Determination of the EEDF by Continuum Emission Spectrum Analysis: Preliminary Results

Thijs van der Gaag(M2), Hiroshi Onishi(M2), Hiroshi Akatsuka
Tokyo Institute of Technology
E-mail: van.t.ab@m.titech.ac.jp

For plasma models or calculations that require the Electron Energy Distribution Function (EEDF), currently only static models or experimental data are available. It is desirable to be able to calculate the EEDF for any given plasma parameters without intrusive measurements. The software presented here uses the continuum emission spectrum to calculate the EEDF, which is applicable to atmospheric-pressure non-equilibrium discharge argon plasma.

The continuum emission spectrum of argon plasma is dominated by e-a bremsstrahlung [1]. Using the formulation of e-a bremsstrahlung from [1] and substituting photon energy $\phi = h\nu = \frac{hc}{\lambda}$, (1) is obtained. This is a Volterra integral of the first kind with kernel $R(\phi, E)$ in (2), where constant C_{ea} is given in (4). Q_{ea}^{mom} from (3) has unit ^{2}[1]. Here n_e and n_a are the electron and atom number density. Due to the complexity of the kernel, conventional solving methods for a first kind Volterra integral have not been successful. Instead, a genetic algorithm has been selected to determine the EEDF.

In a genetic algorithm, a large number of solutions to the problem are proposed. Establishing the fitness function is most important since this function determines how well a proposed solution actually solves the problem. Even though the real solution is unknown, often some relations regarding the solution can be formulated. For example, it is known that the EEDF behaves like a probability density function and that no electrons have a negative energy. As such, (5) can be established with its lower limit equal to zero. This relation and others can be combined into one fitness function.

$$\epsilon_{ea} = \int_{\phi}^{\infty} R(\phi, E) f(E) dE \tag{1}$$

$$R(\phi, E) = C_{ea} Q_{ea}^{mom}(E) \phi^2 \left(E - \frac{\phi}{2}\right) \sqrt{E - \phi} \tag{2}$$

$$Q_{ea}^{mom}(E) = 8.05 e^{-28.024E} + 0.99 E^{1.743} e^{-0.136E} \tag{3}$$

$$C_{ea} = \frac{2^{\frac{3}{2}} \alpha n_e n_a}{3\pi^2 h c^3} \quad (4) \qquad \int_0^{\infty} f(E) dE = 1 \quad (5)$$

In Figure 1, the results of the genetic algorithm in its current state are shown. The input data is calculated with (1) using the Maxwell EEDF with $T_e = 0.5$ eV, where n_e and n_a are 5.00×10^9 m^{-3} and 3.40×10^{11} m^{-3} respectively. It can be seen that after seven iterations, the Maxwellian EEPF and the algorithm results clearly start to resemble each other. Furthermore, comparing the difference between the two EEPF and the difference between the emissivity functions shows that the emissivity calculation is coherent with the change in EEPF.

The final fitness value of this function (which ranges from 0 to 1, where 1 corresponds to a perfect solution) is 0.031. Given more time, the algorithm can obtain solutions with much higher accuracy. However, due to the non-optimized, non-finalized state at the moment of producing these results, it is considered sufficient to show that the algorithm is capable of closely converging to a Maxwellian EEPF, given that the Maxwell distribution is the real solution in this case.

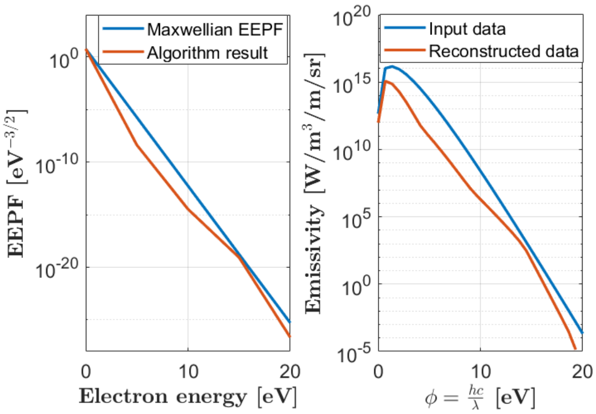

Figure 1: Genetic algorithm results (final function fitness = 0.031 at the seventh iteration). The input emissivity data is calculated using the Maxwell EEDF

At this point, it is not yet responsible to draw any solid conclusion. The algorithm is clearly not finished yet and the results are not of desired quality nor rigidity. All that can be concluded is that so far the accurate and correct determination of the EEDF using a genetic algorithm without additional assumptions seems to be possible. A more conclusive conclusion and finalized results will be presented at a later time.

In future work, after finishing the presented algorithm the focus will be on verification of the algorithm results by for example probe measurements. Furthermore, the flexibility and applicability will be tested in different situations (pressure, gas, temperature, ionization degree etc...). Since the EEDF is a very general function for each type of plasma, the algorithm results should be verified for a wide variety of plasmas before considering it to be correct.

[1] Sanghoo Park *et al.* Appl. Phys. Lett. **104** (2014), p. 084103.