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Research of plasma multi-color imaging diagnosis based on metasurface

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Achieving core fuel replenishment while efficiently removing helium ash from the reaction region is one of the critical scientific issues that urgently need to be addressed for the operation of fusion reactors. Turbulent transport operation is the main part affecting plasma transport.For the problem of fuel feeding and ash discharge, the main approach is to address the particle transport differences between deuterium and tritium fuels and impurities such as helium ash. To achieve selective regulation of multiple particles, it is necessary to conduct in-depth research on the transport mechanism of multi-component turbulence. When the electrons of different particles in a fusion plasma undergo energy level transitions, they radiate spectral lines of specific wavelengths[1]. Therefore, the design and development of a multi-color imaging diagnostic system can obtain the evolutionary behavior of multi-component particles, and then analyze the transport characteristics of each particle.

However, traditional spectral diagnosis mainly relies on components such as spectroscopes and filters[2]. They not only lose a large amount of optical information, but also lead to limited spatiotemporal resolution. Optical metasurface technology, with its micro-structured, tunable, and fast-response characteristics[3,4], can precisely control the phase, amplitude, and polarization of incident light, offering a new approach to addressing this issue.

In this study, we are based on the connection between spectrum information and plasma parameters, the principle of simultaneous high spatiotemporal resolution diagnosis of plasma with different components is proposed by using wideband filter metasurface. A physical model matching the metasurface structure with the spectral diagnostic data is established. For linear devices, the radiation band of the common working gas is the visible light band. We designed the corresponding metasurface modulation unit. The spectrum resolution of the prototype is tested by numerical simulation, and the space-time and frequency distribution of plasma evolution is extracted. The feasibility of the diagnosis scheme is verified, which lays a theoretical foundation for the establishment of the follow-up experimental measurement system.

References

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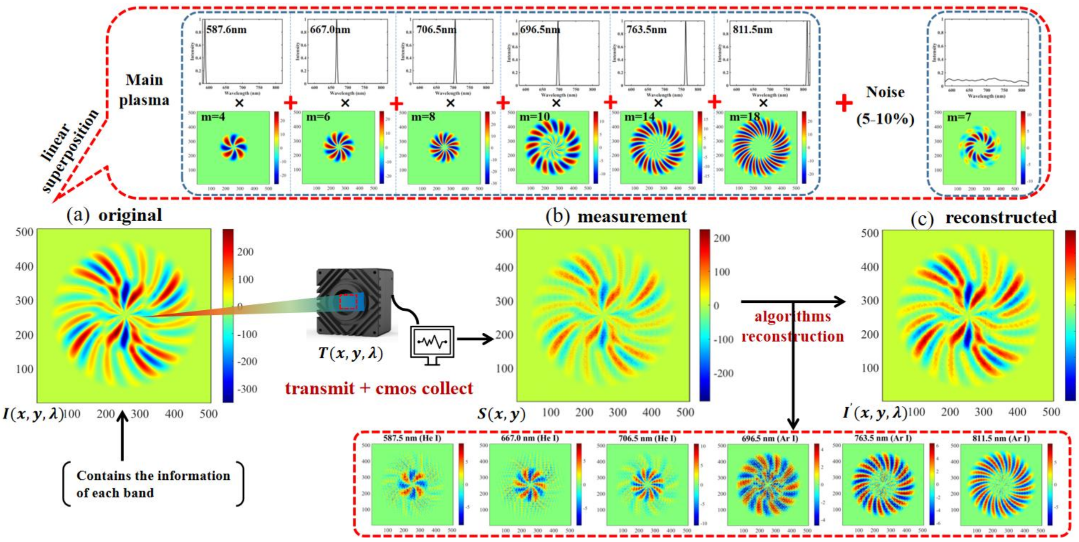

Figure1. Simulation results of MMI diagnosis system. (a) Input images of plasma evolution (relative intensity). (b)Intensity image of pixels in CMOS after the light to be measured passes through the metasurface array. (c) Plasma evolution image reconstructed by MMI system.