

A very large aperture spectrometer for low light optical emission spectroscopy

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Abstract. In low light experiments such as low temperature plasma or astronomical spectroscopy usual tools such as Czerny Turner based spectrometer (CTS) may have a limited efficiency due to the fact that a large entrance slit implies a large broadening of the instruments profile. To overcome the brightness issue of spectrometer, the so-called Bowen Chamber spectrometer (BCS) was designed to accept a large aperture slit, without significant deterioration of the spectrum. The BSC characteristics are presented and a close comparison with a CTS spectrometer is detailed. A simple geometrical model have been developed to still improve the BSC specifications.

1. Introduction

The Optical emission spectroscopy diagnostics have been widely used for many decades [1]. A simple experimental set up, composed of a spectrometer, can provide in-situ information regarding a light source from the electron, ion, neutral and metastable temperature and density [2]. Space and time resolved spectroscopy can be experimentally established readily with more care [3].

However, in low light experiments such as low temperature and low pressure plasma or astronomical spectroscopy usual tools such as Czerny Turner based spectrometer (CTS) may have a limited efficiency. The brightness limitation of the spectrometer is due, in the first place, to the fact that a large entrance slit aperture implies a large broadening of the spectrum. As a consequence most spectrometers are used with a maximum aperture of a few tens of micrometers to minimize the spectrum degradation, limiting in the same time the quantity of light entering the spectrometer.

Nevertheless, in the early seventies the CERCO (the French center for optical research and computation) designed the so-called Bowen Chamber spectrometer (BCS) under the supervision of Prof. A. Lesage from the “Observatoire de Meudon”. The spectrometer was built to obtain plasma spectrum in low light shock wave experiments where the plasma is observed during only a few millisecond. The data were used to establish the transition rate coefficient and the Stark broadening of atomic spectrum for metallic atoms and ions [4].

This paper propose to reevaluate the specificity of the Bowen chamber spectrometer in low light experiments or for fast imaging spectroscopy. The authors do not clam the paternity of the design but wants to fill in the lack of information regarding the BCS in the literature.

2. The CERCO’s Bowen Chamber spectrometer

The BCS was designed to collect a maximum of light, therefor it is characterized by a large numerical aperture of 0.294. The spectral dispersion and the magnification were experimentally measured at



respectively 2.344 nm/mm and 0.14. The BCS is composed of three stages as seen in Figure 1: the collimating optics, the dispersive system and the Bowen Chamber.

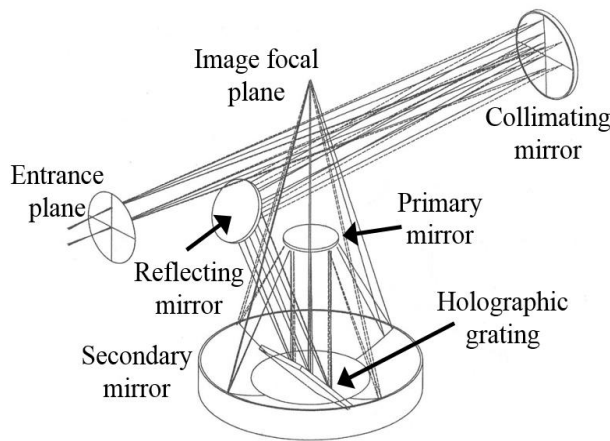


Figure 1. Schematic view of spectrometer showing the path of light throughout the BCS.

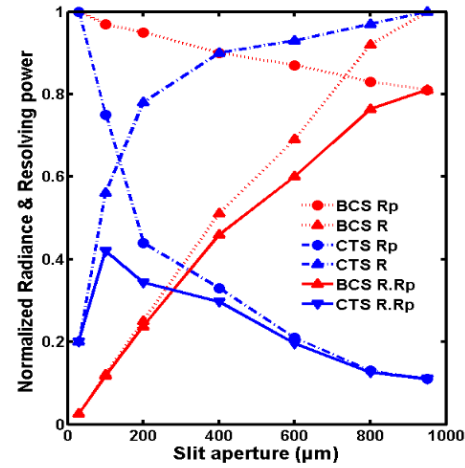


Figure 2. Comparison of the BCS and the CTS instrument profile for different slit aperture.

The collimating stage is composed of a micro-controlled entrance slit (ES) 60 mm wide. The slit opens symmetrically up to 1000 μm . Behind the ES a field lens gathers the light from the ES and direct it toward the collimating mirror. The collimating mirror has a focal length of 1300 mm. To reduce the size of the spectrometer a flat reflecting mirror guides the light toward the dispersive system. The second part of the spectrometer is composed of a holographic reflection grating of dimension 130x220 mm^2 . The grating used during the experiments has 2230 g/mm and is optimized for radiations in the range 500 to 600 nm. The last part is the so-called Bowen chamber, composed of two spherical mirrors. The primary mirror is convex and gathers the light dispersed by the grating and reflects it toward the secondary mirror. This mirror is concave and images the light at the focal plane of the Bowen chamber.

3. BCS versus CTS

To evaluate the BCS brightness and instrument profile (IP) we use a classical Czerny-Turner spectrometer of focal length 500 mm, $f/\# = 8.0$ with an holographic grating blazed à 500 nm and dimension 64x64 mm^2 . A He-Ne laser source at 632.8 nm has been used to provide a Dirac spectrum. The enlargement of the measured laser spectrum is assumed to be induced only by the IP of the spectrometer. Therefore, the determination of the full width at half maximum (FWHM) gives a direct access to the IP. The injection scheme and the detectors are strictly set in the same condition for both spectrometers. Experiments have established a resolving power of 0.15 nm and 0.18 nm respectively for the BCS and the CTS for an entrance slit of 30 μm . In the same condition the radiance is measured at 936.5 counts (cc) and 2560 cc respectively for the BCS and the CTS.

On Figure 2 is shown the evolution of the He-Ne spectrum normalized radiance and resolving power as a function of the entrance slit aperture from 30 to 950 μm . We see that the radiance profile of the CTS increases according to a saturation profile. On the other hand the BCS exhibits a linear radiance profile, from 30 μm up to 950 μm , where approximately doubling the ES aperture double the radiance. The resolving power profile point out the fact that the CTS quickly enlarges the He-Ne spectrum. For an ES aperture of 950 μm the spectrum is 90% larger than for an ES of 30 μm . The BCS presents a linear reduction of the resolving power with a maximum of 20% enlargement for an ES of 950 μm . As described in [5], the product of the normalized radiance and resolving power (R.Rp) indicates, when R.Rp reaches a maximum, the optimal slit aperture of a spectrometer. Figure 2 clearly shows that the CTS has an optimal slit aperture around 100 μm . Over this limit the gain in radiance does not justify the

loss in resolving power. However the BCS R.Rp product reveals no maximum showing without ambiguity that the optimal ES aperture is wider than 950 μm .

Finally the absolute brightness of the two spectrometers is compared by measuring the light intensity at the image focal plane as a function of the light emitted by a calibrated black body source. The spectrometers are set to limit the IP enlargement to a few per cent. Figure 3 indicates, on a log-log scale, that the BCS (red down triangle) is 8 to 10 times brighter than the CTS (blue up triangle).

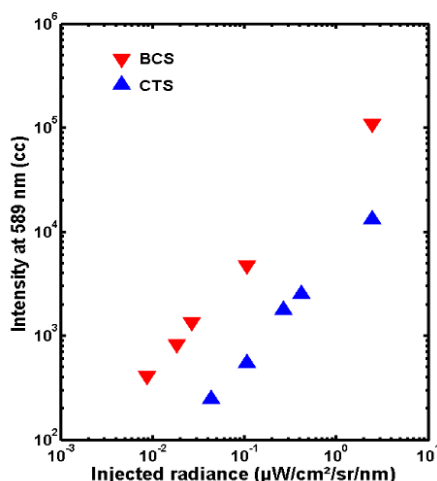


Figure 3. Absolute brightness comparison between the BCS and the CTS with a calibrated black body source. The spectrometers are set to optimise the spectral resolution.

4. Modelling and optimisation

Despite the brightness of the BCS attentive studies of the collimating stage have pointed out that a large part of the incoming light is lost during the collimating process. To optimize the light injection into the BCS a 3D geometrical ray tracing like model has been developed. Giving the optical characteristics of the different mirrors, the model gives information regarding the mirror position and dimensions. The model is able to quantify the light transmitted from the entrance slit to the image focal plane and gives insight regarding spherical and astigmatism aberration. This model is being used to design a new collimating stage for the actual Bowen chamber spectrometer.

5. Conclusion

The Bowen chamber spectrometer shows remarkable brightness due to its ability to work with a very large slit aperture up to 1000 μm . A 3D ray tracing model is in development to optimize the BCS and to guide us in the prototyping of a Bowen chamber based spectrometer with a reasonable size grating in order to provide a new powerful tool to spectroscopists.

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