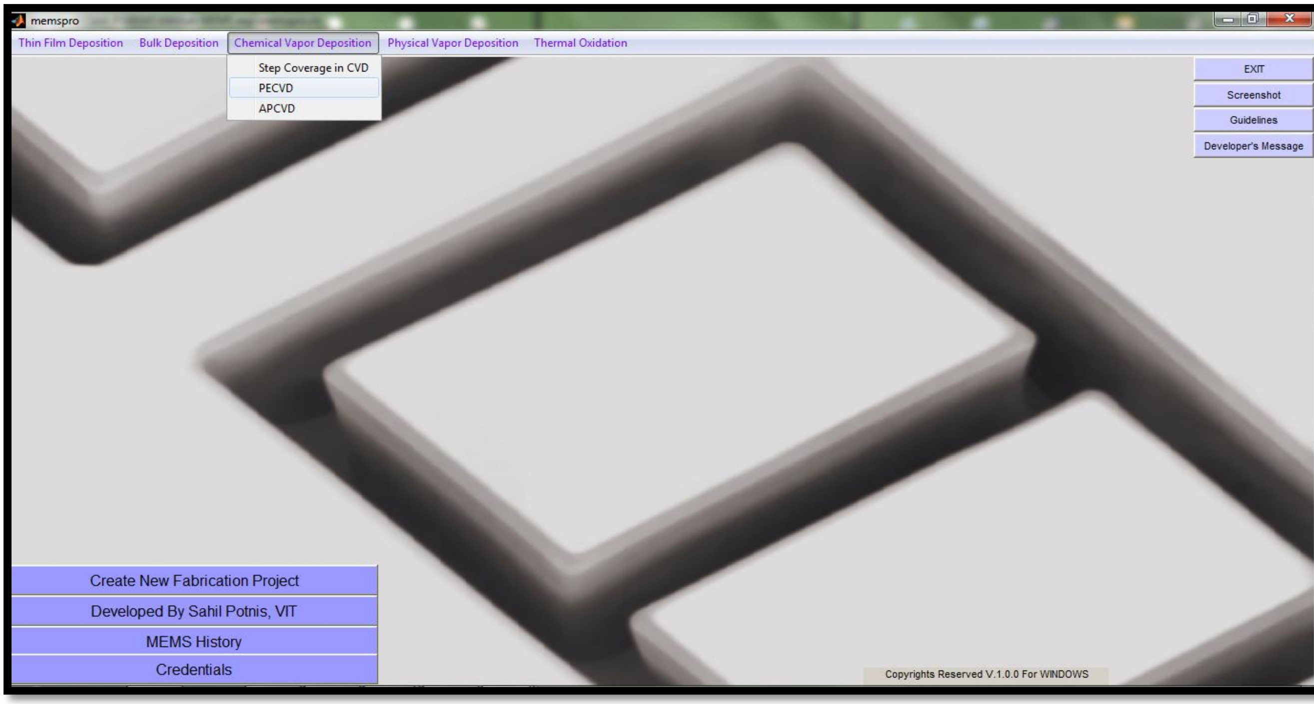

Figure 1. Opening Window of the *memspro*

updated with every run of the code. A secondary database consisting of default process parameters is used when default process is to be loaded. The data flow in the simulation is as follow:

User enters values→Database Updated→Database read & parameters calculated→Database Updated→Parameters fetched & figures displayed. There are Guidelines available in .pdf formats about standard operating procedure of the tool and about the process information for microlithography processes.

Functionalities of the tool consists of calculation of following parameters in Single Process Simulations-

Thickness of the spin coated photoresist, thickness of the deposited metal in electrodeposition, stress in thin films, time for injection moulding, step coverage in CVD, APCVD and PECVD deposition rate, thermal evaporation and sputtering deposition thickness, oxidation reaction rate constants.

Functionalities of the tool consists of calculation of following parameters in Multiple Process Simulations-

Deposition parameters such as Motor R.P.M, etching time, resist developer time, oxide deposition time, CVD time. Along with there are options to view device, photomask and generate report as per requirement.

3. Single Process Simulations

The provision of single process simulation enables the users to calculate the parameters related to single process.

3.1 Spin Coating

The empirical formula for calculating the photoresist thickness depends upon chuck R.P.M, spinner material constant, and percentage solids in the resist [5]. A graph of Time (sec) vs Resist thickness (nM) is plotted as shown in Figure 2. For RPM=50, Spinner

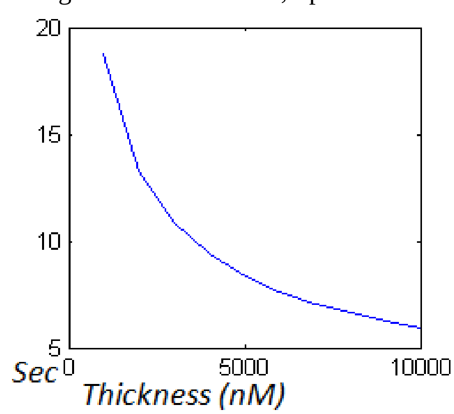

Figure 2. Time vs. Thickness for Spin casting

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constant=75 and Percentage solid content=50. Spin casting is used for photoresist developing rinsing and drying. The default process consists of Positive photoresist PMMA with 2.0uM thickness.

3.2 Electrodeposition

Metals can be deposited more accurately using the process of electrodeposition. The thickness of metal is found to be a function of deposition time, electrochemical equivalent for the metal, current density, metal density [1]. A linear graph of Thickness (uM) vs. Current Density (Amp/Cm^2).

3.3 Thin film Stress

Thin films are essentially characterized by additional forces resulting from grain-grain boundaries interaction. This thin film stress is modulated by grain nucleation density [6]. Thin film stress is calculated by using Stoney's formula assuming Film thickness << 10 x Substrate thickness. Impurities present in the film act at low substrate temperature and create critical impurity concentration that generates passivation layer which promote secondary nucleation. Graph of Stress (N/m) vs Substrate thickness (uM) is plotted for the user values. It is dependent on Film & Substrate thickness, radius of curvature of film and substrate, Poisson's ratio and elastic constant of substrate.

$$stress = \left[\frac{1}{R1} - \frac{1}{R2}\right]\left[\frac{(a * st * st)}{(6 * ft(1 - pr))}\right]$$

Equation 1. Stoney's Formula

R1= radius of curvature of substrate (uM)
R2= radius of curvature of substrate + film (uM)
a= Elastic constant of substrate (N/uM^2)
st= Substrate thickness (uM)
ft= Film thickness (uM)
pr= Poisson's Ratio for substrate

3.4 Injection Moulding

This process of bulk deposition is accretion of Intermediate Time, Injection Time and Cooling Time. The time required for injection is given as [7]

$$Tinj = \left[\frac{cavity\ volume}{Injection\ Rate}\right] + Delay\ Time$$

Equation 2. Injection Time for Moulding

Cooling time can be estimated by using the equation-

$$tc = -0.2435 \cdot \frac{l^2}{a} \cdot \log\left(\frac{\Pi}{4} \cdot \frac{\theta - \theta s}{\theta o - \theta s}\right)$$

Equation 3. Cooling time for Injection moulding

The total time required for Injection Moulding is addition of Cooling time, Intermediate time and Injection time. *Memspro* helps us to calculate the total time required after specifying the parameters.

3.5 PECVD

The most common technique of deposition of Silicon Nitride films is PECVD. GaAs microwave monolithic integrated circuit (MMIC) deploys Silicon nitride films for surface passivation, humidity, metal ion diffusion barrier and mechanical protection [9]. The deposition rate of PECVD is a function of Ammonia-Silane gas ratio, RF power in watts, Pressure in torr and temperature in Celsius.

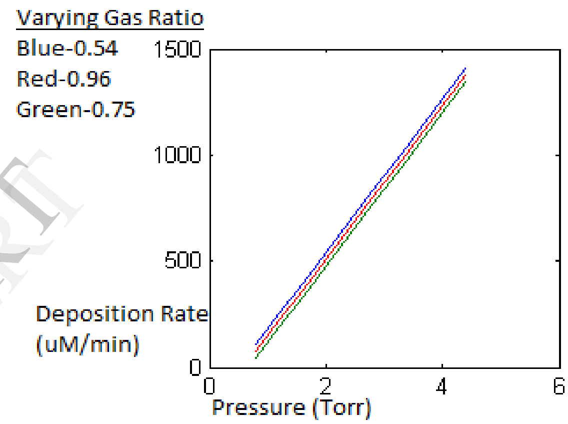

Figure 3. Deposition rate vs. Pressure for PECVD

3.6 APCVD

APCVD process is simulated by using a mathematical model limited by Surface reaction and mass transport [8][3]. Doped/undoped low temperature oxides can be deposited using APCVD with simple reactor composition. The model is governed by the equation 3.

$$V = \left[\frac{1}{\frac{1}{Ks} + \frac{1}{Hg}} * \frac{C}{N} * \sigma\right]$$

Equation 4. APCVD Deposition rate

V=apcvd deposition rate (uM/min)
Ks=surface reaction parameter
Hg=transport parameter
C= Boundary layer concentration
N= atomic density of deposited material
σ= normalized total pressure

Memspro computes the deposition rate in uM/Min using limiting conditions and atomic density of the material deposited. APCVD and PECVD parameters are to be entered in the multiple process simulation – *newspro* for the CVD option which in turn use these mathematical models when function is called.

3.7 Thermal Evaporation

Thermal evaporation is a type of open source resistive heating used for Physical Vapour Deposition of metallic and mostly aluminium films [10]. The thickness of the aluminium metal deposited using PVD is a function of density of the metal to be deposited, distance between target and source and the mass evaporation rate of the metal. An additional factor of ɵ (theta) is taken into consideration while designing the simulation of this process; it determines the angle of inclination of target with respect to substrate.

$$T = t * \left[\frac{D}{\Pi * d * d * me}\right] * \cos(\emptyset)$$

Equation 5. Thickness of Metal Deposited

T = thickness of the metal deposited (uM)
t = time for deposition (sec)
D= density of the metal (gm/Cm^3)
me= mass evaporation constant (gm/sec)

Memspro generates Time (sec) vs. Thickness (uM) graph for the different values of parameters entered.

3.8 Plasma Sputtering

In plasma sputtering the rate of deposition is dependent on the target material, sputtering current and coating time. However, at low sputtering voltage it is necessary to use gas flow control for obtaining uniform step coverage. The interface for Plasma sputtering provides material constant for a particular metal-inert gas combination [5][10]

$$T = k * I * t.$$

Equation 6. Plasma sputtered thickness

T= sputtered thickness (Å)
k= material constant for metal-gas pair
I= current (mAmp)
t = time (ms)

In modern low voltage systems for plasma sputtering variable frequency method is used to vary the thickness of the deposited layer instead of the variable voltage method. These systems require a voltage of 400V-600V with a low current of 10mA for 30 seconds.

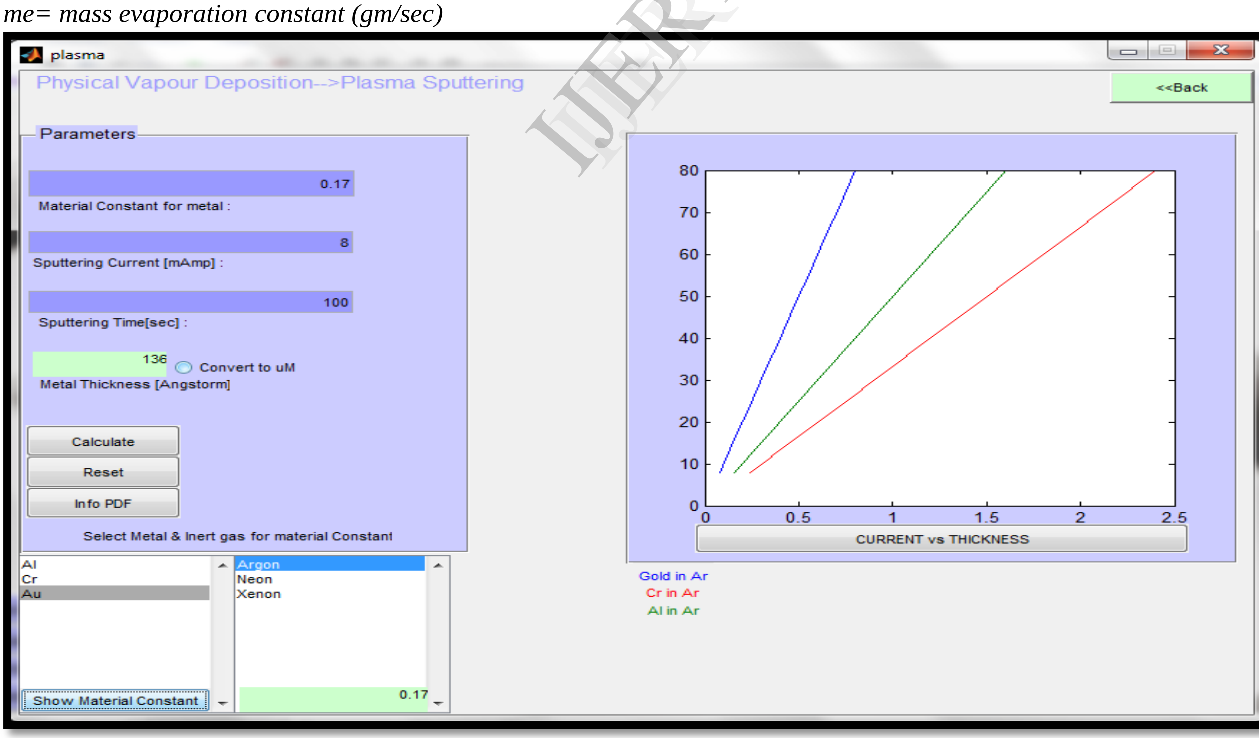

Figure 4. Plasma Sputtering Graphical Interface

9. Oxidation

The *memspro* consists of both dry as well as wet oxidation simulation. Both water-vapour and oxygen can easily diffuse through the silicon surface forming native oxide at 900° C to 1200°C [2]. The underlying principle in modelling oxidation is considering the decrease in oxidation rate with increase in the oxide thickness. Linear rate constant and parabolic rate constant for different crystal orientations are helpful in determining the oxide growth on Silicon.
Temperature variations of Parabolic rate constant and linear rate constant are plotted by obtaining time-thickness data from the user. Additional 'Initial oxide growing' time is considered in Dry oxidation to compensate for the consumption of substrate in oxide process. The theoretical ratio of oxide growth above and below the original surface of the wafer stands out to be 54%:46%. [2][4]

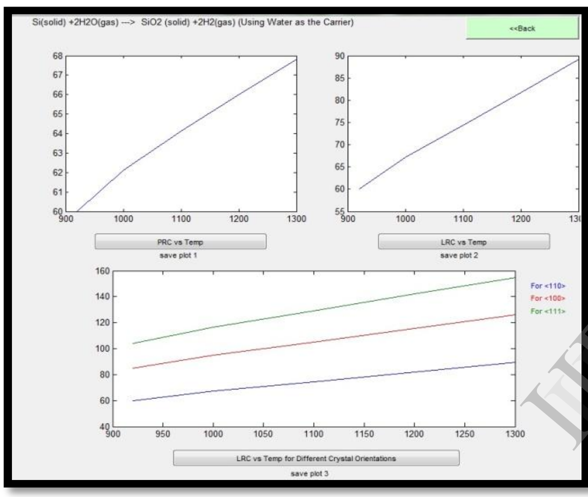

Figure 5. Wet Oxidation temperature plots

A number of other factors besides temperature that influences oxide growth includes pressure, crystal orientation and impurity doping.. High pressure oxide growth is used in low temperature VLSI processes since the linear/parabolic rate constants are proportional to the partial pressure of oxidizing species [2]. The crystal orientations are found to change the number of bonds available at Silicon interface which influences the oxide growth rate and quality of the Silicon-Silicon oxide interface.

4. Multiple Process Simulation

Multiple process simulation is required to be used for designing the important process parameters at one time. Step wise allocation of processes enables the users to design process ranging from device dimensions to the etching of device. All the steps are guided by a status bar at the top of interface.

4.1 Material & Dimension selection

The database of *memspro* consists of four variants in oxide, polymer and metals with Silicon and glass as the substrate. User needs to select all the materials required for device and enter the dimensions. If any field is left blank, default process values are considered. Exposure source is kept constant at 430nM Deep UV. Silicon substrate with silicon nitride film and PMMA as photoresist, Aluminium as the metal are loaded in the programme by default. A binary grating mask is selected by default. Once updated the database is loaded with material constants and dimensions.

4.2 Polymer & Dielectric deposition

Step 2 consists of selection of oxidation process if desirable or a CVD process by entering APCVD/PECVD parameters. Oxidation rate constants are set by default to 0.2 as parabolic rate constant and 0.4 as Linear rate constant. Spin casting option needs to be checked for resist coating.

4.3 Metal deposition

Metal deposition is done on the device using plasma sputtering or thermal evaporation. An additional layer of the metal gets added above the dielectric and can be used as masking layer for oxide etching. Default parameters for metal deposition includes 20 as the angle of inclination, 0.2 cm as the distance between source and wafer and mass evaporation constant of Aluminium is considered.

4.4 Etch back process

When designing a new process to fabricate micromachined devices, the etch rate of each layer that is to be patterned must be known [11].Three variants are provided each for oxide and metallic etching. The etching profile is considered to be directional in both Wet and Dry etching. Etch rate for all the etchants is present in the database, which is fetched after 'updating'. Etching time is calculated based on the thickness of a particular layer. Selective etchants are included in the list to prevent metal layer being etched while patterning oxide [11].

Informational .pdf files are available on each step to assist in process technicalities. Once a particular step is updated, code performs the calculations and stores the results at particular locations, updates the flags to be fetched by fabrication report analysis. Reverse tracking technique is used in multiple process simulation. The mathematical models used in single process simulations are back tracked to generate process parameters, thus saving on code length.

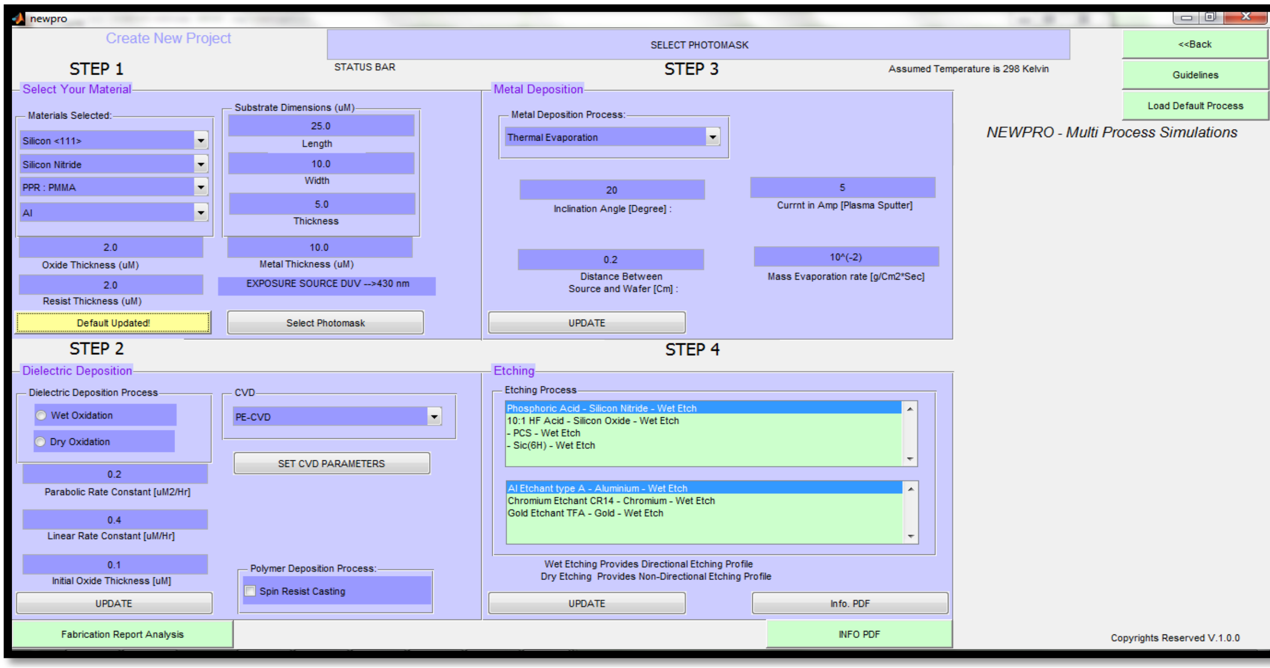

Figure 6. Interface for Multi Process Simulation

5. Fabrication Report Analysis (FRA)

Fabrication report analysis generates the Fabrication report with material properties of the device, deposition parameters and photomask-device visuals. There are options for saving the device and photomask images. Deposition parameters include Spinning time, metal and oxide deposition time, CVD deposition time. Etching parameters include PR developer time with separate metal-oxide etching time. PR developer time consists of dispensing, rinsing and drying.

The main purpose of these parameters is to estimate the amount of time required in modification processes of Microlithography. Additional time is required for prebake, alignment, post exposure bake and post bake. A rough estimate of this time is added in every report and 'Total Estimated Time' is returned to the user.

A separate .m code is present for the Fabrication Report Analysis that reads the values stored in the database and displays them in appropriate fields. The modelling is done after the user updates his inputs in Multi process simulation and results are stored at particular locations. FRA fetches these results and displays all the values and figures.

6. Future Scope

Such applications will play an important role in educating and modelling processes in microlithography and dispensing information amongst interested groups. The version 1.0.0 of *memspro* is a beta stage application and additional features as well as modules will be added to enhance its functionality. The future stage of development for *memspro* is to deploy it on the web server using Matlab complier. This will enable the users without Matlab IDE to run it on their web page. Additionally, users can design their own photomask and use it to create a device.

7. Acknowledgements

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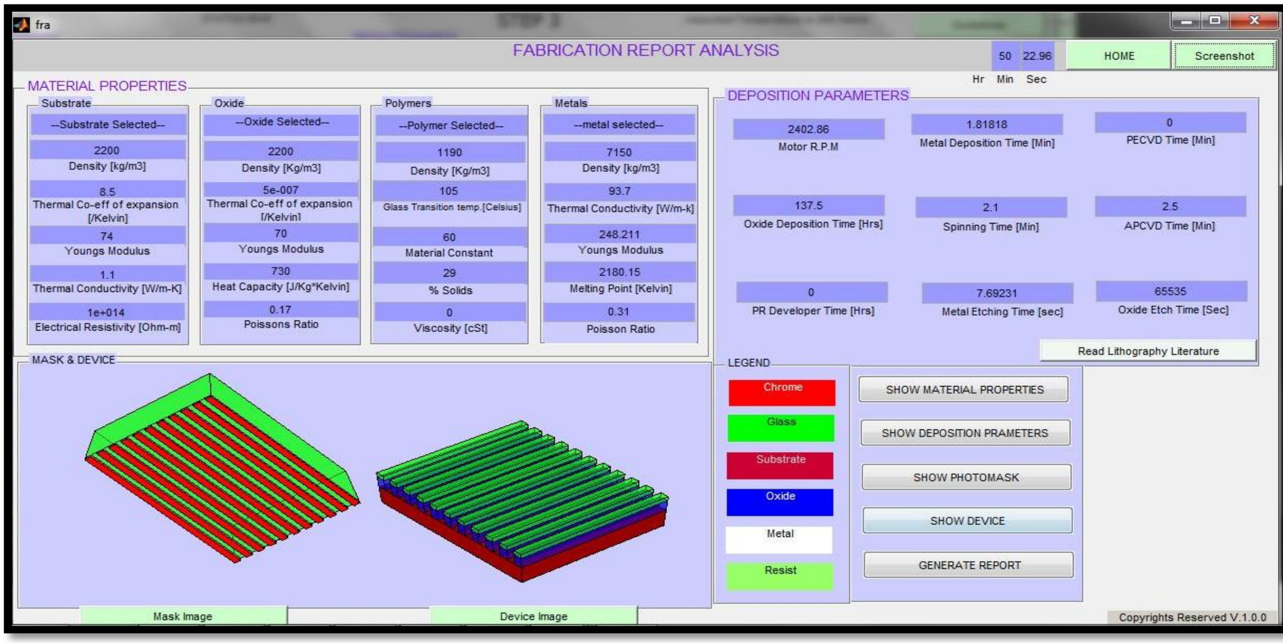

Figure 7. Fabrication Report Analysis generated

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