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CAVITY MIRROR DEVELOPMENT FOR OPTICAL ENHANCEMENT CAVITY OF STEADY-STATE MICROBUNCHING LIGHT SOURCE*

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Abstract

Optical enhancement cavity (OEC) provides the high intensity and high stability modulation laser field in steady-state microbunching (SSMB) light source. An SSMB extreme ultraviolet (EUV) light source targeted for lithography application is currently being developed at Tsinghua University, which demands for megawatt scale intra-cavity average power for OEC. Cavity mirrors are the key components of the OEC to realize its designed parameters. Here we report the development progress of the cavity mirrors.

ITRODUCTION

Steady-state microbunching (SSMB) mechanism was proposed by Chao and Ratner in 2010 [1], of which the key idea is to replace the microwave cavity in the storage ring to optical cavity, thus the micro-bunched longitudinal electron beam size can be reduced from millimeter scale to nanometer scale. So the electron radiation would be coherent for wavelength larger than nanometer scale. And the optical enhancement cavity (OEC) provides the high intensity and high stability modulation laser field in SSMB light source. Currently, an SSMB extreme ultraviolet (EUV) light source targeted for lithography application is being developed at Tsinghua University [2, 3]. A kilo-watt scale SSMB EUV light source demands for the OEC to have intra-cavity laser beam average power of mega-watt scale and laser stability if expressed in linewidth to be <10 kHz [4]. Translated to the demands for the key components of OEC - cavity mirrors, it would be high damage threshold of >10 MW/cm^2, ultra-low loss of reflectivity >99.999% and ultra-low absorption loss, scattering loss, transmission loss all at ppm scale. It can be told that this is a quite challenging group of parameters for the state-of-art mirror manufacturing technology. And cavity mirror damage is the bottleneck needs to be broken. If succeeded, these cavity mirrors can also play crucial roles in multiple important fields besides SSMB light source including gravitational wave detection [5], dark matter detection [6], electron transmission microscopy [7], fusion energy experiment [8] etc. In this paper, we will report the development progress of the cavity mirrors to meet the demands mentioned above.

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MEASUREMENT OF MIRROR REFLECTIVITY

As a reflectivity >99.999% is demanded for the cavity mirror, it is necessary to precisely measure the mirror reflectivity before the destructive mirror damage mechanism study experiment. As schematic layout shown in Fig. 1, cavity ring-down spectroscopy [9, 10] is setup for mirror reflectivity measurement. The measurement is separated into two major steps. First step, different from the layout shown in Fig. 1, the ring down cavity mirror M2 is put at input coupling position to form a two-mirror cavity with M1. Ring-down time τ of this two-mirror cavity is measured. It is related to the reflectivities of the two cavity mirrors as [11]:

$$\tau = \frac{L}{\left[\alpha L - \frac{1}{2} ln(R_1 R_2) + \gamma\right] \cdot c}, \tag{1}$$

in which L is the two-mirror cavity round-trip length; α is the intra-cavity absorption; R_1 and R_2 are the reflectivities of the two cavity mirrors; γ is the sum of all other losses except absorption including scattering, mirror diffraction loss etc.; c is the speed of light. Then the second step is to put the mirrors as shown in Fig. 1. Ring-down time of this three-mirror cavity τ' can be expressed as [11]:

$$\tau' = \frac{L'}{\left[\alpha L' - \frac{1}{2} ln(R_1 R_2 R_x^2) + \gamma\right] \cdot c}, \tag{2}$$

in which L' is the three-mirror cavity round-trip length, R_x is the reflectivity of the sample mirror to be measured. To ignore all the losses, we can derive the relation between R_x and the two ring-down time [11]:

$$R_x = exp\left(\frac{L}{\tau c} - \frac{L'}{\tau' c}\right). \tag{3}$$

Based on equation above, we successfully checked sample mirror reflectivity reaching 99.999% with an absolute precision of ±1.2 ppm.

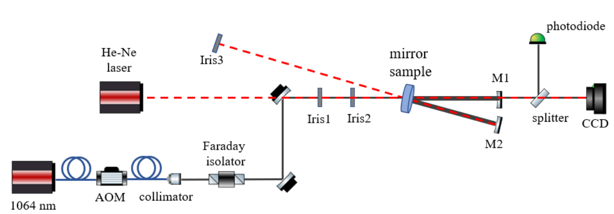

Figure 1: Schematic layout of mirror reflectivity measurement by cavity ring-down spectroscopy.

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STUDY OF MIRROR DAMAGE MECHANISM

For experimental study of mirror damage mechanism and quantitatively measure the damage threshold of sample mirror, we are constructing an experimental mirror damage test platform as schematically shown in Fig. 2. An IPG laser with wavelength of 1070 nm and average power up to 6 kW is implemented to be focused on sample mirror surface reaching continuous-wave power density >10 MW/cm^2.

Multiple online diagnostics are planned to be implemented including: thermometer to monitor the mirror surface temperature; imaging system to monitor the mirror surface deformation; power meter to monitor mirror reflectivity change; photodiode to measure laser scattering signal.

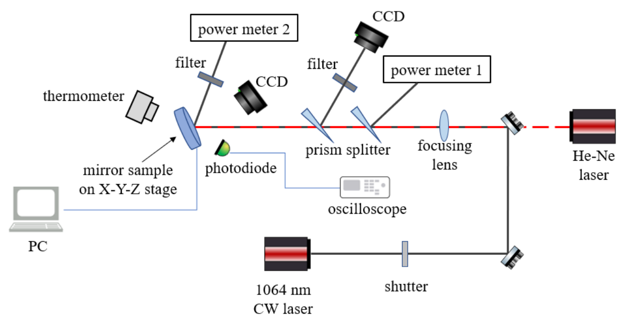

Figure 2: Schematic layout of mirror damage mechanism study experiment.

Preliminary mirror damage study experiment had been carried out, and on-mirror power density is estimated to reach >10 MW/cm^2. Mirror damage was imaged with optical microscope and atomic force microscope as respectfully shown in Fig. 3 and 4. Typical thermal effect induced damage morphology can be observed. Yet more data need to be collected to perform systematical mirror damage mechanism analysis, with the further goal of providing optimization advices for mirror substrate and coating manufacturer.

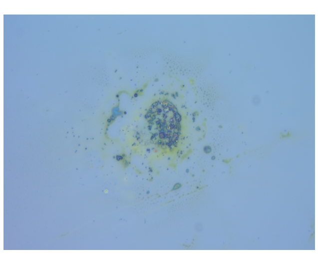

Figure 3: Mirror damage imaged with optical microscope.

SUMMARY

To meet the demands of mega-watt scale high-stability OEC to be used in SSMB EUV light source, series studies for developing cavity mirror the key component of OEC have been carried out. Cavity ring-down spectroscopy has been performed to measure sample mirror reflectivity of more than 99.999% with an absolute precision of ±1.2 ppm. Laser-induced mirror damage test platform has been constructed and preliminary experiment has been carried out with typical thermal effect induced mirror damage morphology observed with optical microscope and atomic force microscope. More data need to be collected to perform systematically study of laser-induced mirror damage mechanism to help optimise cavity mirror manufacturing technology.

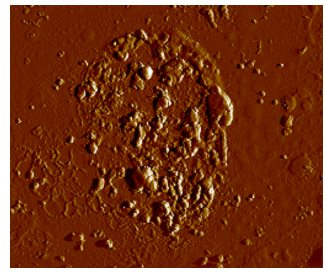

Figure 4: Mirror damage imaged with atomic force microscope.

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