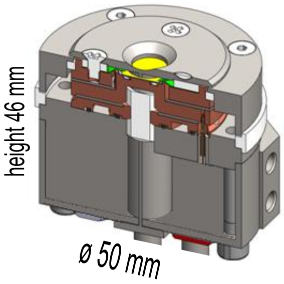
Multifunctional Plasma and Deposition Sensor



- Multifunctional sensor that combines three measurement principles at the same measurement spot [1] [2]
- Measurement of the total energy influx, the growth rate and the plasma parameters (Langmuir probe)
- Almost simultaneous measurements at the same position

Measurement of the total energy influx based on the radiometer principle of Gardon [3]

- Measurement of thermal radiation from the backside of the sensor
- External calibration of the absolute energy influx **E_{tot}** with an energy (radiation) source or internal calibration using the electrons of the process plasma
- Energy flux range: about 1 mW/cm^2 to 1 W/cm^2
- Front electrode potential adjustable in the range from -100 V to +50 V (adjustable ion/ electron current to surface)

Quartz crystal microbalance (QCM) measuring of the frequency change of a crystal

- Determination of deposition rate **R** and current film thickness **d**
- Useable for thin film deposition and film etching
- Usage of commercial quartz crystals (ø14 mm, f_0 = 6 MHz)

Planar Langmuir probe

- Measurement of the voltage-current characteristics at the front electrode of the quartz crystal (voltage range -100 V to +50 V, max. current 100 mA)
- Determination of the plasma parameters floating- **V_{float}** and plasma potential **V_{Plasma}**, electron temperature **T_e** together with electron **n_e** and ion density **n_i** using a LabView based analysis software
- In combination with film rate R measurement calculation of the energy influx per film-forming particle **$P_{in} / J_{neutral}$** and and the ion-to-neutral particle ratio **$j_{Ion} / j_{neutral}$**
- Current measurement at static potential

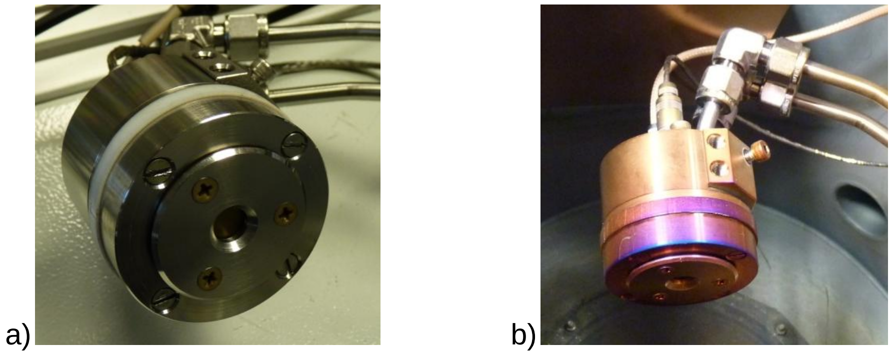


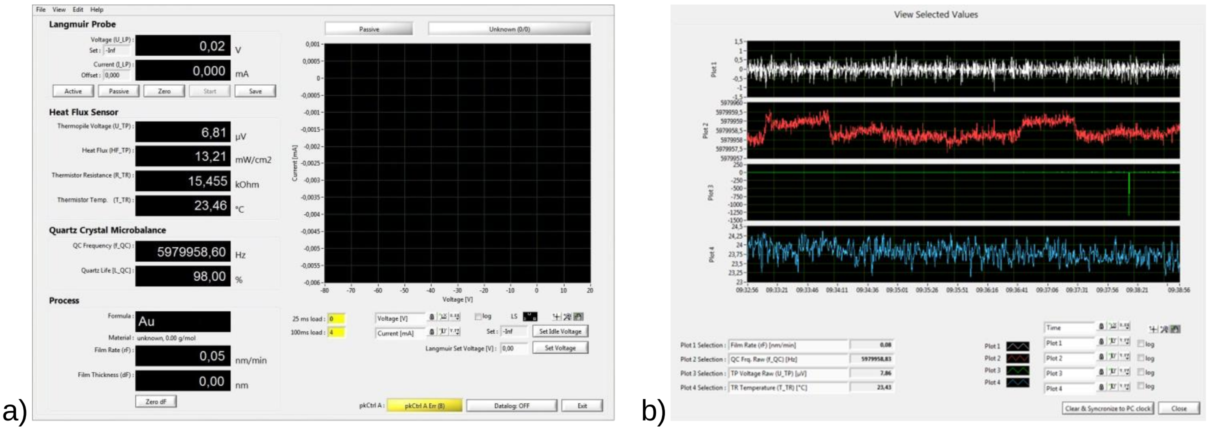
Fig.1: (a) Assembled sensor head and (b) inside deposition chamber mounted with water cooling

General Data

- Sensor head dimensions (without mounting): ø 50 mm, height 46 mm
- Radial resolution/ aperture diameter: 8 mm (variable size available on request)
- Axial/ radial movement possible by mounting on a linear/ rotatable feed through
- Sensor head electronic box located outside of the vacuum chamber

Control and measurement software

- LabView based intuitive user interface
- Saveable raw data, median filtered and exponentially smoothed data
- Chart view with selectable values



Langmuir Probe
Voltage (U_LP) : 0,02 V
Set : -Inf
Current (I_LP) : 0,000 mA
Offset : 0,000

Heat Flux Sensor
Thermopile Voltage (U_TP) : 6,81 µV
Heat Flux (HF_TP) : 13,21 mW/cm2
Thermistor Resistance (R_TR) : 15,455 kOhm
Thermistor Temp. (T_TR) : 23,46 °C

Quartz Crystal Microbalance
QC Frequency (f_QC) : 5979958,60 Hz
Quartz Life [L_QC] : 98,00 %

Process
Formula : Au
Material : unknown, 0,00 g/mol
Film Rate (rF) : 0,05 nm/min
Film Thickness (dF) : 0,00 nm

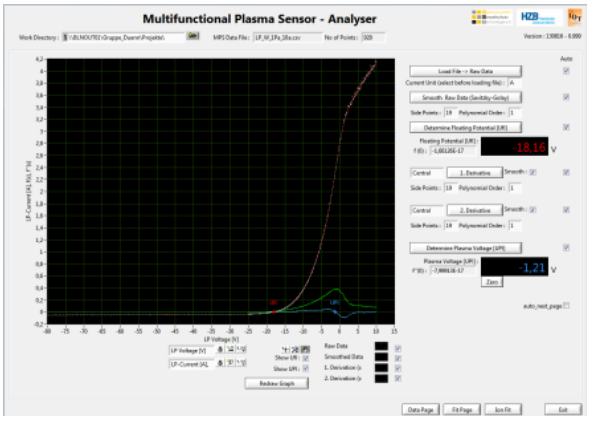
25 ms load : 0
100ms load : 4

Plot 1 Selection : Film Rate (rF) [nm/min] 0,08
Plot 2 Selection : QC Frq. Raw (f_QC) [Hz] 5979958,83
Plot 3 Selection : TP Voltage Raw (U_TP) [µV] 7,86
Plot 4 Selection : TR Temperature (T_TR) [°C] 23,43

Fig.2: (a) Control and visual display software with (b) time chart

Analysis software for Langmuir probe curves

- Adjustable smoothing of measurement curves and derivations with different algorithms
- Determination of floating V_{float} (current voltage measurement curve) and plasma potential V_{plasma} (second derivation)
- Calculation of electron temperature T_e and electron density n_e by selecting different electron energy distribution functions (Maxwell, Bi-Maxwell or general distribution function [Flender & Wiesemann / Rundle et al. [4, 5]]) by fitting the second derivative
- Determination of the ion density n_i based on the fit of the current voltage measurement curve (ion saturation current)
- Calculation of energy influx per film-forming particle P_{in} / $J_{neutral}$ and ion-to-neutral particle ratio j_{ion} / $j_{neutral}$

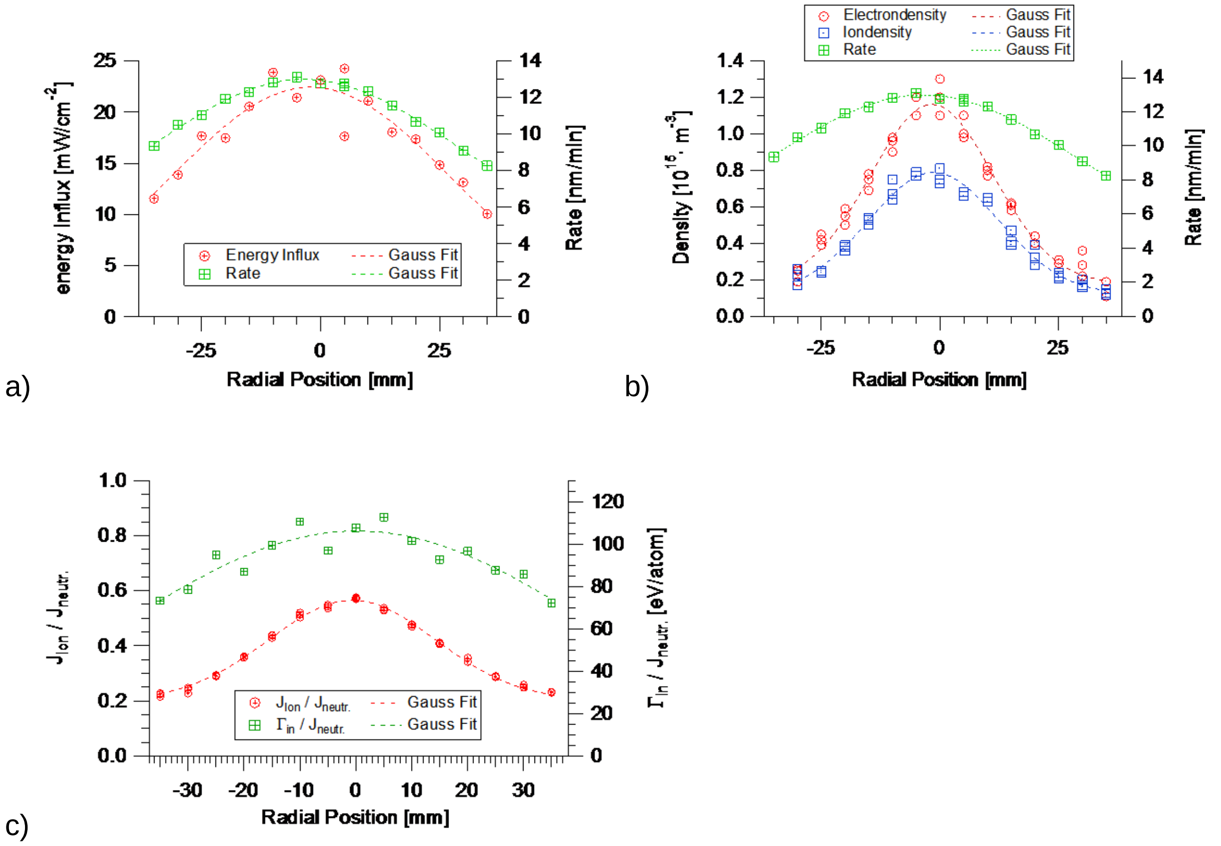


Floating Potential [Uf] : -18,16 V
Plasma Voltage [UP] : -1,21 V

Fig.3: Analysis software for Langmuir-probe voltage-current curves: smoothing of curves and determination of Potentials

Application examples

1. Investigation of the radial distribution of a 2” magnetron sputter source with a tungsten target



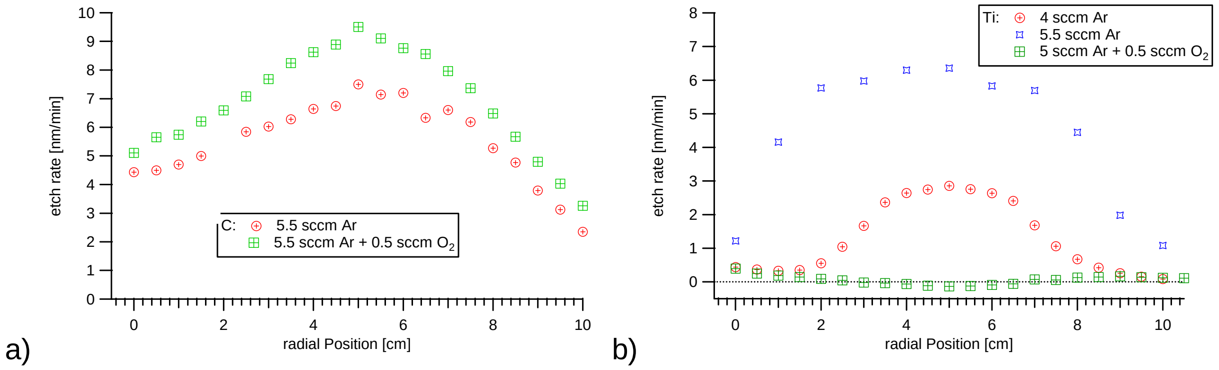
a)

b)

c)

Fig.4: Radial distributions of (a) deposition rate and energy flux, (b) electron and ion density and (c) ion-to-neutral ratio $j_{ion}/j_{neutral}$ and energy per film atom from a 2” magnetron sputtering source with a tungsten target. Sputtering parameters: P_{DC}= 50 W, p_{Ar}= 1.0 Pa, F_{Ar}= 41 sccm , V_{dis}= 267 V, I_{dis}= 189 mA. Distance magnetron-sensor: 6 cm

2. Investigation of the radial distribution of an etching process with an RF-ICP-ion-source



a)

b)

Fig.5: Radial distribution of average etching rate without and with additional supply of oxygen at a (a) carbon and (b) titanium coated sample. Ion source parameter P_{RF} = 100 W, V_{beam} = 352 V, I_{beam} = 30 mA, V_{accel} = 95 V, I_{accel} = 1 mA, Distance ion source-sensor: 17.4 cm

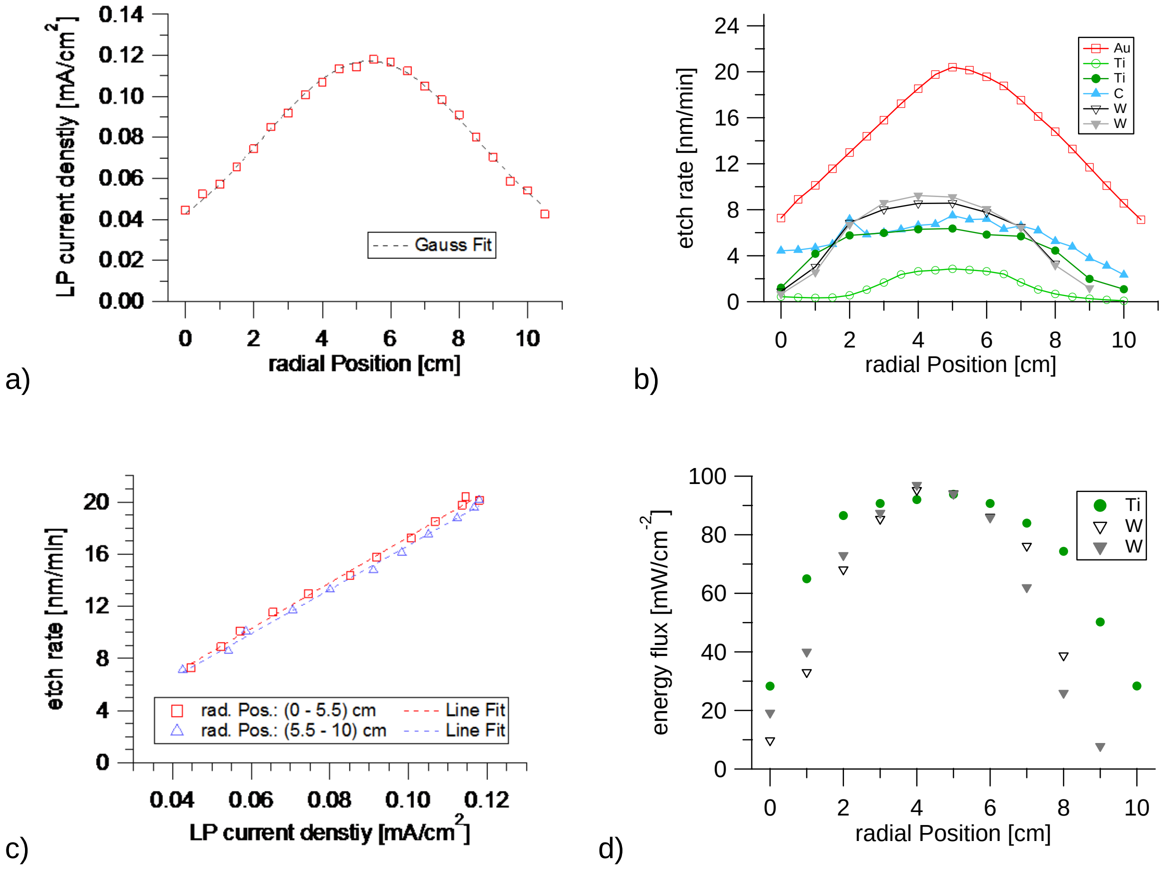


Fig.6: Radial distributions of (a) the current density at the front electrode of the quartz, (b) radial distributions of different etching rates, (c) the linear dependence of the etching rate of an Au film on the Ar^+ current density (taken at the center of the ion beam), and (d) the energy flux distribution of a 2” ion beam source operated with pure argon. Thin films of Au, C, Ti, and W on the quartz crystal were used for the etching experiments. Ion beam source parameters: P_{RF}= 100 W, F_{Ar}= 4 - 5.5 sccm, V_{beam}= 350 - 352 V, I_{beam}= 25 - 33 mA, V_{accel}= 94 - 96 V, I_{accel}= 1 - 5 mA. Distance ion beam source-sensor: 17.4 cm

Specifications

- Total energy influx
    - Energy flux range: about 1 mW/cm^2 to 1 W/cm^2
    - Time resolution: - electronic (steady state): 100 ms
      - physical (after sudden heat exposure): about 5 s
    - Measurement with potential (-100 V to +50 V) at front electrode possible

- Quartz crystal microbalance
    - Commercially available crystals (quartz) with RC-cut (recommended), AT-cut possible too
    - Diameter crystal oscillator 14 mm
    - Resonance frequency (uncoated): 6 MHz
    - Min. Deposition rate 0.01 Å/s, min. Film thickness: 0.1 Å, max. Film thickness about 10 µm
    - Time resolution: - electronic (steady state):100 ms
      - physical (after sudden heat exposure): about 5 s
    - Measurement with potential (-100 V to +50 V) at front electrode possible

- Planar Langmuir-probe
    - Voltage range: $U_{electrode}$ = -100 V to +50 V
    - Voltage resolution: 10 mV
    - Current resolution: min. 0.1 µA, max. current 100 mA
    - Current measurement a fixed potential

- Dimension sensor head: ø 50 mm, height 46 mm
- Active sensor area / aperture diameter: ø 8 mm (changeable)
- Cooling: water cooled sensor head (Provision of cooling water necessary)
- Mounting flange selectable (Space for water and signal feed through necessary)
- Mounting at linear or rotatable feed through possible
- Pressure range: vacuum to atmospheric pressure (Undistorted measurement of heat influx up to about 10^{-2} mbar)
- Materials exposed to vacuum / plasma: steel (1.4301), PEEK (polyether ether keton) (Additional materials inside the sensor at vacuum: AlN, Al_2O_3, Cu, PTFE, Viton)
- External sensor electronics, about 20 x 15 x 30 cm^3 mounted near flange and 19“- rack slide
- Power supply: 230 V_{ac}
- PC-connection: Ethernet
- Operating system: Windows 8 / 7 / Vista / XP / 2000

References

[1] K. Harbauer, K. Ellmer, T. Welzel, A combined sensor for the diagnostics of plasma und film properties in magnetron sputtering processes, Thin Solid Films, 520 (2012) 6429-6433.

[2] T. Welzel, M. Kellermeier, K. Harbauer, K. Ellmer, Development of a compact combined plasma sensor for plasma surface engineering processes, Appl. Phys. Lett., 102 (2013) 211605-211601...211605.

[3] R. Gardon, An Instrument for the Direct Measurement of Intense Thermal Radiation, Rev. Sci. Instr., 24 (1953) 366-370.

[4] U. Flender, B.H.N. Thi, K. Wiesemann, N.A. Khromov, N.B. Kolokov, RF Harmonic Suppression in Langmuir Probe Measurements in RF Discharges, Plasma Sources Sci. Techn., 5 (1996) 61-69.

[5] H.W. Rundle, D.R. Clark, J.M. Deckers, Electron Energy Distribution Functions in an O_2 Glow Discharge, Canad. J. Phys., 51 (1973) 144-148.