Gaseous spectral filters to mitigate infrared radiation

Chimaobi Mbanaso, Gregory Denbeaux, Frank Goodwin, Ady Hershcovitch, and Alin Antohe

Gas molecules that absorb infrared photons can reduce the incidence of out-of-band radiation at 10.6 μm in extreme ultraviolet exposure tools that use a carbon dioxide drive laser.

Extreme ultraviolet (EUV) lithography is a promising technology to print features 22 nm in dimension or less for the semiconductor industry. To generate the EUV light (13.5 nm wavelength) needed for this technology, a leading technique uses an infrared carbon dioxide (CO₂) laser pulse to ionize a target to produce a plasma. The spectrum of this laser-produced plasma is dominated by infrared radiation from the CO₂ drive laser (10.6 μm wavelength). Of this infrared radiation incident on the collector optics, over 90% is reflected towards the intermediate focus—the exit point for the light generated in the EUV source region. An issue with this technique is that infrared radiation heating causes thermal deformation of the optical components beyond the intermediate focus. Therefore, in EUV systems that include a CO₂ laser-produced plasma, spectral filters that can withstand high-heat loads with minimal EUV transmission loss are needed to mitigate 10.6 μm infrared radiation.

Recent proposals to tackle the reduction of the unwanted radiation included a grid filter, a low-infrared reflecting mirror, and a blazed-reflection grating. These structures show remarkable suppression of the infrared radiation at the intermediate focus. But EUV transmission loss resultant from their use continues to be a critical concern in these photon-limited exposure tools.

We are developing a system that uses infrared-absorbing gas to target the mitigation of the unwanted CO₂ laser light. A continuous flow of the gas across the path of the incident light absorbs the infrared photons at 10.6 μm wavelength: see Figure 1. Heat-load concerns and manufacturing inconsistencies, which affect some spectral filters, are largely avoided with this method.

Our work focuses on measuring the infrared absorption of gases with infrared-active vibrational modes that coincide with CO₂ laser lines near 10.6 μm: see Table 1. The ultimate goal is to maximize the absorption of infrared radiation with minimum EUV absorption. One gas of interest is sulfur hexafluoride (SF₆), which has an infrared active ν₃ vibrational mode that is resonantly excited by photons from the laser lines in Table 1. The infrared molecular excitation at each wavelength indicated is due to quantized transitions in the fundamental ν₃ band of SF₆.

Production of radical SF₆ fragments due to the incidence of high-energy EUV photons (92 eV per photon) in the immediate

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**Figure 1.** Configuration of CO₂ laser-produced plasma source with focusing collector mirrors and possible location of the infrared absorbing gas.

Continued on next page
vicinity of the optics may be undesirable due to potential damage. To address this concern, a method must be adapted to confine the interaction region of the SF₆ gas molecules and the incident radiation, while maintaining minimal EUV transmission losses. One possibility uses a jet of an inert gas to prevent SF₆ molecules from entering into the optics chamber. Inert gases such as helium, neon, and argon show greater than 90% EUV transmission and so are attractive options for this purpose. An improvement to this method uses a low-density plasma of the inert gas jet to enhance the confinement achieved. The use of a stabilized short-plasma arc to provide an obstruction to gas flow without any interfering solid structures has been demonstrated previously. This apparatus, known as a plasma window, has been used to separate two regions of different pressure, while allowing particle beams and radiation to be transmitted.

Hundreds of watts of infrared power are expected at the intermediate focus. Estimating what fraction of the heat energy can be dissipated by the infrared absorbing gas is critical to our research. Multiphoton absorption effects in SF₆, especially in the presence of buffer gases, may enhance the expected number of infrared photons absorbed. The rate of collisional-relaxation processes following photon absorption by SF₆ molecules plays a vital role in avoiding saturation.

A strategy to use an infrared absorbing gas to reduce the infrared radiation from CO₂ laser-produced plasma sources used for EUV lithography is promising. Preliminary experiments have confirmed the significant absorption of SF₆ across the CO₂ laser wavelengths compared to EUV light. Mass spectrometer measurements reveal that an argon plasma has a slightly better obstruction to the diffusion of SF₆ molecules than an argon-gas jet. In the future, we will focus on the design specifications of the spectral filter that will use an infrared absorbing gas to mitigate radiation at 10.6 μm in CO₂ laser-produced plasma EUV exposure tools.

Table 1. CO₂ laser wavelengths (λ) near 10.6 μm. P(X): The laser line originates from a quantized transition from vibrational sublevel X−1 to sublevel X.

<table>
<thead>
<tr>
<th>CO₂ laser line</th>
<th>λ(μm)</th>
<th>Wavenumber (cm⁻¹)</th>
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<tbody>
<tr>
<td>P(14)</td>
<td>10.53</td>
<td>949.48</td>
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<tr>
<td>P(24)</td>
<td>10.63</td>
<td>940.54</td>
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References

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