Stark broadening method of Hydrogen Balmer beta for low-density atmospheric pressure discharges

Nikola Cvetanović[1] and Bratislav M. Obradović[2]

[1]Faculty of Transport and Traffic Engineering, 11000 Belgrade, Serbia
E-mail: nikola@ff.bg.ac.rs
[2]University of Belgrade, Faculty of Physics, 11001 Belgrade, Serbia

In recent years there has been a growing demand for measuring the electron density in atmospheric pressure discharges suitable for application. Such data is crucial for modeling and reactor optimization. These discharges include volume dielectric barrier discharges, surface barrier discharges, low temperature plasma jets, RF discharges with bare electrodes or covered by dielectric. However, here measurement of plasma density using spectroscopic methods poses a difficult task, since all such plasma is of low to mid density. Therefore, the nonhydrogenic atomic lines spectra cannot be used and the only option are the hydrogen lines, mostly Balmer beta and gamma. Fortunately, in atmospheric pressure plasma hydrogen is always present in traces, and Balmer lines are strong enough to be employed, see for example Cvetanović et al. 2018.

The H_β line is commonly used to obtain electron density due to its advantages of strong Stark broadening dependence on electron density, and weak sensitivity to electron temperature. However, its broadening can only be applied in the case of considerably high electron density ($>10^{20}$ m^{-3}) making it difficult to apply to many types of low temperature plasma, N. Konjević et al. 2012. Using the classical Voight fit below this value may lead to significant error and uncertainty. Therefore, a fine-structure fitting method must be applied to get more accurate results. This fitting method is based on assuming that the broadening mechanism of H_β line also applies to the 7 fine-structure components. This method has been used by Hoffman et al. 2011, to analyze the electron density in atmospheric pressure RF plasma jet. Palomares et al. 2012 experimentally validated the applicable range of this method down to $6{\cdot}10^{18}$ m^{-3} by comparing it to an independent method - Thomson scattering.

In the fine-structure fitting, Stark broadening is calculated by assigning a Voigt shape to each fine component. The overall profile is then analyzed by convoluting separate fine structure transitions of H_β as line profiles, with relative line strengths and line shifts being the same as in the zero-field case. Due to the low plasma density, this may be taken as a valid assumption. In other words, each fine-structure transition is assigned with its corresponding Doppler, Van der Waals, Stark broadening, and instrumental broadening so that the overall profile is obtained as a superposition of profiles. In this approach, the same Stark width which is expected from theory for the entire line, is assigned to each fine-structure component. The fine-structure fitting can be used to improve the accuracy of electron density calculation close to the threshold of classical method, but above all for checking the validity of the obtained results for plasma density in the conditions when Van der Waals broadening is below the fine-structure limit of 0.05 nm.

Examples of method application are shown in two experiments with atmospheric pressure helium discharges, Wang 2020. The fine-structure fit was compared with results from a simple Voigt fit.

References

Cvetanović N., Oleksandr G., Petr S., Zemánek M., Antonín B., Tomáš H., ,2018, Plasma Sources Sci. Technol. 27 025002

Hofmann S., van Gessel A. F. H., Verreycken T., and Bruggeman P., 2011, Plasma Sources Sci. Technol. 20, 065010

Konjević N., Ivković M., and Sakan N., 2012, Spectrochim. Acta Part B 76, 16

Palomares J. M., Hübner S., Carbone E. A. D., de Vries N., van Veldhuizen E. M., Sola A., Gamero A., and van der Mullen J. J. A. M., 2012, Spectrochim. Acta Part B 73, 39

Reader J., 2004, Appl. Spectrosc. 58, 1469

Wang L., Cvetanović N., Obradović B.M., Eusebiu-Rosini I., Dinescu G., C. Leys, A. Nikiforov, 2020, Jpn. J. Appl. Phys. 59 SHHB01