**Response to Referees‘ Comments on RSI: RSI25-AR-01434R**

Title: Optimization and Active Stabilization of a Far-Infrared Laser for NSTX-U High Poloidal WavenumberScattering Diagnostics

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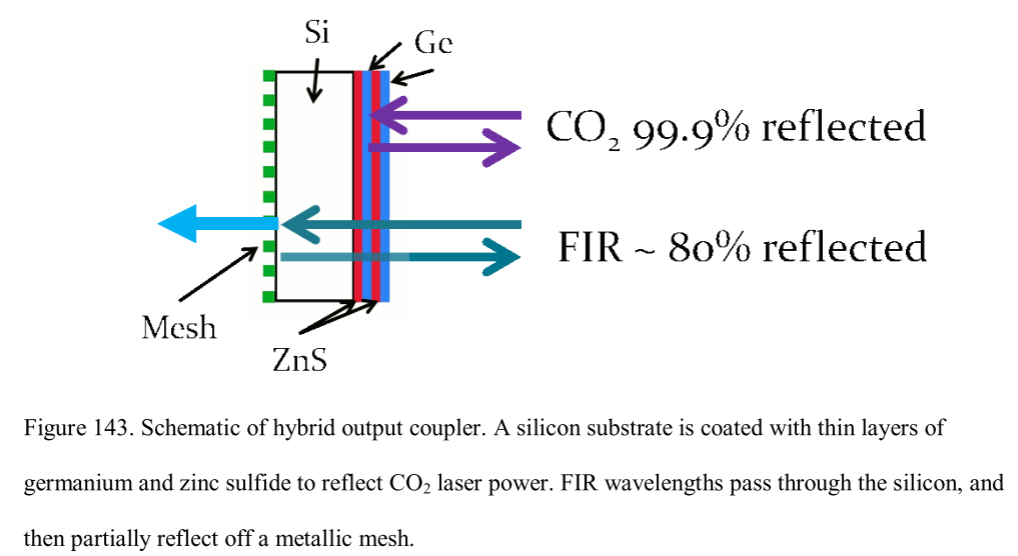
We very much appreciate the referees’ comments and suggestions which obviously improve the quality of our manuscript. The manuscript has been revised accordingly. Below, we have provided details on our response to the referees. *The text in blue is our reply*, and *the text in red is what is added/modified in the revision.*

**Reviewer: 1**

Comments to the Author

1. Page 3: "A dielectric-coated silicon wafer optimized for dual functionality, while achieving 98% transmission in the FIR range and reflecting 99% of the incident CO2 laser radiation". Please consider to give more information about the structure of this part of the laser as could be expected from a scientific instrument journal article.

Response: Thank you very much for your valuable comment. The detailed structure of the dielectric-coated silicon wafer is described in the doctoral thesis by Robert A. Barchfeld, “Development of Laser Based Plasma Diagnostics for Fusion Research on NSTX-U” (pp. 177–178), as shown below. The difference in the figure is that a mesh is placed behind the coated silicon wafer, which is used to reflect the FIR signal. Following your suggestion, we have now explicitly added a more detailed description in our manuscript. According to Barchfeld’s thesis, this multilayer coating enables the wafer to reflect 99% of the incident CO₂ radiation while transmitting ~98% of the FIR signal. Since the FIR transmission strongly depends on the wafer thickness due to coherence effects, in my own opinion, I am not quite agreeing with his results, but add here just for reference.

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The detailed description of this silicon wafer has been added in the paper (page3,2nd paragraph) as follows:

The silicon wafer is coated with thin layers of germanium and zinc sulfide, forming a high/low refractive index pair. Each layer has a thickness equal to one-quarter of the CO₂ laser wavelength in its respective medium, which enhances the reflection of the CO₂ laser. Meanwhile, the transmission in the FIR range is strongly influenced by the thickness of the silicon wafer due to coherence effects.

1. Page 4: In the first paragraph the feed-in description is not very clear. It seems that the 1m focal length lens focuses the beam through the input coupler, consisting in a metal mirror with a hole in the center but the sentence describes a lens for collimation. In figure 4, it is mentioned a "focus lens". This should be re-arranged in order to be more coherent. Another point is that the laser waveguide is not described: the material and dimensions are important to understand the system and to interpret the beam profiles presented later.

Response: Thank you very much for your comments. This focus lens is used to focus the beam size so the beam could shine into the center hole of the metal mirror.

I modified the first paragraph on page 4 as:

Inside the input window, as shown in Fig. 3, a rear mirror with a 4 mm-radius central aperture is positioned adjacent to the FIR input window. A focusing lens with a 1 m focal length is used to reduce the beam radius, creating a narrow waist near the input window. This allows the CO₂ beam to pass through the copper mirror via the central hole and then expand within the cavity. As illustrated in Fig. 3, the beam continues to expand during reflections between the two mirrors inside the cavity. This configuration enables controlled beam expansion within the FIR cavity while minimizing back-reflected power that could disrupt CO₂ laser stability.*”*

In addition, we have added a description of the waveguide cavity on page 3, second paragraph, and rephrased the sentence to avoid confusion:

These optical elements are housed within the FIR laser system, forming the complete resonant cavity structure in the laser cavity waveguide. The waveguide consists of a borosilicate tube approximately 62 inches long with an inner diameter of 38.1 mm (1.5 inches), surrounded by an outer water-cooling tube with a diameter of 2.375 inches to dissipate heat generated by the CO₂ laser.

1. Page 7: "...marked as # 1)". These sentences seem to refer to Fig. 7, please add "Fig. 7".

Response: Thank you very much for your comments. I have added the Fig.7 in the sentence.

1. Page 7: First paragraph: the dielectric-coated silicon wafer in the described again, please refer to the description of page 3.

Response: Thank you very much for your comments. I have referred to the description of page 3 for this sentence.

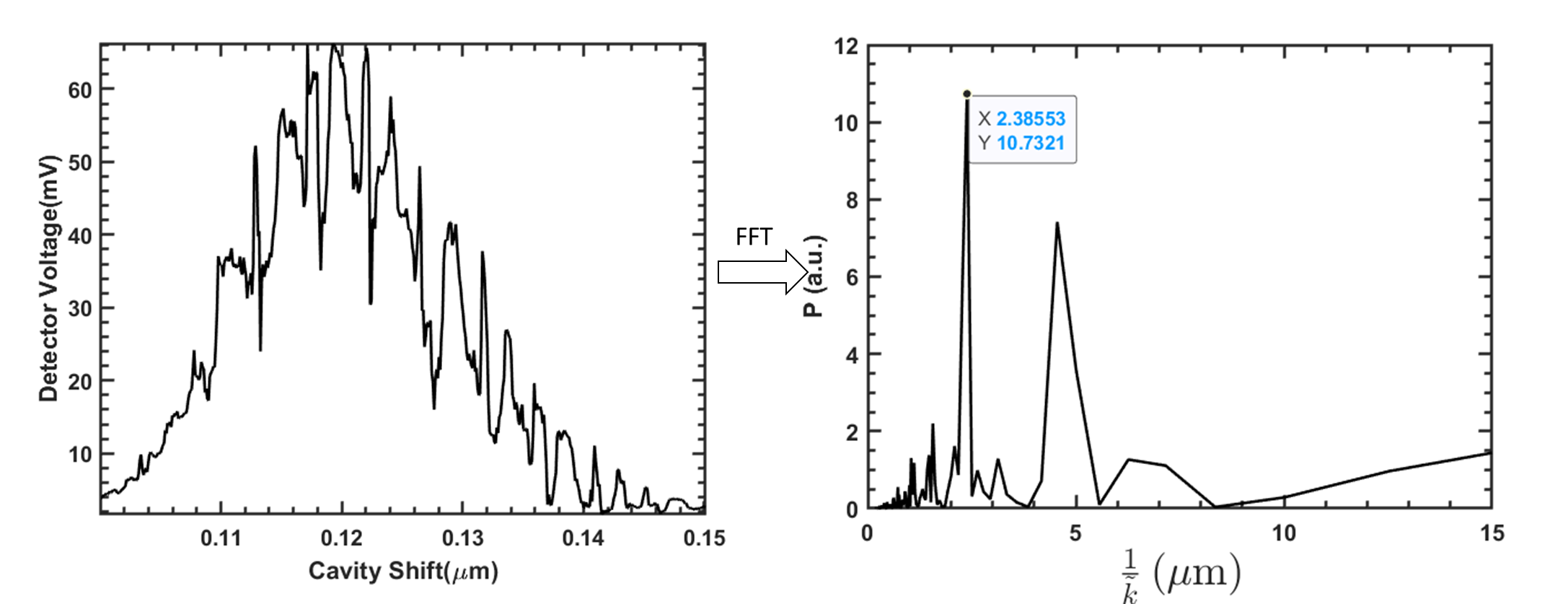
The front mirror (designated as # 2 in Fig. 7), which is also shown in Fig. 3, is used to couple the FIR and CO₂ wavelengths.

1. Page 11: First paragraph, some aspects like the feed-in system has already been described before. Third paragraph: "As demonstrated in Fig. 9, ": It seems that the sentence refers to Fig. 10.

Response: Thank you very much for your comments. We referred back to the feed-in system simply to summarize the work we have done to improve the coupling coefficient. Regarding the third paragraph, it actually refers to Fig. 10. We appreciate your careful reading and thank you for pointing that out!

1. Page 12: The figure obtained in figure 12 is clearly periodic with a FIR half-wavelength period as expected (upper figure). It is less obvious for the bottom figure, perphaps a Fourier transform could be used to visualize more clearly the different periodicities that are probably present. When the cavity length changes (which optics is really moving ?), it changes also the feedback to the CO2 laser changing potentially the pumping conditions. So the behavior could be more complicated than a simple Fabry-Perot cavity, more cavities can be involved.

Response Thank you for your insightful comments. We agree that the bottom figure in Fig. 12 shows less obvious periodicity. Applying a Fourier transform is indeed a good suggestion, and we have used this approach to better visualize the different periodicities present, as shown below, where  . After applying the FFT to the original signal, one clear peak is observed at , which agrees well with the theoretical value of .



In the original figure 12 on page 12, I mistakenly labeled the . The figure label has now been corrected as .

Regarding the cavity length changes, it is primarily the metallic mesh and front mirror (as shown in Fig.3, which both are on the translational optical platform) that moves, which also affects the feedback to the CO₂ laser and can modify the pumping conditions. In fact, the relationship between the pumping conditions and the resulting power performance is not fully understood. Each time the laser is turned on, we need to scan the cavity across different resonant conditions to identify the optimal position for the best performance.

I have added the description for the optics movement on page 3 at 2nd paragraph:

Both the metallic mesh and the front mirror are mounted on translational optical stages along the waveguide axis, allowing the cavity to be adjusted by moving the two optics using stepper motors.

1. page 13: "without compromising system performance": a few lines below, the authors mention that this improvement comes at the cost of reduced FIR power, it is not fully coherent. This part could be re-written to be more clear. It could be also mentioned that the increase of formic acid pressure increases the absorption of the pump beam and thus reduces the amplitude of the standing waves resulting in a smoother curve when the cavity length is scanned.

Response: Thank you for your valuable suggestion. We agree that this section was unclear and have revised it for clarity. The explanation has been modified as follows (page 14, first paragraph):

Increasing the formic acid pressure enhances the absorption of the pump beam, which reduces the amplitude of the standing waves and results in a smoother curve when the cavity length is scanned.

1. Page 17: A part of reference 24 is missing.

Response: Thank you for your reminding.

R. A. Barchfeld, Development of Laser Based Plasma Diagnostics for Fusion Research on NSTX-U. University of California, Davis, Doctoral dissertation (2017).

**Reviewer: 2**

Comments to the Author

1. The manuscript is mostly clear, but a few grammatical errors and awkward phrases could

benefit from proofreading. Examples: “Mythology” should be corrected to “Methodology” in the

author's contributions

Response: Thank you for your careful review and helpful comments. We have carefully proofread the manuscript and corrected the grammatical errors and awkward phrases. Specifically, “Mythology” has been corrected to “Methodology” in the author contributions section.

1. The power stability improvement after feedback activation is shown qualitatively, adding

RMS fluctuation or standard deviation values would strengthen the claim.

Response: Response: Thank you for your valuable suggestion. We have added the description as follows on page 14, second paragraph:

As shown in Fig. 14, without auto-adjustment, the output power decreases to zero within 4 minutes, whereas with auto-adjustment, the output remains in standard deviation values in 10% over an extended period.

1. The paper could be strengthened by comparing the proposed FIR laser system to other

diagnostic approaches (e.g., microwave or other laser-based systems) in terms of performance,

cost, or complexity. This would better highlight the system’s unique advantages

Response: Thank you for this valuable suggestion. We agree that including a comparison with other diagnostic approaches would strengthen the paper. In the revised manuscript, we have added a brief discussion comparing the proposed FIR laser system with microwave- and other laser-based systems in terms of performance to better highlight the unique advantages of our approach.

We have modified the sentence on page1 at 3rd paragraph:

This capability enables comprehensive coverage of the predicted electron temperature gradient (ETG) and other electron-scale turbulence spectra. Compared to millimeter-wave diagnostics such as the 270 GHz high-k scattering system, which benefits from a compact source, stable power, and ease of maintenance [1], laser-based diagnostics offer enhanced spatial resolution, a wider wavenumber range, and simplified optical alignment due to lower refraction effects[1,2].

[1]. Development and preliminary results of 270 GHz microwave forward scattering diagnostic system on the experimental advanced superconducting tokamak (EAST)

[2]. Microwave scattering system design for scale turbulence measurements on NSTX).

1. The font size of Fig. 9e is too small. Please replace it with a bigger font size.

Response: Thank you for this valuable suggestion. We have modified the figure with bigger font size.

