## §12. Research and Development of High-Density Helicon Plasma Source with Very Small Diameter for Negative Ion NBI

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High power neutral beam injection (NBI) heating with negative ion sources has been actively executing in NIFS, utilizing an arc filament method. As to the advanced, future plasma source in NBI, one of critical issues is easier plasma production by an rf wave such as a helicon wave [1] with a high stability, high plasma density and high ionization. Here, helicon plasmas have been recently attracting much attention because of a flexible operation of the external parameters. It is also important to develop a small plasma source for unitization. In addition, a low magnetic field operation is desirable due to the small effect on the ion source as well as the small necessary power supply and light weight.

The present objective is to develop and characterize a very small diameter, high-density, helicon plasma source with a relatively low magnetic field by the use of the helicon wave scheme.

We have developed the Small Helicon Device (SHD) [2], as shown in Fig. 1: A stainless steel vacuum chamber has an inner diameter of 16.5 cm with an axial length of 86.5 cm, which is evacuated by a turbomolecular pump with a pumping speed of 200 l/s (base pressure is < $10^{-4}$ Pa). Two sets of magnetic field coils, made by ourselves, have windings of ~ 400 turns each, and can supply up to 0.086 T each for 30 A coil current. A diameter of plasma source part (quartz tube) can be easily changed, and a mass flow controller up (to 30 sccm) is installed (working gas is typically argon). Here, we have tried a helicon plasma production using a wide range of RF excitation frequency (7, 12, 50 and 70 MHz with an input power of less than 1 kW), considering the helicon wave dispersion relation and other production schemes. Here, a two-loop antenna is used. Plasma parameters are measured by Langmuir probes, and plasma light emissions are monitored by a monochromator.

In the case of 2 cm inner diameter tube, which is the smallest in the world in a helicon source category at that time, with a magnetic field of 0.057 T and 20 sccm flow rate, we could see a so-called density jump at RF power of 750 W (7 MHz excitation frequency): near the antenna region, a high-density of close to $10^{13}$ cm$^{-3}$ was obtained. Figure 2 shows an example of the electron density as a function of the axial position ($z$ = 0 mm means the position between a quartz tube and a vacuum chamber). Near the antenna, electron density is ~ $6 \times 10^{12}$ cm$^{-3}$, and it decreased along the axis (positive direction), especially in the vacuum chamber, where the divergent magnetic field is formed. In the case of 1 cm inner diameter tube, we could also have a high-density plasma production, and even with very low power less than a few tens of W, plasma production was possible with 50 and 70 MHz RF frequencies.

In conclusion, the smallest diameter (1 and 2 cm), high-density ($10^{12}$-$10^{13}$ cm$^{-3}$) helicon plasmas was successfully produced, developing the new device SHD. We will continue this development and characterization on very small diameter plasma with a high-density to be applied to the real ion source requirements.

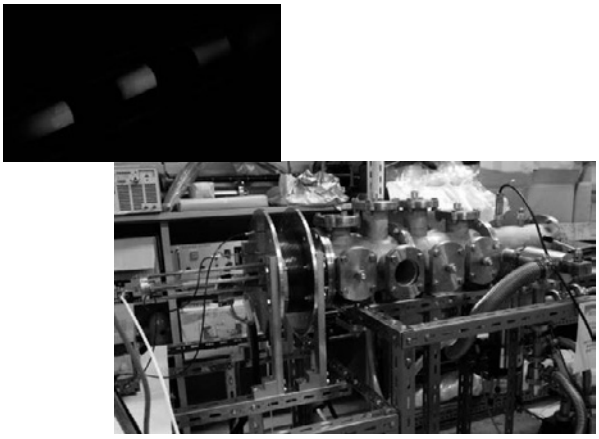

Fig. 1. (Top) Helicon plasma light near antenna, (bottom) Small Helicon Device (SHD).

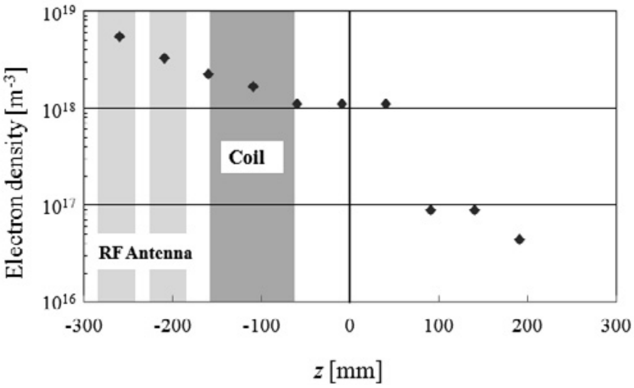


Fig. 2. Axial distribution of electron density.

1) S. Shinohara: Jpn. J. Appl. Phys. **36** (1997) 4695. **(Review Paper)**: S. Shinohara: J. Plasma Fusion Res. **78** (2002) 5. **(Review Paper)**: BUTSURI **64** (2009) 619. **(Review Paper)**
2) S. Shinohara *et al.*, Trans. Fusion Sci. Technol. (2013) in press.