Spectroscopic Ellipsometer (SE-2000)

STANDARD OPERATING PROCEDURE (SOP) 2018 (v.1)

NCPRE

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INTRODUCTION

SE-2000 spectroscopic ellipsometer is capable of measuring the thickness and optical constants of thin films deposited on substrates (silicon, glass). It has a separate detachable solar chuck stage which is capable of measuring thickness and optical constants of thin films deposited on textured monocrystalline silicon substrate. It has a motorized 2D mapping capability for a maximum substrate size of 6 inch (circular). The present model is a Rotating Compensator (RC) based ellipsometer.

Spectroscopic Ellipsometer

It is a non-contact, non-destructive indirect optical characterization technique for measuring thickness and optical functions (e.g. refractive index, absorption, ...) of thin layers on any substrates (Si, glass, PET foil, ...). Very thin layer characterization (from mono layer) and complex multilayer characterization for each layer individually is possible.

Equipment Configuration

The basic units of the the tool are

- SE-2000 main frame which holds the goniometer (10^{o} - $<90^{o}$), polarizer and analyzer arms and lamp source (75W pressurized Xenon lamp)
- The detector (visible range 300 nm to 990 nm)
- Sample stage (Normal chuck and a specialized Solar chuck for measurements on textured silicon substrates)
- Monitor, mouse, keyboard and a vacuum pump

Software

The SE-2000 hardware unit is controlled by the SAM acquisition software. The SAM software records the measurements made by the hardware. The other software is the SEA interface in which the user can make their desired sample (single layer/multi-layer) structures and use appropriate optical models to obtain the best fit that matches with the measured data.

System Installation

- Major components of equipment including Windows10 system and Main unit shown below in Fig A.
- Main unit mainly consist of the sample holding chuck, goniometer frame with polarizer and analyzer arms and motorized x-y stage. (Fig. A)

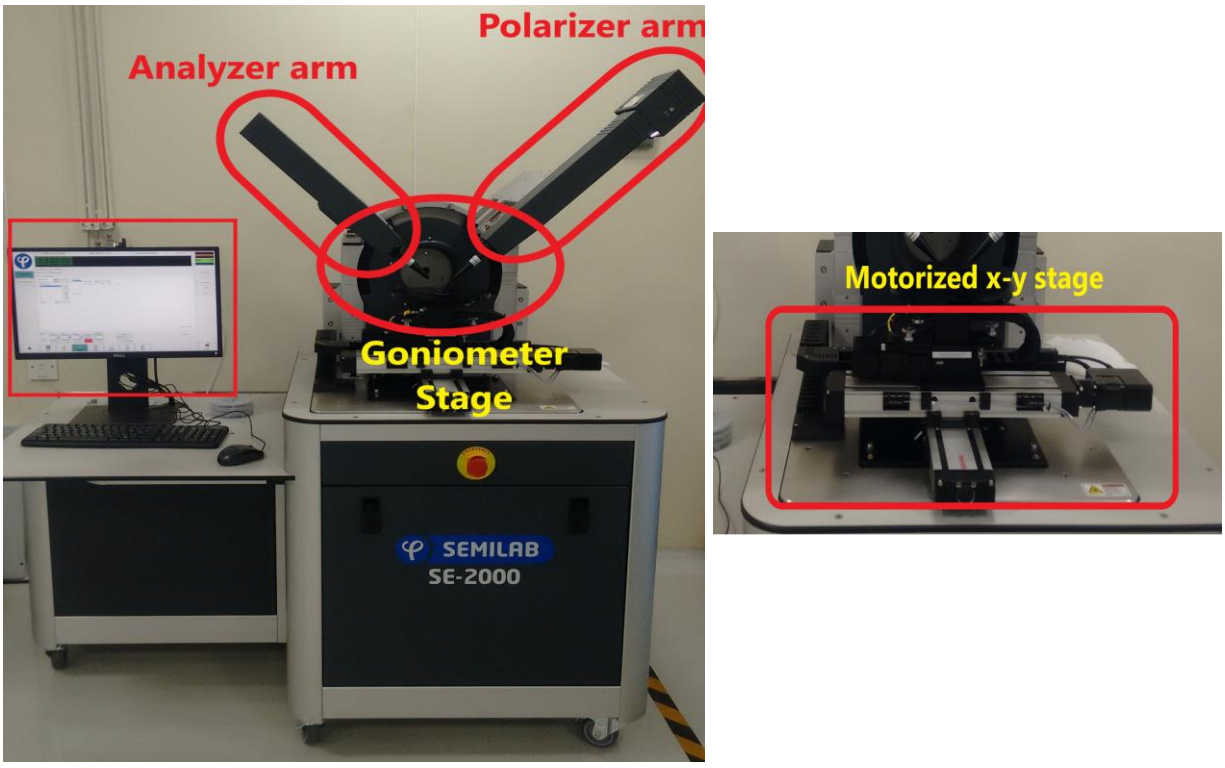


Fig. A

- Power supply connection to the main unit. (Fig. B)

Fig. B

- CDA connection (Fig. C)

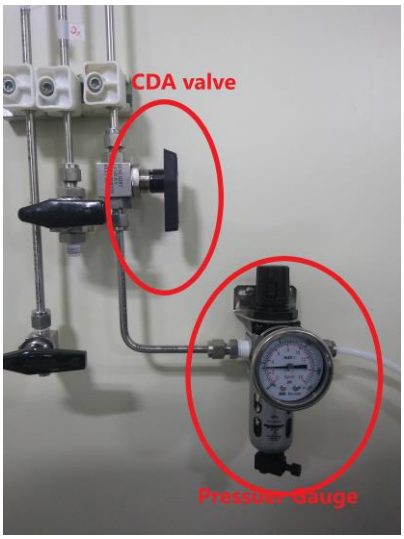
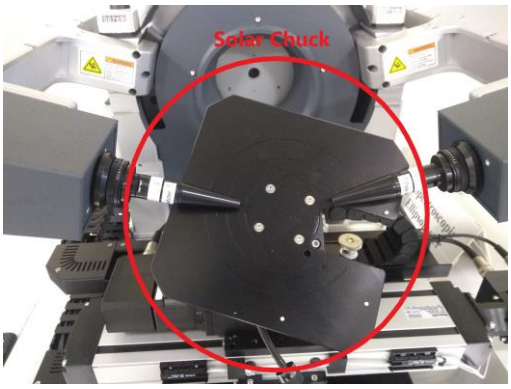


Fig. C

- Solar chuck connections. (Fig. D)



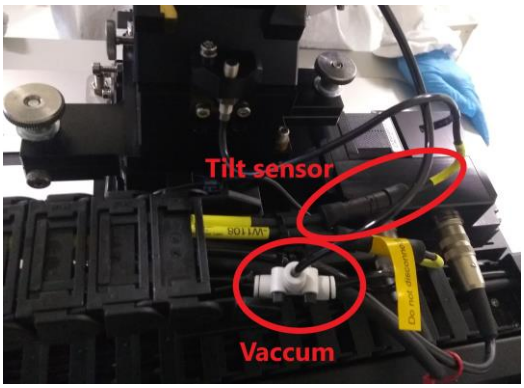


Fig. D

SAFETY PRECAUTIONS

1. The CDA (Compressed Dry Air) line pressure should never go beyond 6 Bar i.e 6.58 Kg/cm^2. For safety, the CDA line pressure is maintained at 3 Bar and the users are not allowed to make any changes to it. (**Operating pressure – 3 Bar, maximum pressure – 6 Bar**)
2. Xenon lamp emits UV radiations, so avoid staring directly into the operating lamp and bringing the lamp close to any flammable materials such as cloth or paper.
3. Do not modify any file in Calibration and Configuration folders as it can cause error in running the software.
4. **"All measurements are to be made only after selecting Microspot mode"**
   Before moving the XY motorized stage and Z position of the chuck through SAM software ensure that the optical mode chosen is Microspot (MS) and not Parallel Beam (PB). This is to ensure that the chuck don't crash against the MS hardware during focussing and damage the MS lens.
5. Do not keep your samples or other consumables on the optical bench. This would lead to optical bench misalignment resulting in error in measurement and would require further calibration.
6. The equipment is fitted with one emergency stop button (Figure. 1)
   - Once it is activated, it causes the safe shutdown of all the motors of the system.
   - Release the button by rotating in clockwise direction.
   - Exit the SAM software and launch it once again to proceed with the measurement.

Figure.1

CLEANING METHOD

- ✓ The desktop, keyboard and its surrounding area should be cleaned.
- ✓ Do not clean the polarizer and analyzer arm and microspot lenses.
- ✓ Gently clean the optical bench and the xy stage motorised belts using lint-free cloth and IPA.

  Note:

  a. The goniometer arm should be kept at 46.35^{o} (less than 50^{o}) and stage at safety position.

  b. Care must be taken not to touch the microspot hardware extensions.

OPERATION THEORY

Ellipsometry is a sensitive, non-destructive and non-contact, optical method to determine the complex refractive index and thickness of bulk materials and thin film structures. The method is based on the polarization state change of polarized electromagnetic radiation interacting (reflected or transmitted) through material surfaces. Light reflected from the surface or interface of a sample leads to change in the polarization state with respect to the incident beam. This change is a characteristic of the reflecting surface as well as the structure and material of the investigated sample. Ellipsometry detects and interprets the changes in the state of polarization of light upon reflection from (or in special cases, transmission through) thin layer surfaces or interfaces. The measured data are traditionally expressed as two ellipsometric angles Ψ and Δ which describe the changes in the relative amplitude ratio and phase difference of the parallel and perpendicular components of the electronic field vector of the light wave (with respect to the plane of the incidence). These two ellipsometric parameters contain the information related to the optical properties of the sample. In case of spectroscopic ellipsometry Ψ and Δ are measured as a function of wavelength (or photon energy). Spectroscopic ellipsometry (SE) enables to obtain the spectroscopic dispersion as well as photon absorption properties of the studied materials. The basic optical configuration for rotating compensator (RC) ellipsometry is shown below.

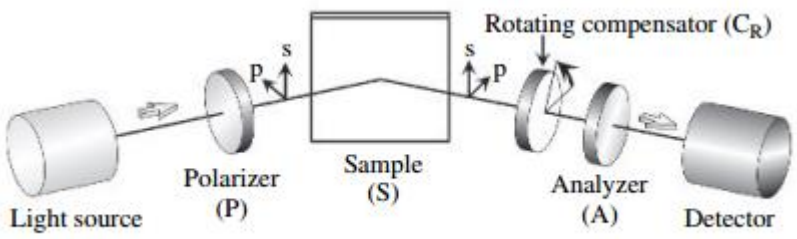
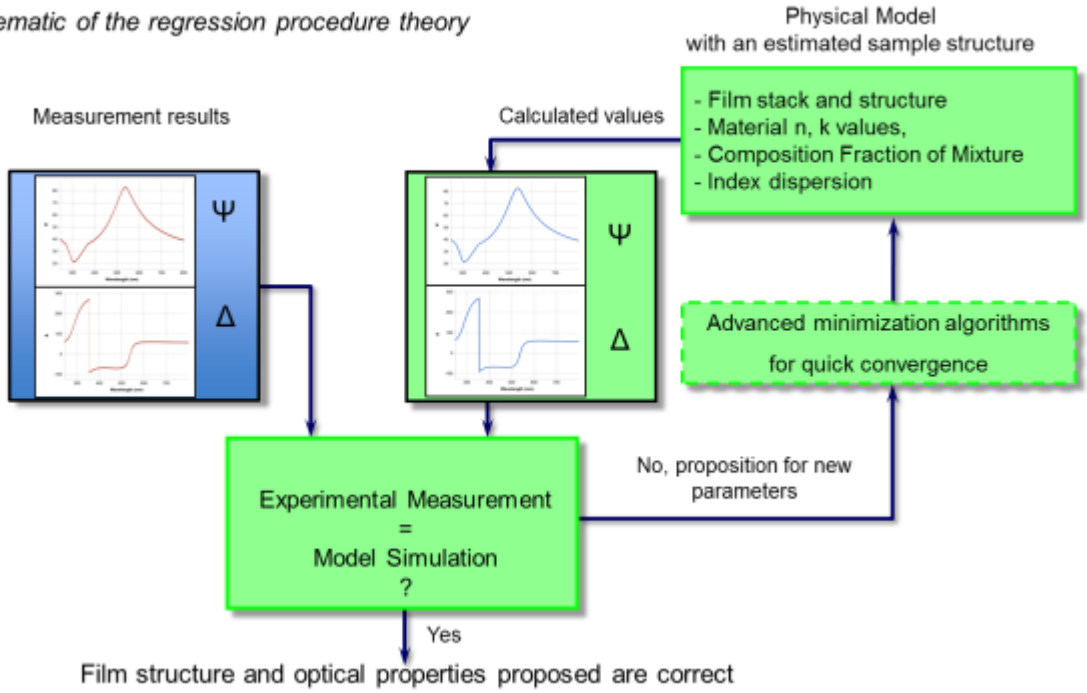


Figure A: Optical configuration of RC ellipsometry

Theory - optical modeling of the sample

Schematic of the regression procedure theory



STANDARD OPERATING PROCEDURE

Section 1: CHUCK CONFIGURATIONS FOR MEASUREMENT

1) **Normal Chuck configuration**:
   - Used for monocrystalline (polished) and multicrystalline (both polished and textured) silicon and smooth glass substrates.
   - Used for 2D mapping.
2) **Solar Stage Chuck configuration**:
   - Used for textured monocrystalline silicon substrate.
   - Cannot be used for 2D mapping.

Section 2: OPERATIONAL PROCEDURE

Note : Intermediate files of *SAM* (used for sample measurements) and *SEA* (used for analysis of the measured data) software and the measurement results should be saved strictly in the "USERS_DATA" folder located in C drive (shortcut placed on the desktop).

Files outside user folder would be deleted without prior intimation.

Section 2.1: SAMPLE MEASUREMENT USING "NORMAL CHUCK CONFIGURATION"

Note: Microspot lens of both polarizer and analyzer arm aperture should be set to 2.5mm.

Section 2.1.1: Switching on the Tool

2. Open CDA valve.
   Note: Do not change CDA line pressure which is set at 3 bar.
3. Unlock the screen and login.
   Password : semilab123
4. Launch the *SAM* software (shortcut placed on the desktop).
   Please wait for the software to initialize. Wait until you see the message "*System initialization finished*" in the "Info log" screen. (Figure. 2)

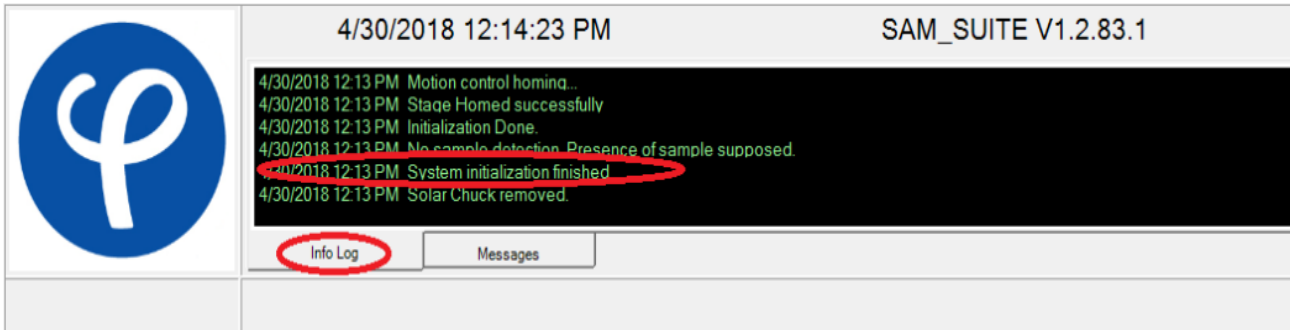


Figure.2

5. Click on the "*Login*" tab:
   Username: admin
   Password:
   And click "*OK*" (Figure. 3)

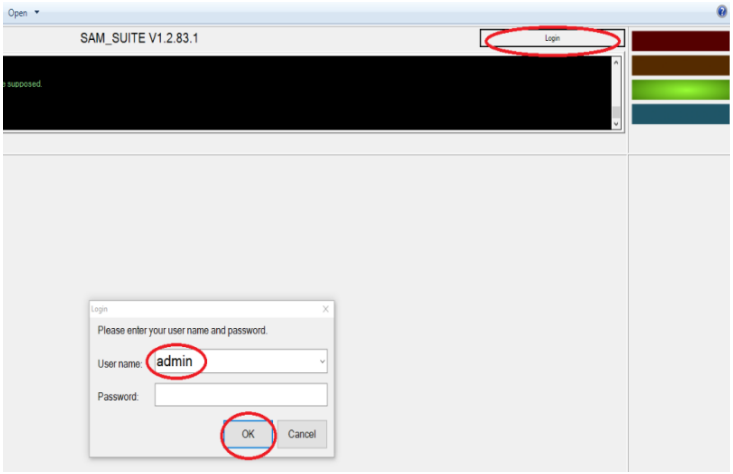


Figure. 3

6. (**Optional**) Switch on the xenon lamp from SAM/System/Light sources panel option. ** **Note** : Wait for approximately 1 hour after switching on the lamp and before performing any measurements. This is required for xenon lamp to warm up and stabilize..

Section 2.1.2: Sample Loading

Note: In the SAM software, users are not allowed to make any changes in the "*Setup*" and "*Tools*" options in the Main Menu located at the bottom of the screen.

- In "*Manual*" menu

7. Select "*Safety position*" and click on "*Move to*…" option. (Figure. 4)

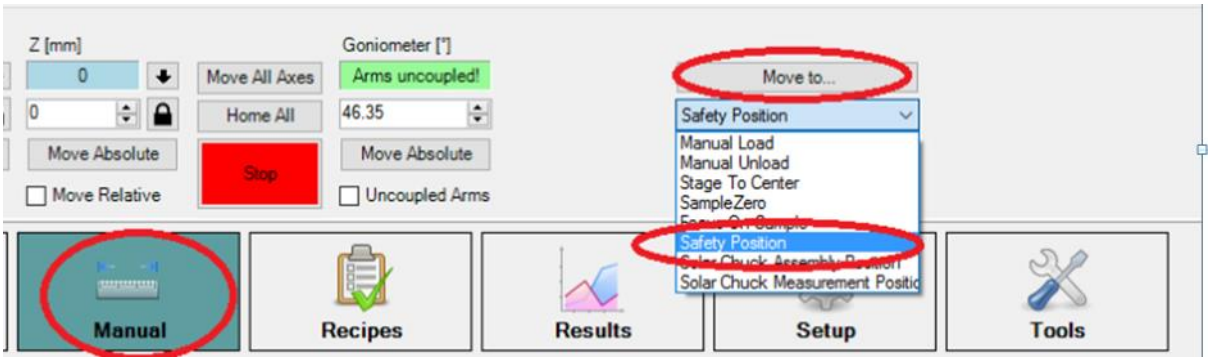


Figure. 4

8. Load your sample and switch on the vacuum by enabling the "*Vacuum*" option. (Figure. 5)
   Note: When loading the sample, don't touch the analyser and polarizer Microspot lenses.
9. Select "*Stage to Centre*" option followed by "*Move to*…" (Figure. 5)

10. Input the "*Sample Thickness*" and click on "*Go to PreFocus*". (Figure. 5)
    Now the sample is ready for measurement.

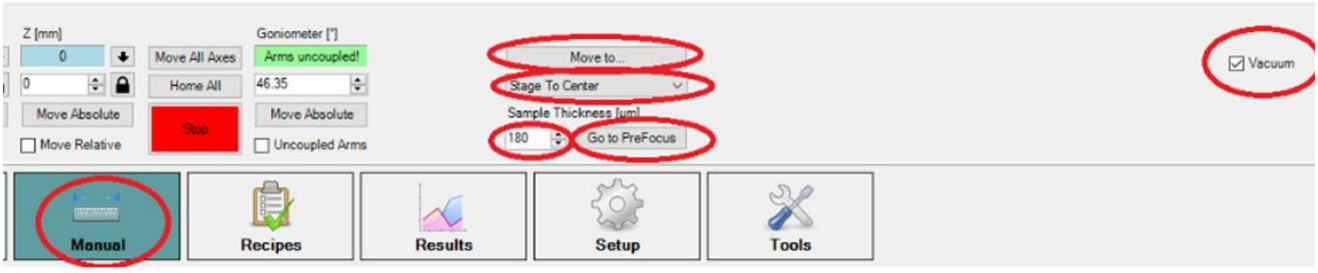


Figure.5

Section 2.1.3: Sample Measurement

➢ In "*Manual*" menu

11. Go to " *RC Focus by Signal*" submenu (Figure. 6(a))
    a. In "*Focus Settings*" option
       i. Select "*Attenuator Mode*" as per your requirement.
       ii. Set "*Spot Optic Mode*" as Microspot.
       iii. Choose "*Measure Wavelength*" in visible region.
       iv. Set "*Incident Angle*", "*Integration Time*", "*Measure Count*", "*Step Size*" accordingly.
    b. Click on "*Start*". (Figure. 6(b))

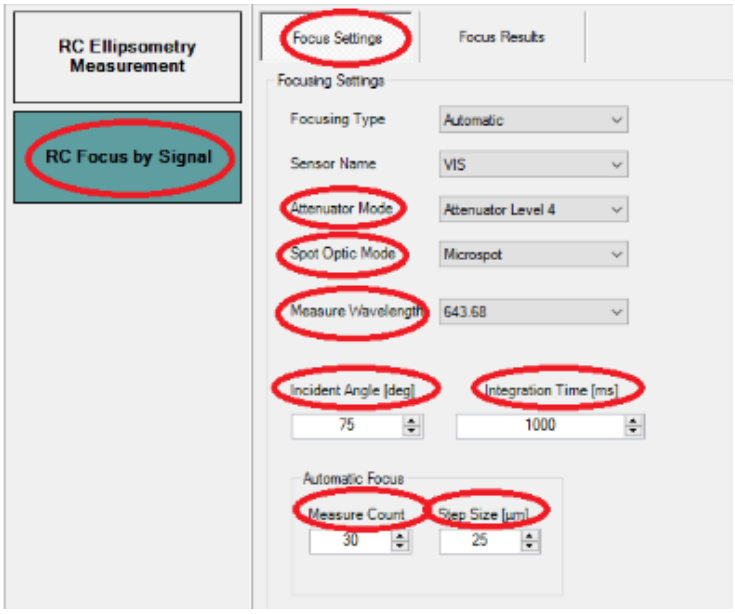


Figure. 6(a)

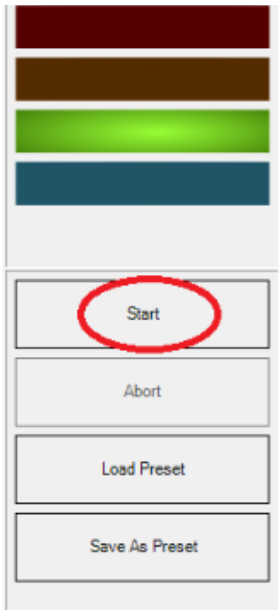


Figure. 6(b)

12. Go to "*RC Ellipsometry Measurement*" submenu

a) Under "*Measurement Settings*" go to "*Measurement*" option(Figure. 7(a))

i. Select "*Spot Optic Mode*" as Microspot.

ii. Enter the "*Incidence angle*".

iii. Select "*Attenuator Mode*" as "Auto".

iv. Choose "*Integration time*" as per your requirement.

b) Click on "*Start Measurement*" (Figure. 7(b))

13. Click on "*Save Measurement*" and save the *.smdx* file in your designated folder. (Figure. 7(b))

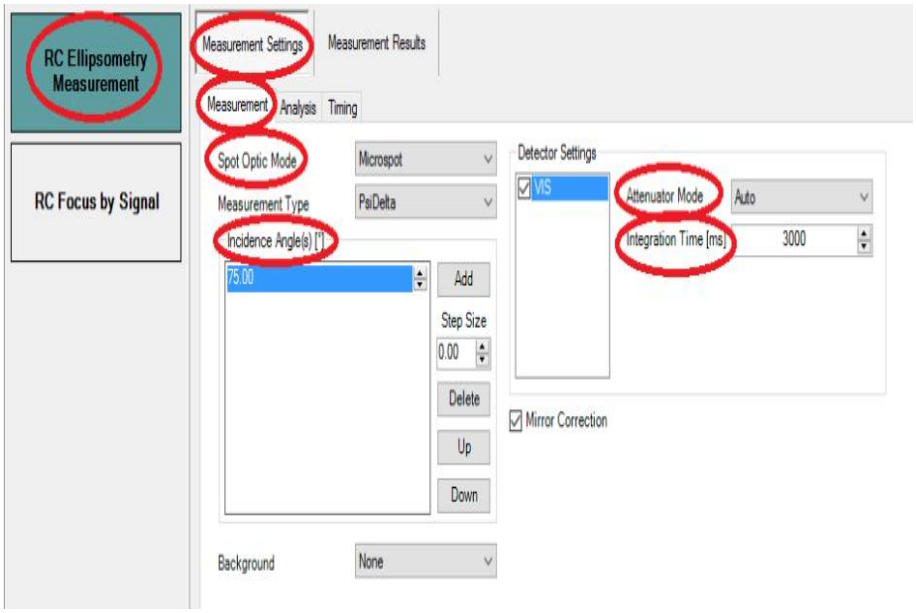


Figure. 7(a)

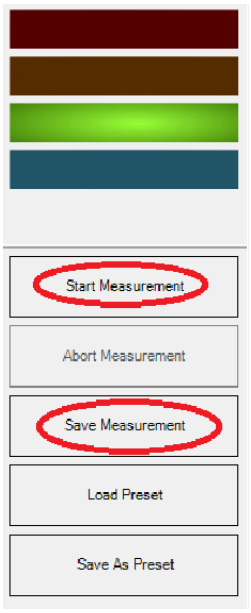


Figure. 7(b)

Section 2.1.4: Data fitting and Analysis

- Launch the *SEA* software (shortcut located on the desktop).

14. Open "*Empty Session*" (Figure. 8)

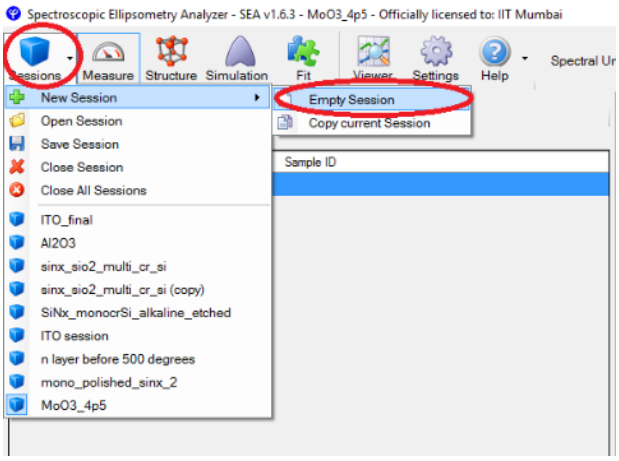


Figure. 8

15. Go to "*Measure*" tab and load the saved *.smdx* file (Figure. 9)

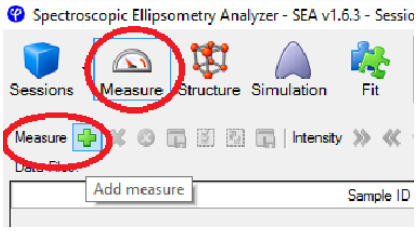


Figure. 9

16. Go to "*Structure*" and build your sample model and initialize the model parameters. (Figure. 10)

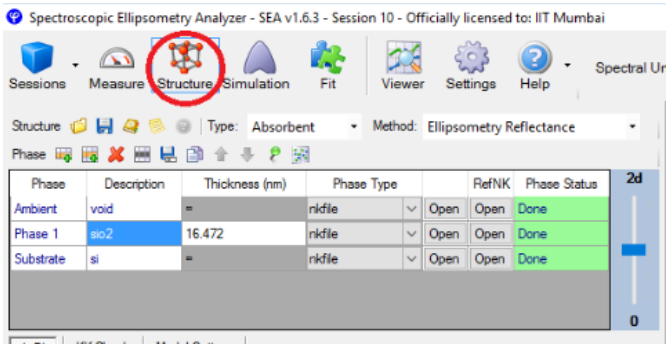


Figure.10

17. Go to "*Fit*" and select the required fit parameters of interest and "*Start Fit*" and click on "*Update Structure*" after every fit iteration. (Figure. 11 (a) and (b))

18. Generate your final report by clicking on "*PDF report*". (Figure 11(b))

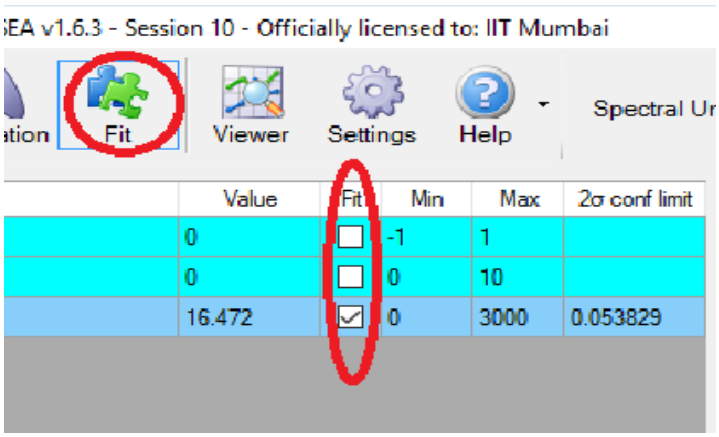


Figure. 11(a)

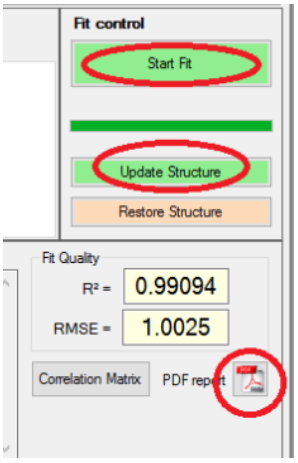


Figure. 11(b)

19. Save your session, if required, to make mapping (multiple point) measurements on your sample.

Section 2.1.5: 2D X-Y mapping

20. Repeat steps 7 to 19 as mentioned above

➢ To create recipe, click on the "*Recipes*" menu in the *SAM* software

21. Go to "*Measurement*". (Figure. 12)

a. Enable "*RC Ellipsometry Focus*" and "*RC Ellipsometry*". Set the "*Sample Dimension*" accordingly.

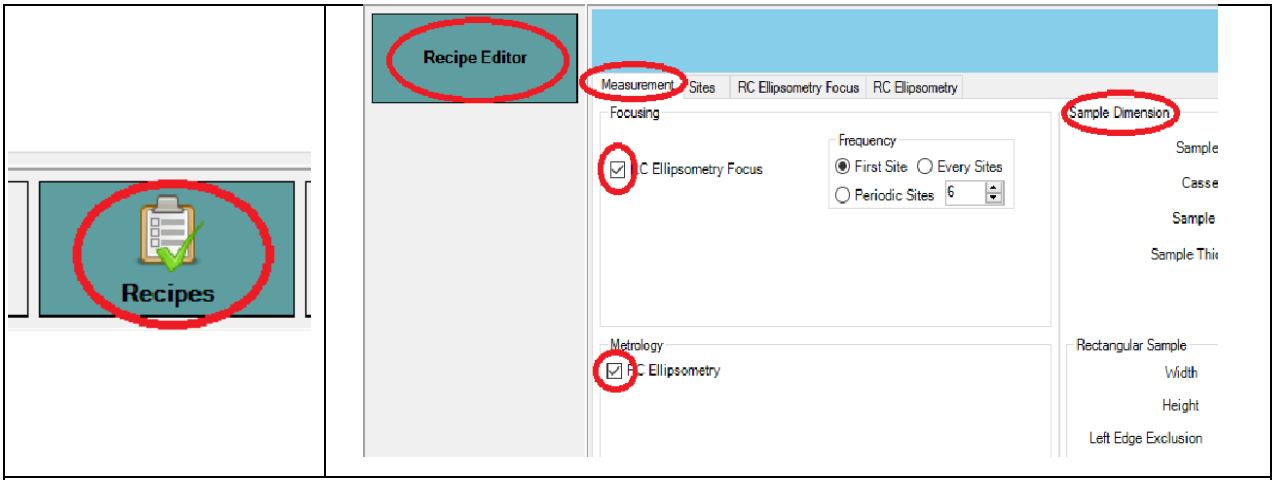


Figure. 12

22. Go to "*Site*" (Figure. 13)

a. Under "*Selection*", mention the number of points at which you require the measurements to take place.

b. Activate the measurement sites by clicking on "*Activate* ".

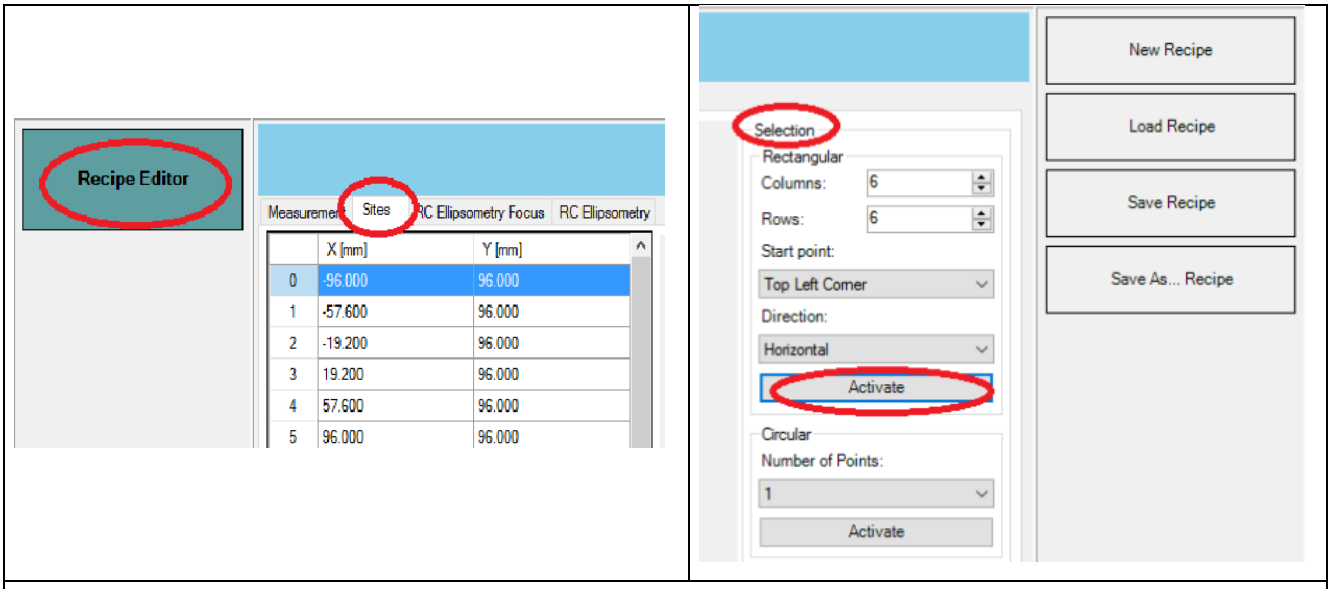


Figure. 13

23. Go to "*RC Ellipsometry Focus*". (Figure. 14)

a. Enter all parameter values exactly same as that mentioned in the "*Manual*" main menu.

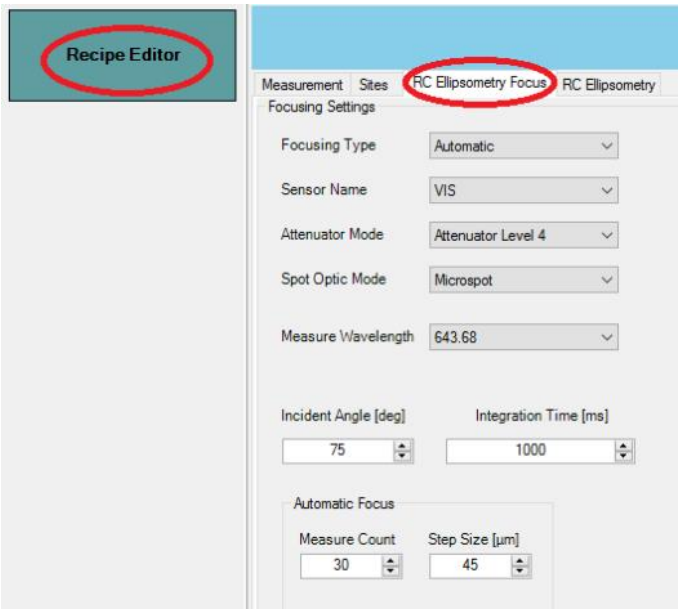


Figure.14

24. Go to "*RC Ellipsometry*" (Figure. 15)

a. Click on "*Measurement*".

b. Choose "*Spot Optic Mode*" as Microspot.

c. Select "*Attentuation Mode*" as "*Auto First*".

Note: All the remaining parameters should be kept exactly the same as that entered in "*Manual*" main menu.

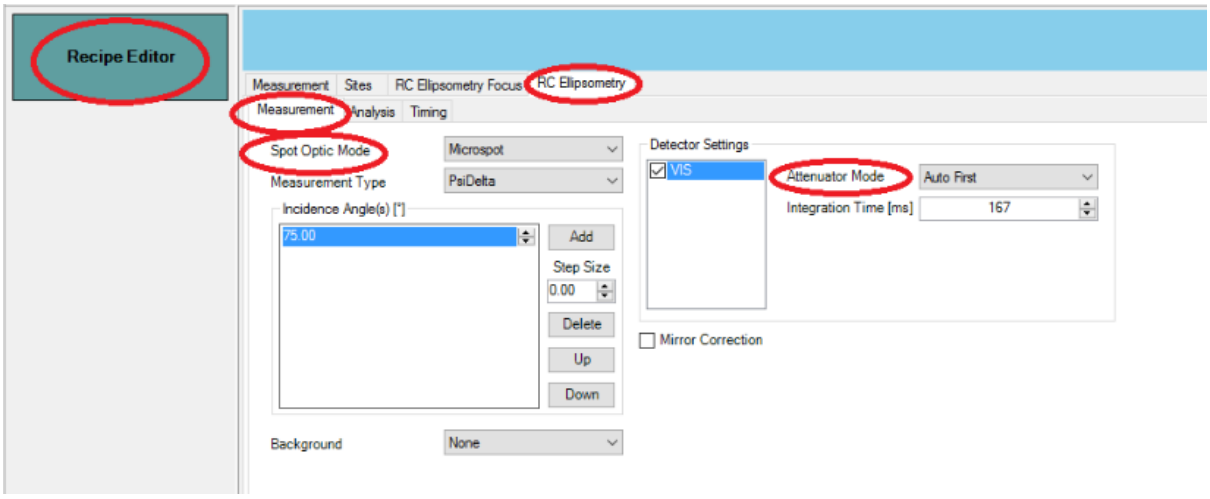


Figure.15

25. Go to "*Analysis*" (Figure 16)

- **a.** Tick on "*Enable Analysis*" and "*Use Previous Result*". (Figure 16(a))
- **b.** Load the *.ses* session file by clicking on "*Browse File*". (Figure 16(b))

26. Save the recipe by clicking on "*Save As…Recipe*" (Figure 16(b))

Note: Save the *.smrx* file into your designated folder **ONLY** and not elsewhere.

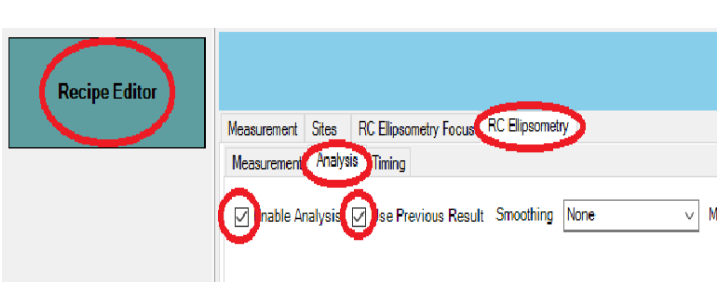


Figure. 16(a)

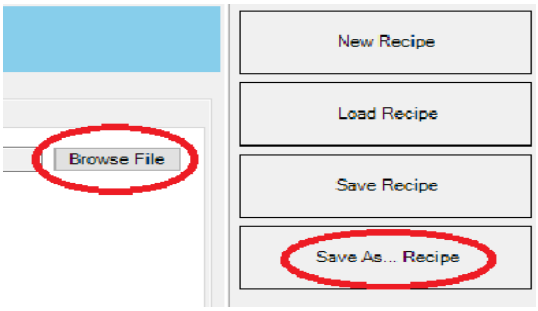


Figure. 16(b)

➢ Click on "*Job*" main menu to start the 2D mapping measurement and fitting

27. Go to Go to "*Job Scheduler*". (Figure. 17)

- **a.** Remove pre-existing recipe, if any, by clicking on "*Remove Recipe*.
- **b.** Load your recently created recipe by clicking on "*Add Recipe*".

28. Now start the measurement by clicking on "*Start Process*". (Figure. 17)

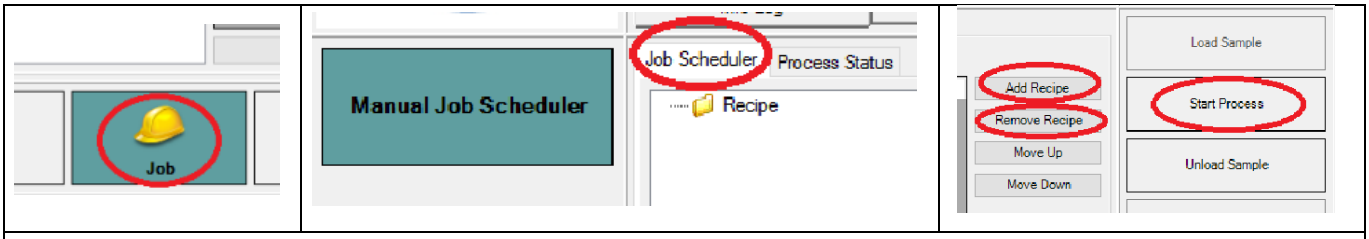


Figure. 17

Section 2.1.6: Unloading the Sample

- Go to the "*Manual*" menu

29. Select "*Safety position*" and click on "*Move to…*" option. (Figure. 4)
30. Disable the "*Vacuum*" option. (Figure. 4)
31. Remove your sample carefully.
Note: Do not touch the analyser and polarizer Microspot lenses during loading the sample.

Section 2.2: SAMPLE MEASUREMENT IN THE "SOLAR STAGE CHUCK CONFIGUREURATION"

Note: Microspot lens of both polarizer and analyzer arm aperture should be set to 5mm**.**

32. Disconnect the vacuum line from the normal chuck and replace it with the solar chuck.
Note : If the solar chuck is not fixed properly to the xy stage then the software would show the error message "*Solar chuck not in horizontal position*". Ensure that the vacuum and tilt sensor connections are properly made.

- In "*Manual*" menu

33. Move the solar stage to "*Solar Chuck Assembly Position*".
34. Load the sample and switch on the vacuum by clicking on the "*Vacuum*" option.
35. Move stage to "*Solar Chuck Measurement Position*".
36. Adjust the tilt of the solar stage at an angle of 54^{o} from horizontal position via the rotating knob connected to the stage.

- Go the "*Tools*" menu (Figure. 18)

37. In the calibration submenu go to alignment option and click on "*Start*".
38. Rotate and fix the knob attached to the tube of the solar stage to a position so as to get maximum "*Intensity [count/sec]* ", which is displayed in dynamic rectangular box.

- In "*Manual*" menu (Figure. 19)

39. Go to " *RC Focus by Signal*" submenu
  a. In "*Focus Settings*" option
    i. Select "*Attenuator Mode*" as "*Attenuator Mode 0*".
    ii. Set "*Spot Optic Mode*" as Microspot.

iii. Choose "*Measure Wavelength*" as "*823.55*"(nm).
iv. Set "*Incident Angle*", "*Integration Time*", "*Measure Count*", "*Step Size*" accordingly.

b. Click on "*Start*"

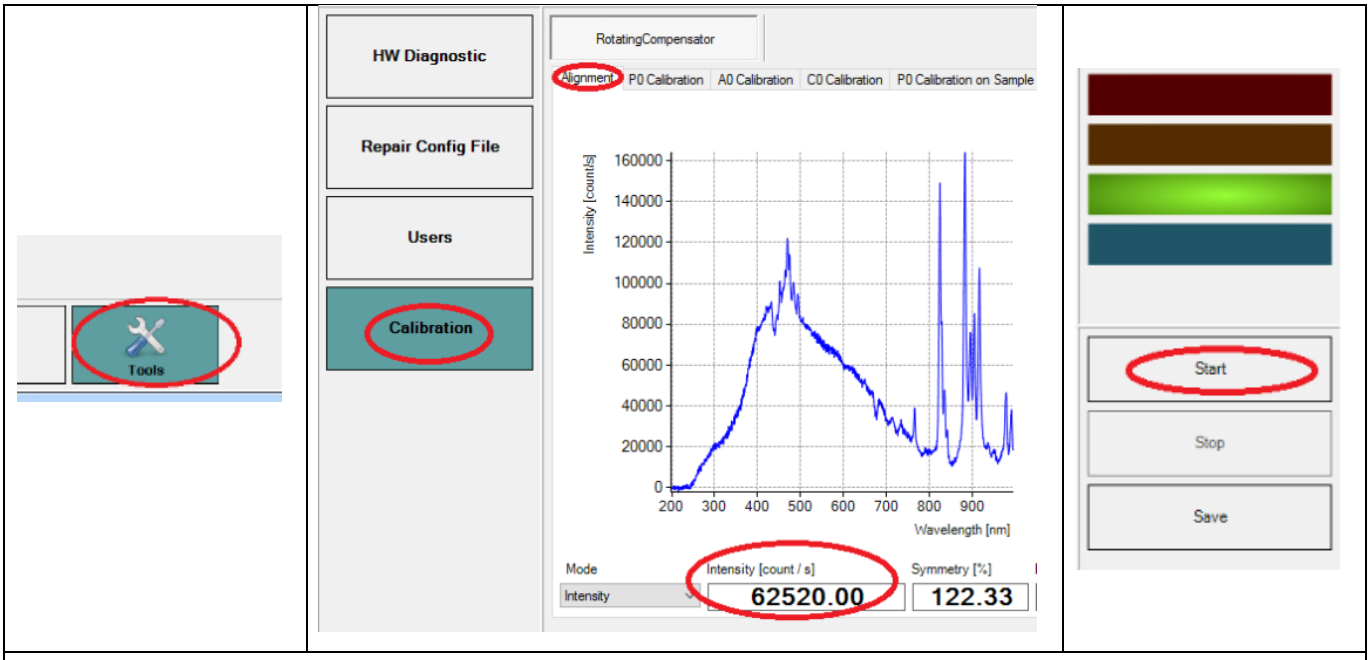


Figure. 18

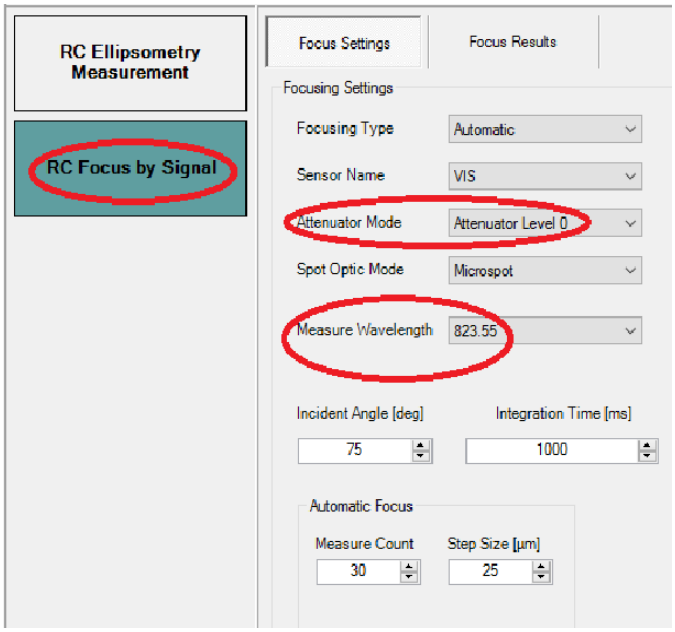


Figure. 19

40. Go to "*RC Ellipsometry Measurement*" submenu

a. Under "*Measurement Settings*" go to "*Measurement*" option:(Figure. 20(a))
  - **i.** Select "*Spot Optic Mode*" as Microspot.
  - **ii.** Enter the "*Incidence angle*".
  - **iii.** Select "*Attenuator Mode*" as "Auto".
  - **iv.** Choose "*Integration time*" as per your requirement.
  - **v.** Select "Mirror position " option.

b. Click on "*Start Measurement*". (Figure. 20(b))

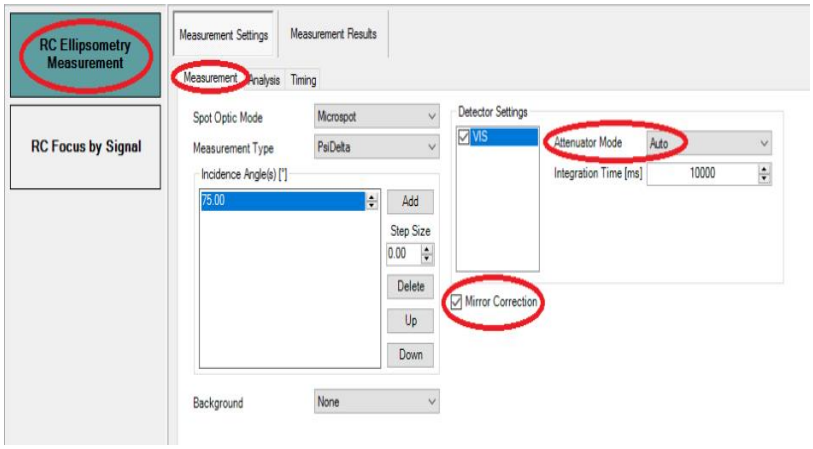


Figure. 20(a)

Figure. 20(b)

41. Click on "*Save Measurement*" and save the *.smdx* file in your designated folder.

42. For analysis and fitting using *SEA* software, follow procedure from steps no. 14 to 19.

Section 2.2.1: Unloading the sample from solar stage

43. Reduce the tilt of solar cell to 0° (horizontal position)

- In "Manual" menu,

44. Move the solar stage to "*Solar Chuck Assembly Position*"

45. Switch off the vacuum and unload the sample.

46. Remove the solar chuck carefully (disconnect the vacuum and tilt sensor wire gently) and replace it with normal chuck.

47. Reduce the Microspot aperture from 5 to 2.5 mm.

Section 2.2.2: Switching OFF procedure

- In "Manual" menu,

48. Select "*Stage to Centre*" option followed by clicking on "*Move to…*"

49. Set the goniometer angle to 46.35° in the "*Goniometer [°]*" option and click on "*Move Absolute*" tab.

50. (**Optional**)Switch off the Xenon lamp from SAM/System/Light sources panel option**. ****

51. Click on "*Exit*" to quit *SAM* software.

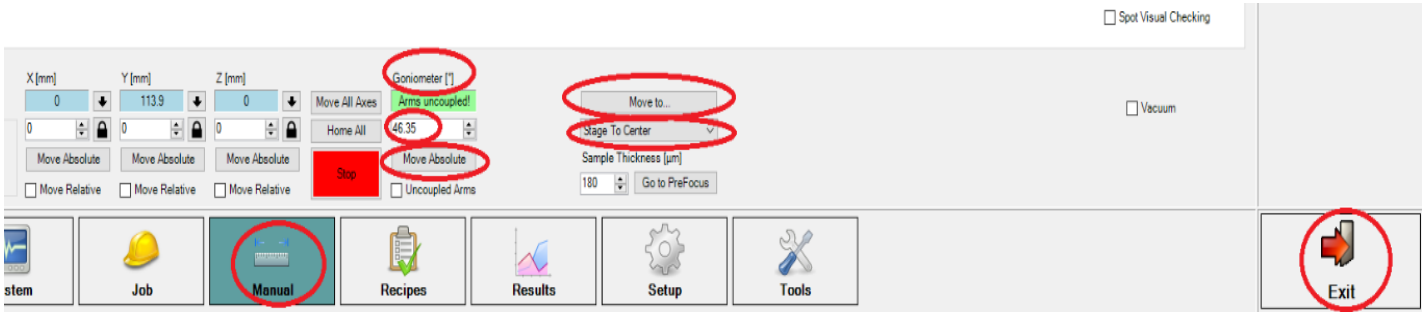


Figure. 21

52. Also close the *SEA* software window.

53. Lock the computer system.

54. Close the CDA valve without fail.

** To avoid damage to the xenon lamp by frequent switching, turn it on in the morning and off in the evening i.e. once a day.

EQUIPMENT MAINTENANCE (FOR SO ONLY)