Copper- and silicon layers, sputtered with a magnetron with controlled primary ion energy

Hermann Schlemm, Jenion, Milda, Germany, hermann.schlemm@jenion.de

Motivation

In contrary to direct ion beam sputtering at magnetron sputtering the energy of the sputtering primary ions is given by the generated sputter plasma and therefore normally restricted to an ion energy range between 250 and 500 eV. It is shown in poster contribution #559 at this conference [1], that with a new, modified magnetron (Dual Target Magnetron – DTM) a primary ion energy range up to 1.000 eV can be reached in magnetron sputtering.

Fig.1 illustrates schematically the charged and neutral particles, generated in magnetron sputtering with argon. Beside the sputtered target atoms (X), that are reflected argon-ions/neutrals with energies up to the argon primary ion energy and argon ions with lower energies, generated at the plasma sheet covering the substrate.

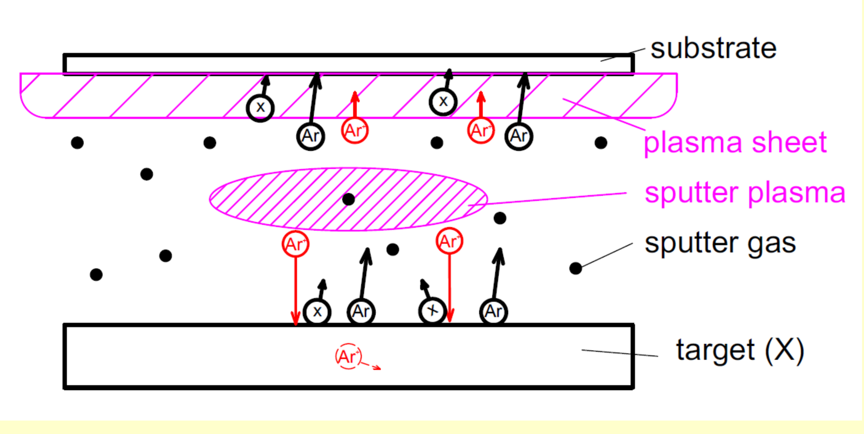

FIG.1: *Schematic illustration of the energetic particles occurring in magnetron sputtering*

Three factors do influence the energetic relations at the substrate, responsible for layer growth:

a) Plasma power:

- increases the plasma sheet voltage and therefore the energy of ions reaching the substrate.

b) mass ratio (m_{argon}/m_x):

- if m_x is lower than m_{argon} both sputtered target atoms and reflected neutral argon atoms have smaller energies,
- if m_x is higher than m_{argon} both sputtered target atoms have higher and reflected neutral argon atoms may have energies up to the primary ion energy.

c) Primary ion energy:

- that only can be controlled at magnetron sputtering with the DTM and increases both the energy of the sputtered target atoms [2,3] as well the energy of reflected neutral argon atoms.

The aim of this work is to illustrate the layer growth obtained by argon-sputtering with the Dual Target Magnetron (varied primary ion energy) for sputtering of copper (m_x is higher than m_{argon}) and of silicon (m_x is lower than m_{argon}) at constant plasma power.

Experimental

A Dual Target Magnetron [1] was operated at 10^{-2}mbar with argon and a plasma power of 80 W. The film thickness was measured both with a quartz microbalance and with a profilometer. The specific resistance of the copper layers was measured by a four point method. Ion current density and ion energy of argon ions at the substrate had been measured with a "PlasmaMon" from Jenion [4].

Results

a) Copper layers

Approx. 200 nm thick copper layers had been deposited on glass substrates at temperatures around 50℃. Fig.2 shows that the specific resistance of the layers decreases and the mass density increases with increased primary ion energy.

Electrical conductivity (Wion) **Mass density (Wion)**

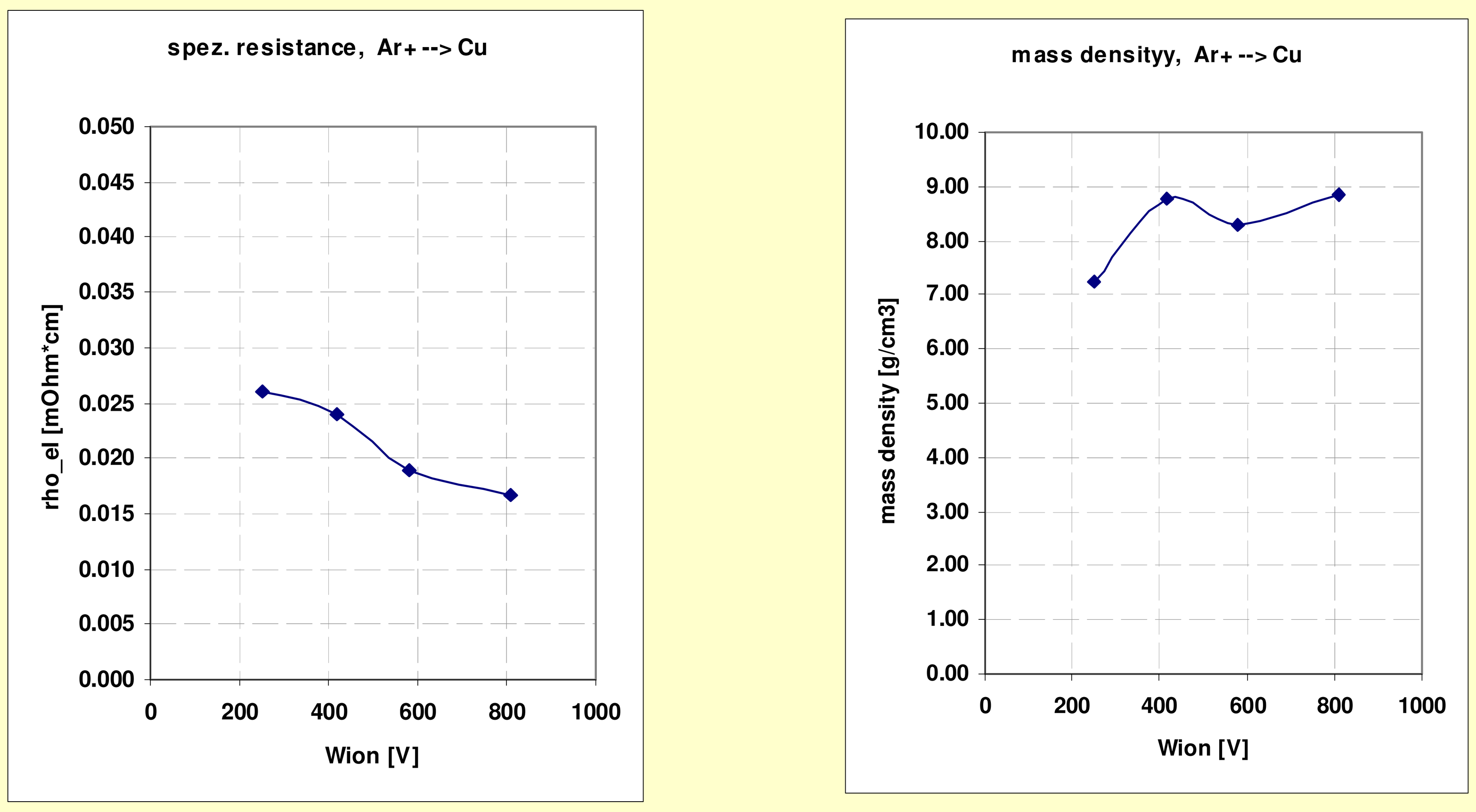

FIG.2: *Specific resistance (left) and mass density (right) of cupper layers in dependence from the primary ion energy sputtered with the DTM*

b) Silicon layers

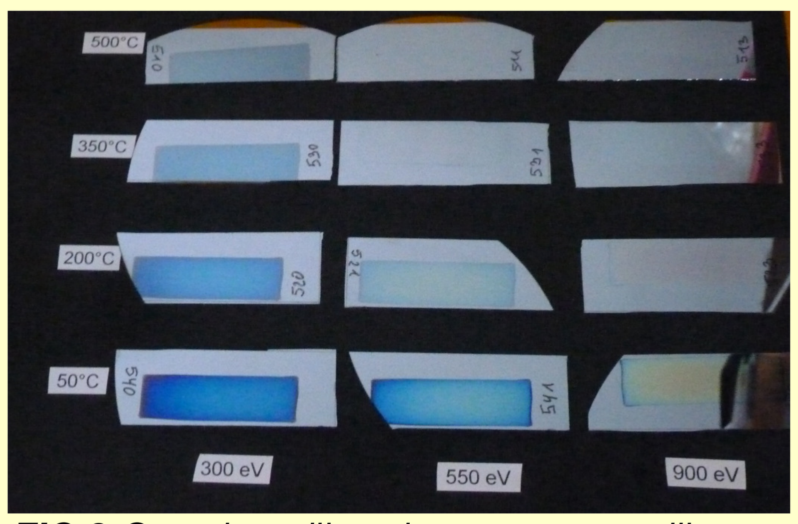

FIG.3: *Overview silicon layers on crystalline silicon in dependence from temperature and primary ion energy*

A high phosphorous doped silicon target had been used. Crystalline silicon substrates prepared with an HF-dip before deposition had been used. The substrate temperature was varied from 50℃ to 500℃.

Fig.3 gives a visual impression of the reached transition from amorphous to crystalline layers. Fig.4 shows the corresponding reflection spectra.

300 eV primary ion energy **900 eV primary ion energy**

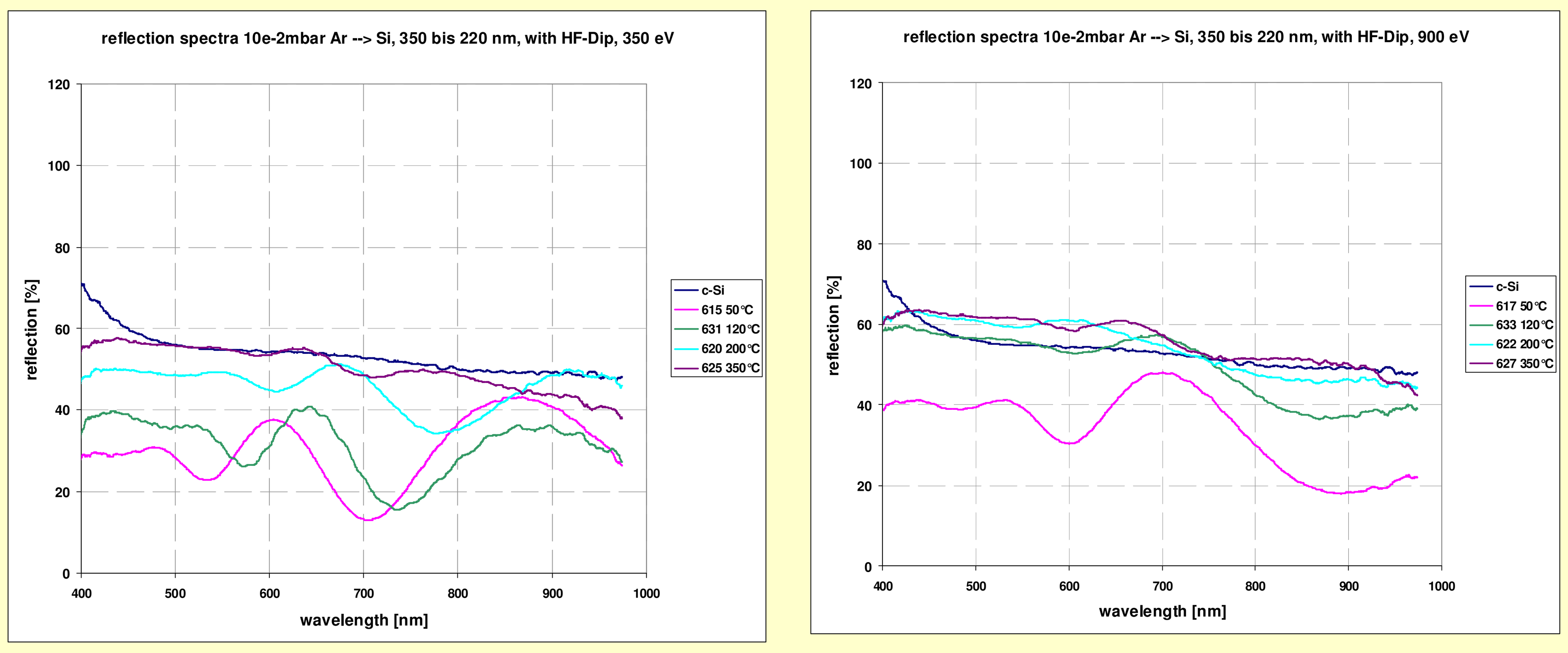

FIG.4: *Reflection spectra of silicon layers (approx. 100 nm on crystalline silicon) for aprimary ion energy of 300 eV (left) and for 900 eV (right).*

c) Estimated energy flux at the substrate

Energy flux Ar+ → Cu, 300 eV against 900 eV **Energy flux Ar+ → Si, 300 eV against 900 eV**

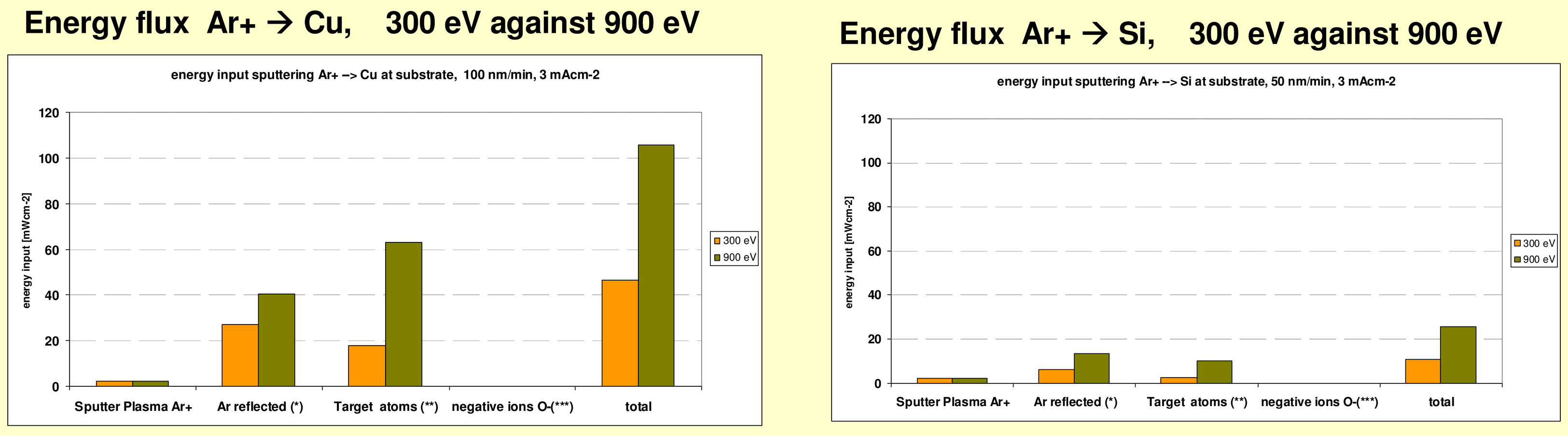

FIG.5: *Energy flux analysis for sputtering with 300 eV (yellow) and 900 eV (green) primary ion energy*

Parameters sputter deposition:

- 10^{-2} mbar Argon, substrate distance 50 mm, → low gas diffraction,
- sputter power 60W, → primary ion current density 3 – 5 mAcm^{-2},
- deposition speed Cu: 50 – 125 nm/min,
- deposition speed Si: 25 – 75 nm/min,

Data taken from:

- **sputter plasma:** plasma probe measurement + RFA [4],
- **reflected argon:** Data from TRIM.SP Simulation [5],
- **sputtered target atoms:** SRIM simulation [6],

Remarks:

- effect of mass ratio at sputtering is good visible (argon mass/target atom mass),
- **Ar(M=40) → Cu(M=52),** heavy target atom,
- **Ar(M=40) → Si(M=28),** light target atom,

Outlook

This work shows first results of layers, deposited by sputtering with the Dual Target Magnetron.

Both in amorphous and in crystalline layers the influence of the enhanced primary ion energy of the DTM could be demonstrated.

Future interesting applications of this method could be e.g.:

- sputtered crystalline semiconductor absorber layers for PV-applications,
- High dense and high conductive layers for bipolar plates for hydrogen electrolysis or fuel cells,
- Sputtered wide band gap semiconductor layers for power electronics.

References

[1] Schlemm, H. PSE 2024, Poster #559, "Magnetron sputtering with controlled primary ion energy"

[2] Stuart R.V., Wehner G.K., J. Appl. Phys., 35, 1819, (1964),

[3] M. Stepanova, S.K. Dew, "Estimates of differential sputtering yields for deposition applications", J. Vac. Sci. Technolog. A 19, 2805, (2001),

[4] http://www.jenion.de/Plasma-Analysis/,

[5] *Eckstein, W., Computer Simulations of Ion-Solid Interactions, Springer Series in Material Science 10, 1991, 162*

[6] http://www.srim.org/, James F. Ziegler, TRIM – Transport of Ions in Matter

Dr. Hermann Schlemm
Ion Beam and Surface Technique
Dorfstrasse 36
D-07751 MILDA, Germany
email: hermann.schlemm@jenion.de
www.jenion.de

JENION