Laser wavelength effects on ionic and atomic emission from Sn plasmas.

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CMUXE Lab

- Center for Materials Under Extreme Environments.
- State-of-the-art material science facility IMPACT
  - AES, XPS, LEISS
  - RGAs
  - PHOIBOS HSA
- Multitude of plasma diagnostics
  - Optical Emission Spectroscopy
  - Nomarski Interferometry
  - Langmuir Probe
  - Faraday Cup analysis

For more information see website at https://engineering.purdue.edu/CMUXE/
Motivation

• Seeking light source at 13.5 nm for high-volume manufacturing EUV lithography.
• Laser produced plasmas have been proposed as light source
• Emit strongly in EUV range with UTA
• Neutral and ionic debris is a huge problem
• A thorough comparison of the ionic and atomic debris as well as the out-of-band emission characteristics of Nd:YAG and CO₂ LPPs
• This knowledge is essential for protecting the multilayer mirrors which reflect the EUV emissions from neutral and ionic bombardment as well as excessive heat-loading
Experimental setup - IMPACT

- IMPACT facility equipped with a multitude of diagnostics
- For these experiments we used X-ray excitation for XPS
Experimental Setup – LPP chamber

- CMUXE LPP chamber
- 0.5m Transmission Grating Spectrograph
- Coupled to ICCD and PMT
- Dove prism rotates plasma image for 2D spectral imaging
- Faraday Cup mounted at 17 cm from target at varying angles
- Si wafers placed at
Experimental Results - XPS

- Debris analysis using XPS.
- 1750 shots for CO$_2$, 700 shots for Nd:YAG.
- Interesting angular distribution: flat distribution close to target normal for CO$_2$.
Experimental results – FC (1)

- Used faraday cup to check ionic angular distribution
- Similar result
- Flat distribution close to target normal for CO$_2$

![Graph showing ion fluence vs. angle for Nd:YAG and CO$_2$ lasers]
Experimental Results - 2D spectral imaging

- See interesting features in spectra
- Considerably **more line emission** from Nd:YAG LPP
- **More continuum emission** from CO$_2$ LPP.
Experimental Results - OETOF

• Proceeded to conduct OETOF to understand the difference in line-propagation distance as well as continuum emission.

• By differentiating linear fits of the maximum probably TOFs we estimated the propagation velocities of both the neutral and singly-charged species.

• Notice: Sn I velocity is almost identical, but for Nd:YAG LPP Sn II velocity is significantly higher.

<table>
<thead>
<tr>
<th>Vel. cms⁻¹</th>
<th>Nd:YAG</th>
<th>CO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sn I</td>
<td>0.89x₁₀⁶</td>
<td>1.0x₁₀⁶</td>
</tr>
<tr>
<td>Sn II</td>
<td>2.0x₁₀⁶</td>
<td>1.4x₁₀⁶</td>
</tr>
</tbody>
</table>
Experimental results – FC (2)

- Energy distribution shows opposite result
- CO$_2$ debris has higher kinetic energy
- CO$_2$ debris also has narrower energy profile
Stark Broadening

- Here we can see that the Nd:YAG LPP is significantly more dense than the CO$_2$ LPP.
- The density of the plasma is directly proportional to the FWHM of the broadened emission line.
Discussion

• The brighter continuum emission from the CO$_2$ implies a higher population of free electrons
• Line emission from Sn in the optical regime originates from only Sn I and II
• To obtain more free electrons it is necessary to ionize target material. This implies a higher degree of average ionization in the case of the CO$_2$ LPP.
Discussion

• Moreover, the initial density of the Nd:YAG LPP is two orders of magnitude higher. This results in a significantly higher amount of 3-body recombination which is proportional to $\sim n_e^2$

$$R_c \propto Z^3 \ln \sqrt{Z^2 + 1} T_e^{-9/2} n_e^2 n_i$$

• 3-body recombination is the dominant mechanism for producing the lowly charged ions present in the plasma emission

• Therefore one must expect stronger line emission to persist farther away from the plasma which possesses the higher initial density
Discussions

• The difference in 3-body recombination rates also explains the disparity between the FC velocity profile and the velocity measured using OETOF.

• Because the plasma density is significantly higher for Nd:YAG at the onset and during the expansion, one expects the recombination to persist away from the target.

• However, the ions that undergo recombination farther away from the target have been accelerated by space charge effects.

• This is why the Nd:YAG LPP’s singly-charged debris travels faster than the CO$_2$ LPP’s singly-charged debris.
Conclusions

• Angular distributions of Sn plasmas debris are markedly different when the plasmas are produced by CO$_2$ and Nd:YAG excitation.
• The amount of debris emission is also markedly different from the LPPs based on their excitation wavelength.
• The discrepancy in debris populations is due to the large difference in initial plasma density.
• Furthermore the out-of-band emission characteristics are markedly different because of the discrepancy in recombination rates arising from the large difference in initial density.
• Finally, space-charge effects are responsible for the disparity between FC ion signals and OETOF analysis.