5. Basic, Applied, and Innovative Research

FY2022 was a transition period in NIFS. Three projects were still conducted, although the NIFS collaboration categories were changed. The “Basic, Applied, and Innovative Research” category in FY2021 was included in “Interdisciplinary Fusion Science Research” in FY2022. In this section, we report highlights of collaborative research related to the basic, applied, and innovative research topics conducted in FY2022.

For basic plasma science, NIFS operates several experimental devices and offers opportunities to utilize them in a collaboration program for university researchers. A middle-size plasma experimental device the HYPER-I is available for basic plasma research. The compact electron beam ion trap (CoBIT) for spectroscopic study of highly charged ions, atmospheric-pressure plasma jet devices for basic study on plasma applications, and other equipment are all used for collaborations.

(I. Murakami)

Investigation of fine structure formation process of spectral line radiation during guide field reconnection in collaboration with NIFS spectroscopy database

Interpretation of the fine structure formation process of line-spectral emission is one of the major interests in plasma physics research. Both in astrophysical and laboratory plasmas such as in solar flares and merging spherical tokamak formation experiments, the line radiation profile typically forms a characteristic structure around the X-point where magnetic field lines reconnect. During the reconnection process, particles flow into the X-point region and are then ejected toward the downstream region. At the region of energy conversion, a plasmoid-like multiple blob structure is typically formed and such a structure tends to be referred to as evidence of plasmoid formation/ejection which contributes to acceleration of the reconnection speed (an open question of astrophysical plasma). Figure 1 is an example in laboratory plasma (TS-6: U-Tokyo reconnection experiment) under the influence of a high guide field. Around the X-point of magnetic reconnection, Ar II (480.6nm) spectral radiation forms two peaks around t = 475ms and the peak positions move from around r ~ 0.2m to the outflow direction and a flare-looptop like structure is formed at r ~ 0.1m downstream in the microsecond time scale. The detected structure apparently shows that there is a particle acceleration process from the X-point region (r ~ 0.2m) to the radial direction; however, spectral line radiation is not simply proportional to electron density. For the proper interpretation of complex line radiation, NIFS is an important leading institution with a sufficient spectroscopy database and we are running a practical collaboration to extract more information, such as electron density and temperature, by monitoring the evolution of multiple spectral line radiation [1].

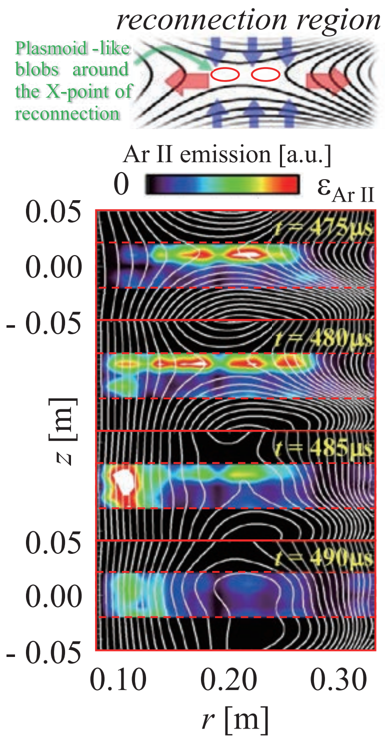

Fig. 1 Time evolution of 2D emission profiles of Ar II line spectrum (480.6nm) around the X-point of magnetic reconnection. At the region of where multiple plasmoids are expected to be formed, a blob-like structure is formed and the characteristic peaks are ejected to the outflow direction.

(H. Tanabe, Univ. of Tokyo)

Generalization for local oscillator integrated antenna array

Microwave diagnostics are key instruments for measuring electron density, electron temperature profiles, and their fluctuations in fusion plasma research. Our group has proposed an antenna array with an integrated local oscillator. This antenna array uses frequency multiplication and superheterodyne techniques to reduce the number of expensive waveguide transmission lines and elements, making it inexpensive and easy to install. We have developed antennas in the 24–80 GHz range [2]. However, when considering microwave measurements in higher-density plasma devices, antennas that can be used at higher frequencies are needed. Therefore, in FY2022, we developed antennas in the W-band (80–110 GHz), which is an even higher frequency band. Figure 2 shows the implementation area of the Monolithic Microwave IC (MMIC) of the W-band receiver, in which a W-band mixer and a W-band frequency multiplier are mounted. Figure 3 shows the conversion gain of the receiver measured using the W-band transmitter developed at the same time. Although the efficiency is not high, the sensitivity is sufficient to confirm that phase measurement is possible. Figure 4 shows an improved version with a transformer implemented at the mixer output, which will be evaluated in FY2023.

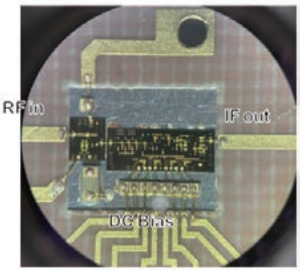

Fig. 2 MMIC board

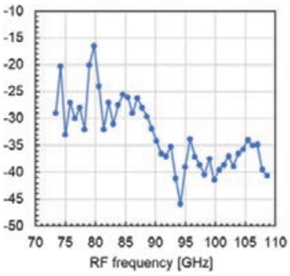

Fig. 3 Conversion loss

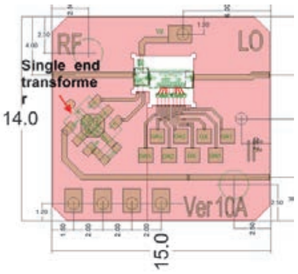

Fig. 4 Improved MMIC board

(D. Kuwahara, Chubu Univ.)

Development of Random Laser for Fusion Environment Measurement

Solid-state lasers generally have excellent temporal and spatial coherence, but when they are used for full-field imaging, they cause spatial intensity irregularities (speckles), which reduce imaging accuracy. On the other hand, a random laser using multiple scattering in irregular structures has low spatial coherence and high intensity, making it a suitable light source for full-field imaging. In this study, we aim to realize a mid-infrared wavelength random laser for full-field imaging of trace molecules such as hydrogen isotopes in water.

In the FY2022 research, prior to the development of mid-infrared random lasers, we aimed to develop ultraviolet random lasers using plasma surface modification of gallium nitride. Using a plasma irradiation system (Co-NAGDIS) for divertor simulation at Nagoya University, random, sub-micrometer-sized surface irregularity structures were successfully formed on a gallium nitride substrate. Emission measurements of the surface-modified samples were performed with 355 nm excitation using a microspectroscopic system at Hokkai Gakuen University. The measured spectra are shown in Figure 5. Band-edge emission of gallium nitride was observed from 360 to 380 nm, and as the excitation power was increased, a spike-shaped emission peak appeared around 365 nm. The intensity of this emission peak had a threshold, indicating that an ultraviolet random laser was emitted. The author has succeeded in obtaining a strong correlation with the oscillation properties by newly defining size parameters such as projected area and representative length. This achievement was published in an original paper in the first issue of ACS Applied Optical Materials, and a joint press release was issued by NIFS, Hokkai Gakuen University, and Nagoya University [3].

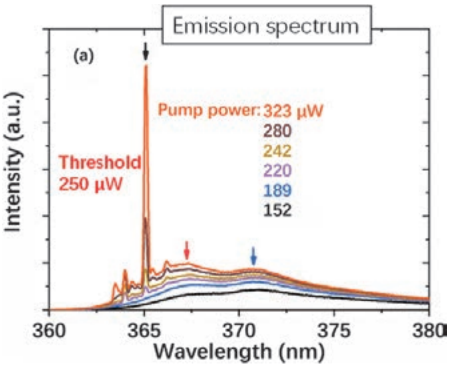

Fig. 5 Emission spectrum of gallium nitride after plasma surface modification.

(H. Fujiwara, Hokkai Gakuen Univ.)

[1] H. Tanabe *et al.*, “Ion heating/transport characteristics of merging startup plasma scenario in the TS-6 spherical tokamak”, 29th IAEA fusion energy conference (FEC2023), EX/P7-26 (2023).

[2] Y. Kondo *et al.*, J. Instrum. **17**, C05023 (2022).

[3] Q. Shi *et al.*, ACS Applied Optical Materials **1**, 412–420 (2023).