Electronic response of a plasma-facing dielectric solid

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Based on the Poisson equation for the electric potential and two sets of spatially separated Boltzmann equations, one for the conduction band electrons and valence band holes inside the dielectric and one for the electrons and ions inside the plasma, we present a kinetic theory for the electronic response of a plasma-facing dielectric solid. It enables us to determine the quasi-stationary density and potential profiles of the electric double layer formed at the interface as well as the electron and ion fluxes maintaining it. To demonstrate the feasibility and the potential of our approach we present numerical results for collisionless double layers at silicon and silicon dioxide surfaces in contact with a hydrogen plasma.

The basic electronic response of a plasma-facing solid is the formation of the plasma sheath. It is the positive part of an electric double layer whose negative part is inside the solid. A stationary sheath develops if electron-ion generation in the plasma is balanced by electron and ion losses at or inside the wall. A complete kinetic modelling of the sheath has thus to contain not only the plasma physics of the positive part of the double layer but also the solid state physics of the negative part.

For a dielectric wall we developed such a synergetic approach [1] which we expect to be particularly useful for integrated microdischarges [2,3], in particular, when their miniaturization continues making thereby the length and time scales of the gaseous discharge comparable with the scales of the confining wall. Our approach is based on the Poisson equation and two sets of Boltzmann equations operating in disjunct half-spaces separated by a planar interface. One set is for electrons and ions inside the plasma and the other is for conduction band electrons and valence band holes inside the wall. The two sets are connected by quantum-mechanical matching conditions for the electron distribution functions, a semi-empirical model for hole injection due to neutralization of ions at the interface, and the matching conditions for the electric potential. Essential for the modelling is the merging of the space charge region with the neutral bulk plasma and the intrinsic or extrinsic bulk of the wall as well as the ambipolarity inside the wall leading to an electron-hole recombination condition.

The overall picture emerging from our kinetic modelling is a double layer whose positive space charge on the plasma side is balanced by a thermalized/trapped negative space charge inside the wall while the quasi-stationary electron and ion fluxes maintaining the double layer are limited by electron-hole recombination inside the wall. Numerical results for collisionless double layers formed at intrinsic and extrinsic silicon and silicon dioxide surfaces exposed to a hydrogen plasma (see Fig. 1 for the plasma-induced band bending in intrinsic silicon dioxide and silicon) show the feasibility and potential of our approach. Issues to be resolved before it can become quantitative for realistic interfaces will be discussed. – Supported by DFG through CRC/Transregio TRR24.

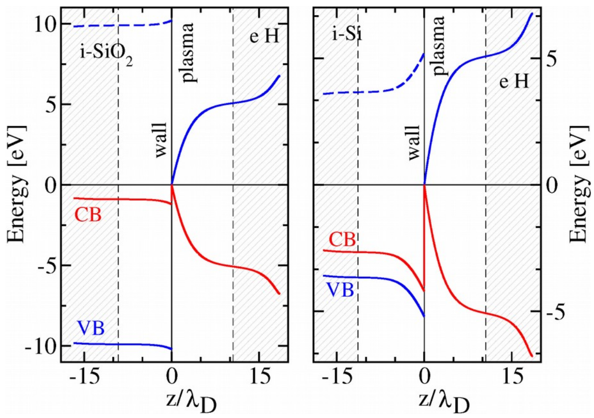

FIG. 1: Band edges for intrinsic silicon dioxide (left panel) and intrinsic silicon (right panel) in contact with a hydrogen plasma [1]. Inside the wall solid red (blue) curves are the edges of the conduction (valence) band while in front of it the curves give the potential energy of the electrons (ions). Dashed blue curves indicate the edges for the valence band holes. The distances from the interface at z=0 are measured in units of the wall's (plasma's) electron Debye screening length. The profiles inside the light grey regions have no direct physical meaning. They arise from implementing technically the physical boundary conditions for the double layer responsible for the band bending. The electron (ion) temperature of the plasma is 2 eV (0.2 eV).

References

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[3] M.K. Kulsreshath et al., J. Phys. D: Appl. Phys. **45** (2012) 285202.