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Development of a gaseous spectral filter for mitigating 10.6 µm radiation in CO_2 LPP EUV sources

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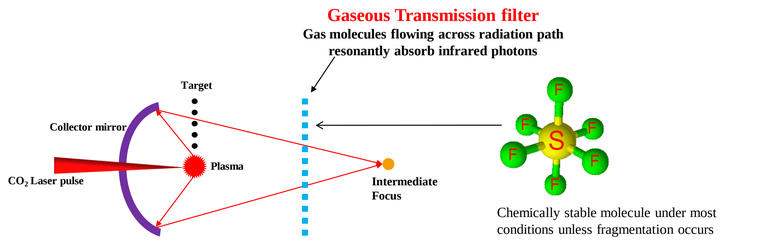
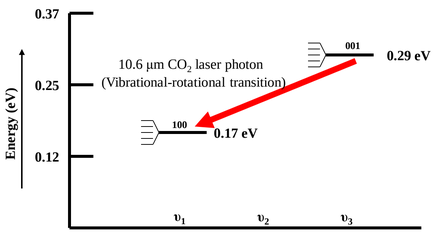
Introduction

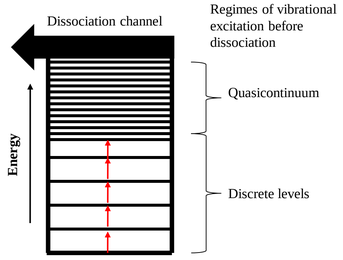
- One of the concerns of using CO_2 lasers as the drive laser for generating EUV radiation from a tin target fuel is that the spectrum from the plasma region of the CO_2 LPP source is dominated by the infrared radiation from the CO_2 drive laser (10.6 µm wavelength).[1]
- The reflectivity of the collector optics at 10.6 µm is over 90%, hence most of the infrared radiation incident on the collector optic is reflected toward the intermediate focus(IF).[2]
- The heating effect of the infrared radiation causes thermal deformation of the optical components beyond the IF and creates overlay issues .[1,3] Spectral filters that can withstand the high heat load from the radiation at 10.6 µm with minimal EUV transmission losses are needed.
- This study was undertaken to explore the possibility of using gaseous species to absorb 10.6 µm light and reduce the number of infrared photons reaching the IF



Chemically stable molecule under most conditions unless fragmentation occurs



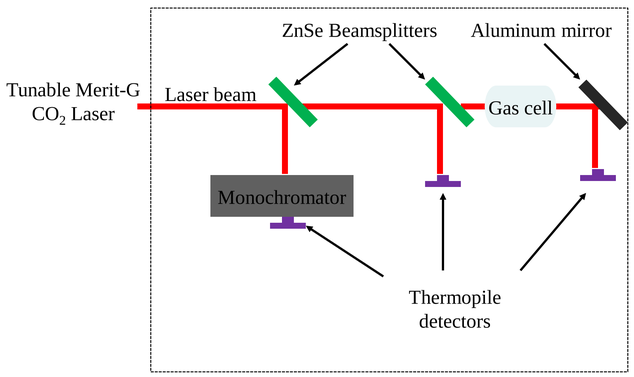
Laser transition between vibrational levels of the CO_2 molecule[7]



Simplified υ_3 vibrational mode energy diagram of SF_6 showing multiphoton excitation[6]

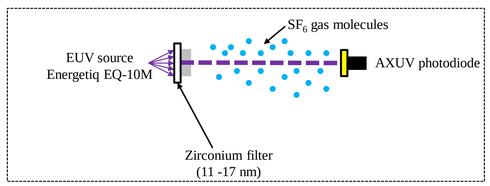
- Gas filters are less susceptible to damage, degradation and manufacturing process inconsistencies in contrast to conventional filters.
- The gas molecules are continuously replenished and the EUV transmission can be adjusted relatively easily by changing the pressure of the gas interacting with the incident radiation.
- The gas molecules can also help with trapping and mitigating debris migrating to IF.
- To minimize EUV attenuation, a low density of the gas molecules has to be used to interact with the incident beam.
- Absorption of infrared radiation by gases involves the interaction of the oscillating electric field of the incident radiation and the vibrating electric dipole of the molecule which results in an increase in vibrational energy of the molecule.[4]
- Sulfur hexafluoride (SF_6) has a υ_3 infrared active mode that interacts with photons from the CO_2 laser at 10.6 µm.
- Despite vibrational anharmonicity, splitting of higher energy levels of the vibrational ladder make multiphoton resonant absorption pathways possible[5] before potential fragmentation.
- The SF_6 molecule has an octahedral symmetric structure with 15 vibrational degrees of freedom.[4]

Experimental details



CO_2 laser enclosure

- Experimental configurations to determine
  - Maximum absorption cross section measured across the wavelength spectrum between 10.53 – 10.65 µm (CO_2 laser output wavelengths closest to 10.6 µm) at room temperature
  - Absorption cross section near EUV wavelength.

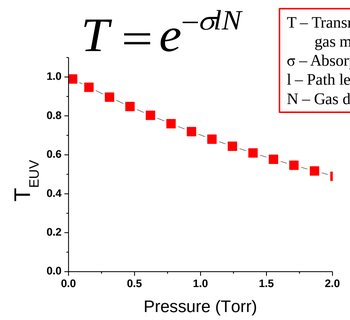


Results and discussion

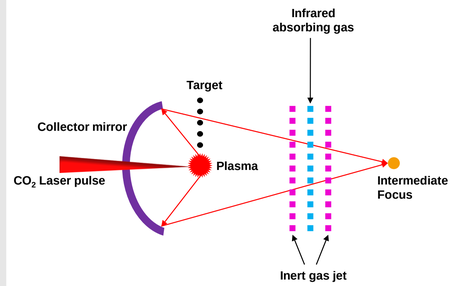
- The EUV transmission as a function of gas density, absorption cross section and path length can be estimated. To plot the transmission as a function of gas density, (T_{EUV} vs. Pressure), we assume the absorption cross section measured[8] from our experimental configuration and a path length of 1 cm. It is evident from the graph (T_{EUV} vs. Pressure) that the EUV transmission decreases with increase in gas density, hence the gas density allowed to interact with the radiation propagating to the IF has to be limited to avoid serious EUV attenuation.
- The amount of infrared energy absorbed also depends on the gas density interacting with the incident radiation among other factors but with an increase in energy absorbed at higher molecular density. The limitation in gas density to avoid serious EUV attenuation will potentially restrict the number of available molecules interacting with the infrared photons.
- Even though the maximum infrared absorption cross section measured was approximately 4X higher than the measured EUV absorption cross section, the absorption cross section of SF_6 molecules for CO_2 laser photons is temperature dependent and the maximum absorption cross section decreases as the amount of vibrational energy in the absorbing molecule increases.[9]
- As the number of photons absorbed by a molecule increases, so does the vibrational energy. Vibrational relaxation[10] of excited SF_6 molecules due to the absorption of infrared photons molecules can be enhanced by introducing an inert gas such as helium, that has a low EUV absorption cross section[11]. This will enable the absorption of more infrared photons and minimize fragmentation that occurs close to the absorption limit of SF_6 (approximately 33 photons).
- To avoid unwanted diffusion of SF_6 molecules to other regions of the EUV exposure tool, a jet of argon molecules can be used to collisionally restrict the lateral flow of SF_6 molecules. We are currently measuring the effectiveness of an argon jet to prevent the diffusion of SF_6 molecules by using a mass spectrometer in a custom vacuum system.

$$T = e^{-\sigma l N}$$

T – Transmission across the gas medium
σ – Absorption cross section
l – Path length
N – Gas density



Estimation of the EUV transmission as a function of pressure (assuming 1 cm path length)



Use of a gas jet to confine SF_6 molecules

Conclusions

- Suppression of infrared radiation (10.6 µm) from CO_2 LPP sources at the IF is critical to their use for generating EUV radiation needed for next generation lithography tools.
- Gaseous SF_6 is a strong absorber of infrared photons originating from the CO_2 laser and has the potential of mitigating some of the heat reaching the IF.
- The amount of heat mitigated by the gas depends on design parameters such as the gas density interacting with the incident radiation.

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