UNIVERSITé DE FRANCHE-COMTé

UBFC UNIVERSITÉ BOURGOGNE FRANCHE-COMTÉ

école doctorale **sciences pour l'ingénieur et microtechniques** SPIM

Titre de la thèse/Thesis title : Emission XUV de nanoplasmas induits par laser femtoseconde / XUV emission of ultrafast laser-induced nanoplasmas	
Laboratoire d'accueil / Host Laboratory : FEMTO-ST/ Optics Department	
Spécialité du doctorat préparé/Speciality : Optics and Photonics	
Mots-clefs / Keywords : laser-matter interaction, ultrafast pulses, shaped laser pulses, plasmas	

Descriptif détaillé de la thèse / Job description

The advancement of Extreme Ultraviolet (EUV) lithography relies on compact, high-brightness sources of EUV radiation. Currently, these sources are large-scale and complex, often requiring extensive installations with multiple CO_2 lasers focused onto a single micro-sphere of frozen water. This bulkiness presents a significant limitation, and the emission has no directional control.

This thesis builds on a decade of research into novel laser-matter interaction schemes using spatio-temporally shaped pulses in our group [1] for laser materials processing applications. When appropriately focused inside transparent solids, for instance using Bessel beams, femtosecond laser pulses can be absorbed via nonlinear ionization in extremely confined nano-plasmas with very high energy densities, which lead to the generation of Warm Dense Matter [2]. The confinement within nanoscale plasmas has been recently assessed by ultrafast pump-probe experiments [3,4]

Here, this thesis will explore the XUV emission of nano-plasma rods, generated through the irradiation of solid dielectrics with high-intensity shaped femtosecond laser pulses. Advanced Particle-In-Cell simulations from our group show that a fraction of the free-electrons in the plasma are highly accelerated, from eV to several keV around the critical plasma surface at which field amplification takes place [4,5]. This suggests that the laser-solid interaction will yield EUV emissions in a highly confined and controllable new scheme.

The initial phase of the research is to develop a setup capable of recording EUV emissions from laser-induced nanoplasmas. Then, the research will focus on identifying the key plasma control parameters that influence brightness, aiming for optimal spatial and temporal control. Finally, spatial shaping of the laser pulse will be employed to engineer the spatial profile of the emission pattern, allowing for greater directionality and luminosity.

The successful implementation of this project is expected to result in a more compact and efficient EUV source, with enhanced luminosity and directional control. This could lead to significant advancements in EUV lithography. This will also offer new insights into the laser-matter interaction mechanisms for laser material processing applications. The findings could also pave the way for future research into compact, high repetition rate EUV sources and their applications in various industries.

Our group: The OPTO group is a large group of more than 30 academics, postdocs and PhD students on different areas of photonics (quantum engineering, artificial intelligence, ultrafast photonics: see group website). The research of the PhD topic will be realized within the team led by François Courvoisier. The team expertise on ultrafast laser-matter interaction, beam shaping, laser materials processing is internationally recognized by more than 70 invited talks at international conferences and an important track-record of funded European project proposals.

Références bibliographiques / Bibliography

[1] High aspect ratio nanochannel machining using single shot femtosecond Bessel beams

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M. K. Bhuyan, F. Courvoisier, P.-A. Lacourt, M. Jacquot, R. Salut, L. Furfaro, and J. M. Dudley, *Applied Physics Letters,* **97**, 081102 (2010) https://doi.org/10.1063/1.3479419

[2] Nanoscale confinement of energy deposition in glass by double ultrafast Bessel pulses
J. del Hoyo, R. Meyer, L. Furfaro and F. Courvoisier
Nanophotonics, **10**, 1089-1097 (2021) https://doi.org/10.1515/nanoph-2020-0457

[3] In-situ diagnostic of femtosecond laser probe pulses for high resolution ultrafast imaging
C. Xie, R. Meyer, L. Froehly, R. Giust, and F. Courvoisier,
Light: Science & Applications **10**, 126 (2021). https://doi.org/10.1038/s41377-021-00562-1

[4] Femtosecond laser-induced sub-wavelength plasma inside dielectrics: I. Field enhancement, Kazem Ardaneh, Remi Meyer, Mostafa Hassan, Remo Giust, Benoit Morel, Arnaud Couairon, Guy Bonnaud, and Francois Courvoisier, *Physics of Plasmas* **29**, 072715 (2022) https://doi.org/10.1063/5.0086708

[5] K. Ardaneh, R. Giust, P.-J. Charpin, B. Morel and F. Courvoisier " Electron heating and radiation in high aspect ratio sub-micron plasma generated by an ultrafast Bessel pulse within a solid dielectric ", *The European Physical Journal Special Topics*, **232**, 2247–2252 (2023). https://doi.org/10.1140/epjs/s11734-022-00751-y

Applicant profile

Excellent scientist, open-minded physicist. The applicant must demonstrate a track-record of previous experimental work (at least significant lab courses). English-speaking is mandatory as our group is highly international. The candidate will join an enthusiastic team with diverse profiles in physics and photonics. Scientific honesty, curiosity and willingness to learn are key values in our group.

Financement/ funding type : MESRI Etablissement / Research Ministry funding

Application deadline : 20 May
Contract start : 1st October 2024
Salaire mensuel brut : 2100€ gross salary

Thesis Supervisor
Francois COURVOISIER francois.courvoisier@femto-st.fr

Applicants are invited to submit their application to the PhD supervisor.
Application must contain the following documents:

- CV
- Cover letter
- Marks of master 1st year and 2nd year (when available)
- At least 1 reference letter