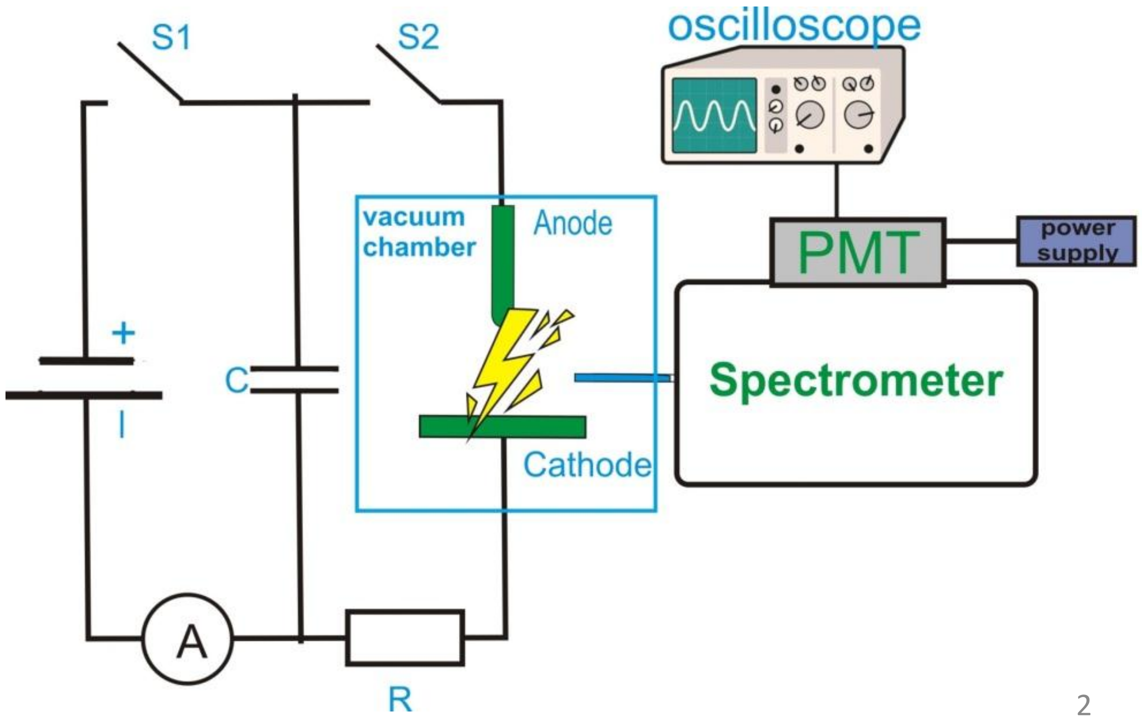
# Optical spectroscopy of breakdowns

08-10-2013 Profatilova Iaroslava,
Breakdown meeting

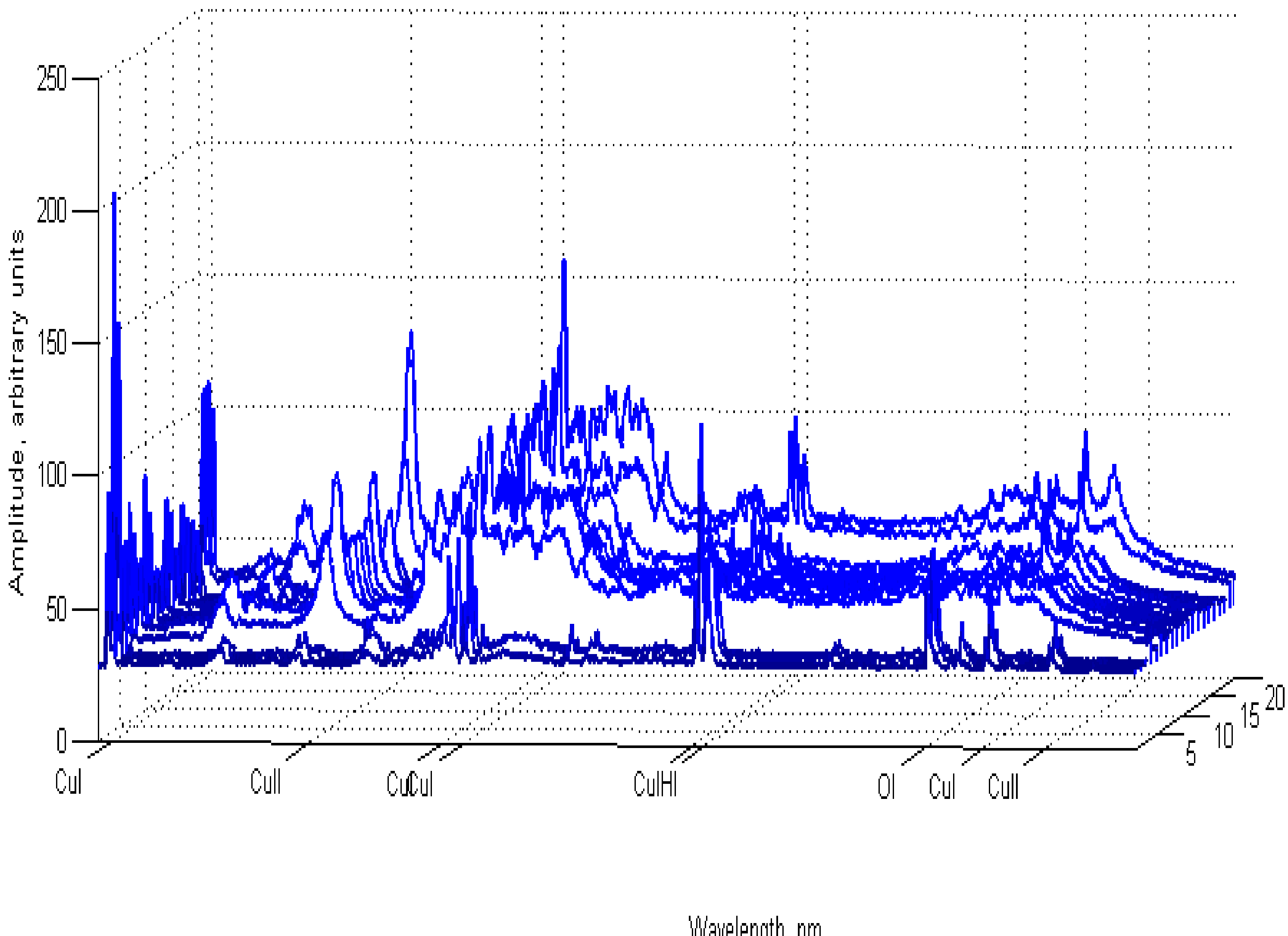
# Ability of DC-breakdowns optical spectroscopy

1. Qualitative analysis (composition and impurities).

2. Plasma diagnostics.



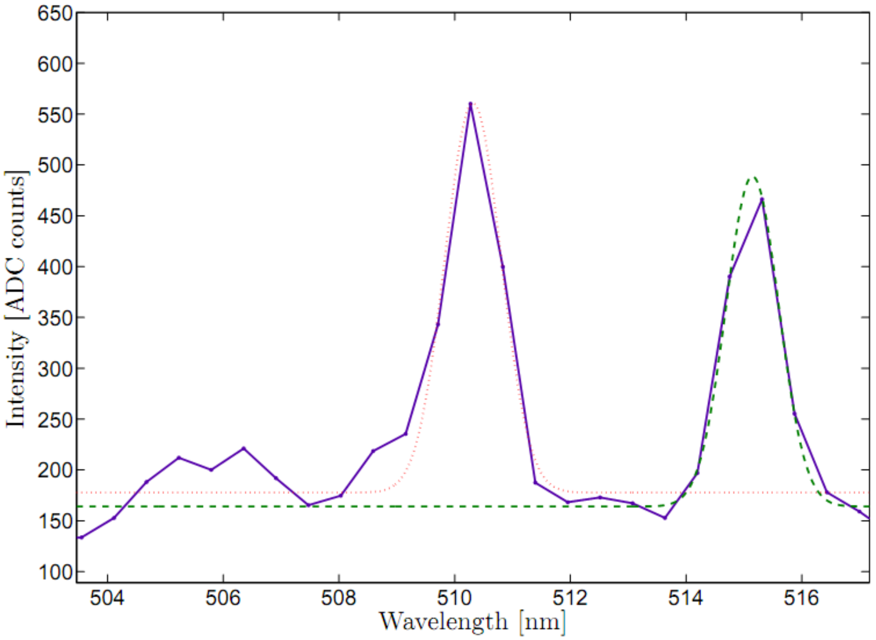
# Qualitative analysis



# Diagnostics of plasma parameters

For plasma in LTE we could use a two-line methods for calculate:

→ Electron temperature $T_e$;
→ electron density $n_e$;
→ plasma conductivity $\sigma_{dc}$.



# For Plasma in LTE:

- Maxwell Distribution: $$\mathrm{d}n_e = 4\pi n_e \left(\frac{m}{2\pi k T_e}\right)^{\frac{3}{2}} e^{-\frac{m v_e^2}{2kT_e}} v_e^2 \,\mathrm{d}v_e$$
- Boltzmann Distribution: $$n_i = n_0 g_i A e^{-\frac{E_i}{kT}}$$
- The Saha's Ionization Equation: $$\frac{n_e^2}{n_g - n_e} = A' T_e^{\frac{3}{2}} e^{-\frac{E_i}{kT_e}}$$

There is equilibrium in a weak radiation field, where T from the Maxwell distribution is equal to the temperature T from Saha ionization equation. This is the so-called plasma in local thermodynamic equilibrium (LTE)

# Boltzmann plot method for T

For plasma in LTE, the energy level populations of the species are given by the Boltzmann distribution law:

$$ln\left(\frac{I\lambda}{gA}\right) = -\frac{E_u}{k_B T} + const. = -aE_u + b$$

$$\frac{I_a}{I_b} = \frac{g_a A_a \lambda_b}{g_b A_b \lambda_a} \exp\left[-\left(\frac{E_a - E_b}{kT_e}\right)\right]$$

$$T_e = -\left(\frac{E_a - E_b}{k}\right)\left[\ln \frac{I_a g_b A_b \lambda_a}{I_b g_a A_a \lambda_b}\right]^{-1}$$

For each line, the wavelength λ, the intensity I, the oscillator's strength f, the statistical weight of the lower level g and the energy of the upper level Eu have each to be measured or be obtained from literature.

# Calculation T

| | Wavelength (nm) | Upper level energy (eV) | Lower level energy (eV) | Upper level degeneracy | Transition probability,s^(-1) |
|---|---|---|---|---|---|
| CuI | 465,11 | 7,74 | 5,072 | 8 | 3,80E+07 |
| CuI | 510,55 | 3,817 | 1,389 | 4 | 2,00E+06 |
| CuI | 515,32 | 6,191 | 3,786 | 4 | 6,00E+07 |
| CuI | 521,82 | 6,192 | 3,817 | 6 | 7,50E+07 |
| CuI | 578,21 | 3,786 | 1,642 | 2 | 1,65E+07 |
| CuII | 268,93 | 13,392 | 8,783 | 7 | 4,10E+07 |
| CuII | 271,35 | 13,432 | 8,864 | 5 | 6,80E+07 |

$$T_1\ (510.55; 515{,}32) = 7624\ K$$
$$T_2(510.55; 521.82) = 7798\ \mathrm{K}$$
$$T_3(521.85; 578{,}21) = 12\ 013\ \mathrm{K}$$

# Saha-Boltzmann equation method for $n_e$

- The electron density using atom and ion spectral lines emitted from the plasma is determined from the Saha-Boltzmann equation as:

$$n_{\rm e} = \frac{I_Z^*}{I_{Z+1}^*} 6.04 \times 10^{21} (T)^{3/2} \times \exp[(-E_{k,Z+1} + E_{k,Z} - \chi_Z)/k_{\rm B}T] \ {\rm cm}^{-3}$$

- where $I_Z^* = I_Z \lambda_{ki,Z} / g_{k,Z} A_{ki,Z}$ and $\chi_Z$ is the ionization energy of the species in the ionization stage Z.

# Plasma conductivity

- RF plasma conductivity

$$\sigma_p = \frac{e^2 n_e}{m(\nu_m + j\omega)}$$

- DC plasma conductivity $(\omega \ll \nu_m)$

$$\boxed{\sigma_{\mathrm{dc}} = \frac{e^2 n_e}{m\nu_m}}$$

# Thermal Desorption Spectroscopy at IAP NASU

The sample was heated at 300°C for 10 minutes for hydrogen removing from surface. Extraction of hydrogen from the sample was held at 1000°C for 10 minutes. The percentage of hydrogen atoms in the copper samples was determined by chromatograph.


| The number of sample | Sample origin | The number of hydrogen atoms in copper, % |
|---|---|---|
| № 1 | standard electrochemical copper, IAP NASU | $4 \cdot 10^{-5}$ |
| № 2 | standard electrochemical copper, IAP NASU | $3.4 \cdot 10^{-5}$ |
| № 3 | only etching, CERN | $5.7 \cdot 10^{-5}$ |
| № 4 | brazing coupler, CERN | $2.1 \cdot 10^{-4}$ |