Ion energy analysis of sputtering ions at planar targets with DC- and RF-sputtering by Retarding Field Analysis

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Motivation

• Magnetron sputtering is a well developed thin film plasma technology and a lot of investigations had been done in the past to characterize the sputter plasma itself and the plasma interaction with the substrate.

• The primary sputter process at the target by energetic ions is well understood, for nearly all elements and for a lot of compounds the sputter yield and other sputter features are available.
• Not so much effort had been done in the past to characterize the ion energy distribution of the sputtering primary ions like Ar^+ or Kr^+.

• The mean ion energy of the sputtering ions (W_{ion}) can be estimated in DC-sputtering from the generator voltage (U) and the plasma potential (V_{pl}) by:

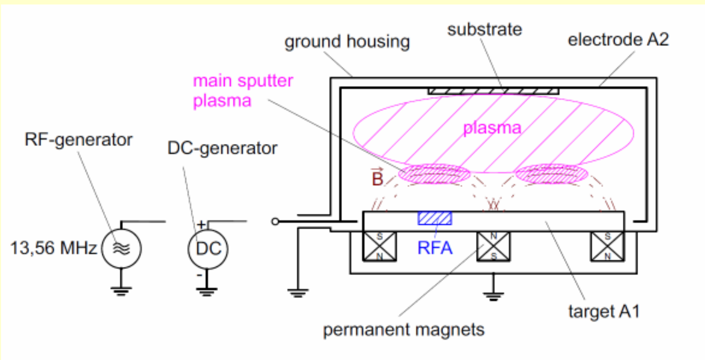
$$W_{ionmean} = U - V_{pl} \qquad (1)$$

• In case of RF-sputtering the maximum ion energy of the sputtering ions is given by the Bias-Voltage of the target.

• In this work a Retarding Field Analyzer (RFA) was integrated into the sputter target at the place with the highest sputter rate (erosion zone), and the ion energy distribution of the impinging ions was measured for DC- and RF-sputtering.

Arrangement of a Retarding Field Analyzer at sputter targets for DC and RF

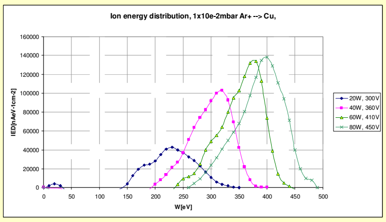
• The cathode voltage in DC sputtering is between -200 and -500V in respect to ground, that means a Retarding Field Analyzer, measuring there the ion energy, has to float and work at this cathode potential.
• Although commercial Retarding Field Analyzer systems working at such potentials are available (see [1]), another approach with a standard RFA [2] at ground was used.
• To keep the target (and the integrated RFA) on ground the potentials for sputtering had been changed/inverted, like shown at the figure below.
• A grounded housing, containing the sputter plasma and the magnetron (target area A1) had been mounted in a vacuum chamber. The magnetron inside was grounded and a electrode (area A2) was isolated mounted on the housing with 2 mm distance (dark room shielding).
• A substrate was mounted at the electrode.
• The sputter plasma now was ignited by connecting the positive output of the generator to the electrode and the negative output to ground.
• In case of RF sputtering the RF-output was connected to the electrode.
• By keeping the electrode area A2 very much larger than the target area A1, the same plasma conditions (plasma sheet potentials) like at normal sputtering had been achieved (A2/A1 = 10).



Principle of the RFA ion energy analysis with inverted potentials inside a grounded chamber

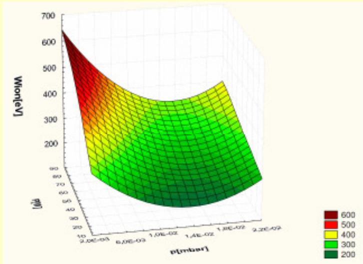
• A special five grid RFA (see [2] PlasmaMon) with laser cutted copper grids (0.25 mm thick) was produced and integrated into a copper target.
• The target had a dimension of 100 x 80 mm and up to 200 W could be applied (corresponding to approx. 5 $mAcm^{-2}$ ion current density at the RFA).
• The Ion Energy Distributions (IED) had been recorded from 0 to 800 eV.

Ion energy distribution for DC sputtering



Ion energy distribution at $1x10^{-2}$mbar at different DC-power

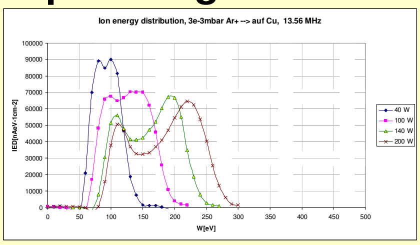
• The figure left shows the ion energy distributions (IED) for DC-powers from 20 to 80W at $1x10^{-2}$ mbar.
• The generator voltage increases thereby from 300 to 450 V.
• The mean ion energy can be estimated by using equ. (1) with a plasma potential V_{pl} of approx. 50 V.
• The Ion Energy Distributions had been measured from $3x10^{-3}$ mbar up to $2x10^{-2}$ mbar.
• Down to lower pressure higher mean ion energies up to 650 eV are reached.



mean ion energy in dependence on pressure and DC-power

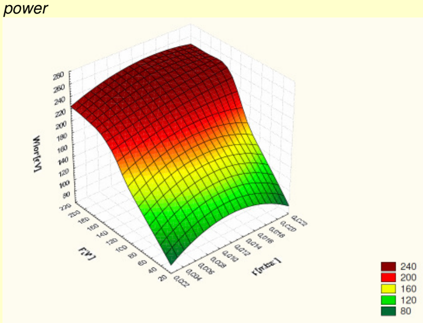
• The figure left shows the dependence of the mean ion energy from pressure and power.
• Smallest primary ion energy occurs at $1.5x10^{-2}$ mbar and low power of 20W.
• Highest primary ion energy is at $2x10^{-3}$ mbar and 80W.

Ion energy distribution for RF sputtering



Ion energy distribution at $3x10^{-3}$mbar at different RF-power

• The figure left shows the ion energy distributions (IED) for RF-powers from 40 to 200W at $3x10^{-3}$ mbar.
• only at 140 W and 200 W a part of the IED overcomes the threshold for significant sputtering (200 eV).
• The principal behavior of the IED is known from the theory of collisions less RF-plasma sheets (double peak structure).
• This double peek structure is clear measured at small pressures and distinguishes up to higher pressures ($2x10^{-2}$ mbar).



mean ion energy (of sputter peak) in dependence on pressure and RF power

• The figure left shows the mean ion energy in dependence from RF-power and pressure.
• there is no significant dependence on pressure.
• Only at RF-powers larger 150W, mean ion energies usable for sputtering are produced.

Summary

Data about the ion energy distribution of sputtering primarily ions in magnetron sputtering are not very much available in literature.

One reason for that may be the difficulty of ion energy measurement on the negative potential of the target.

In this work therefore a Retarding Field Analyzer, measuring on ground potential, was used in combination with an experimental setup enabling inverted potentials on the sputter plasma.

In case of DC-sputtering mean ion energies between 250 and 650 eV could be measured, which corresponds to the generator voltage.

In case of RF-sputtering only at higher RF power densities the mean ion energy overcomes the sputter threshold of approx. 200 eV.

[1] www.impedans.com
[2] PlasmaMon see: www.jenion.de

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