Czech Technical university in Prague
Seminar on time-resolved X-ray spectroscopy
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Generation of short pulse X-ray lasers in laser-produced plasmas. Recent progress at LSAI-Orsay

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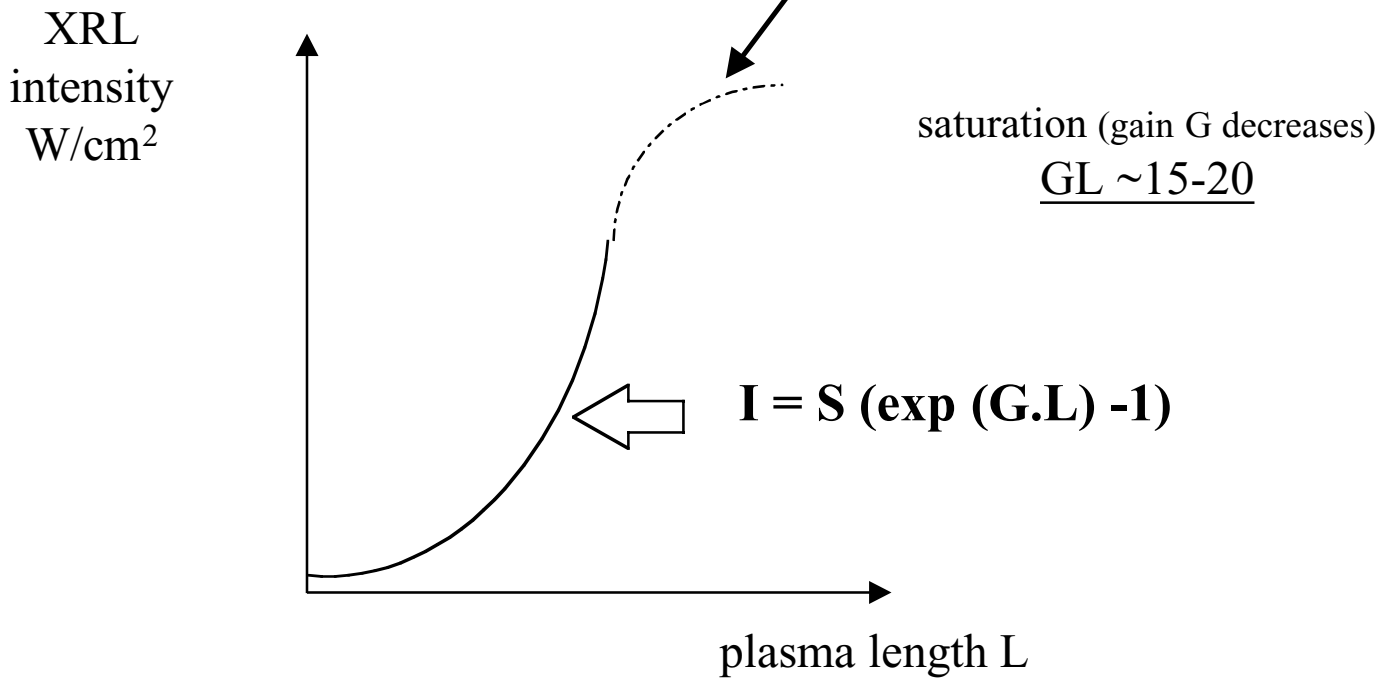
Two main directions of research at LSAI

- Develop saturated X-ray laser sources, improve their efficiency, and the X-ray laser beam characteristics
  - investigate collisonal excitation pumping for different pump pulse durations
  - characterise X-ray laser beam spatially and temporally

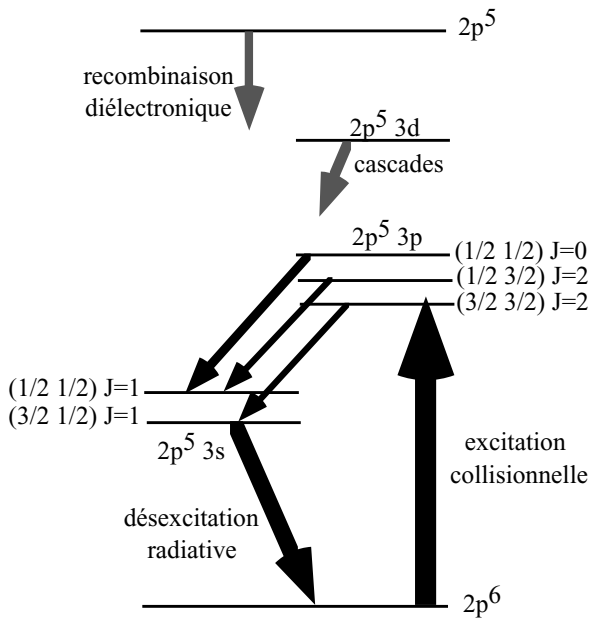
- Prospect and demonstrate new applications of X-ray lasers (high brightness, coherence)
  - imaging of transient, small-scale structures
  - excitation of matter at high intensity

Amplification of Spontaneous Emission (A.S.E.) and saturated operation of X-ray lasers

- extraction of XRL energy maximised
- better shot-to-shot reproducibility
- coherence enhanced

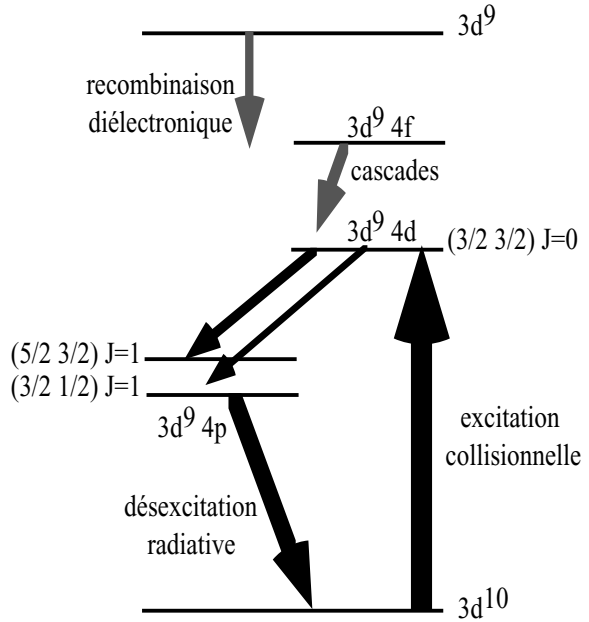


Pumping by collisional excitation



Ne-like ions

$1s^2\ 2s^2\ 2p^6$



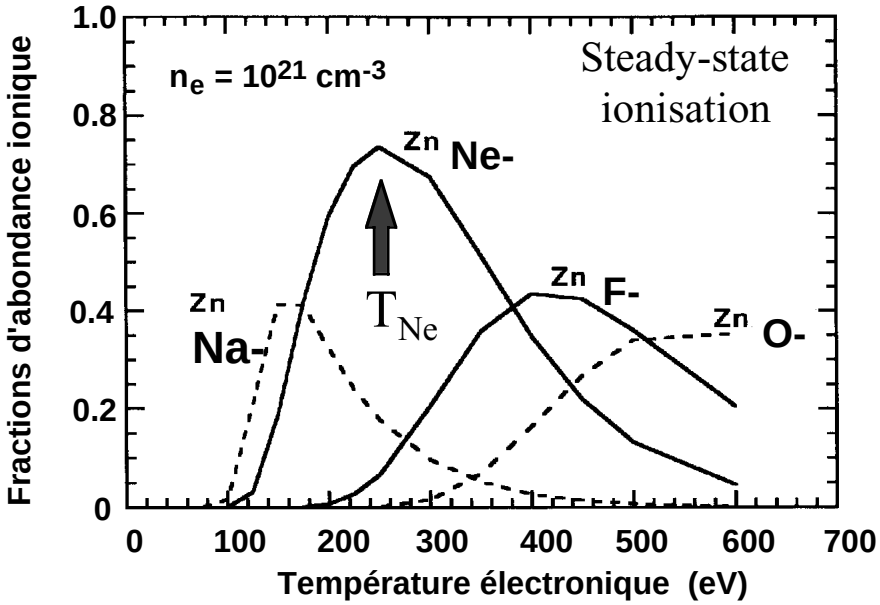
Ni-like ions

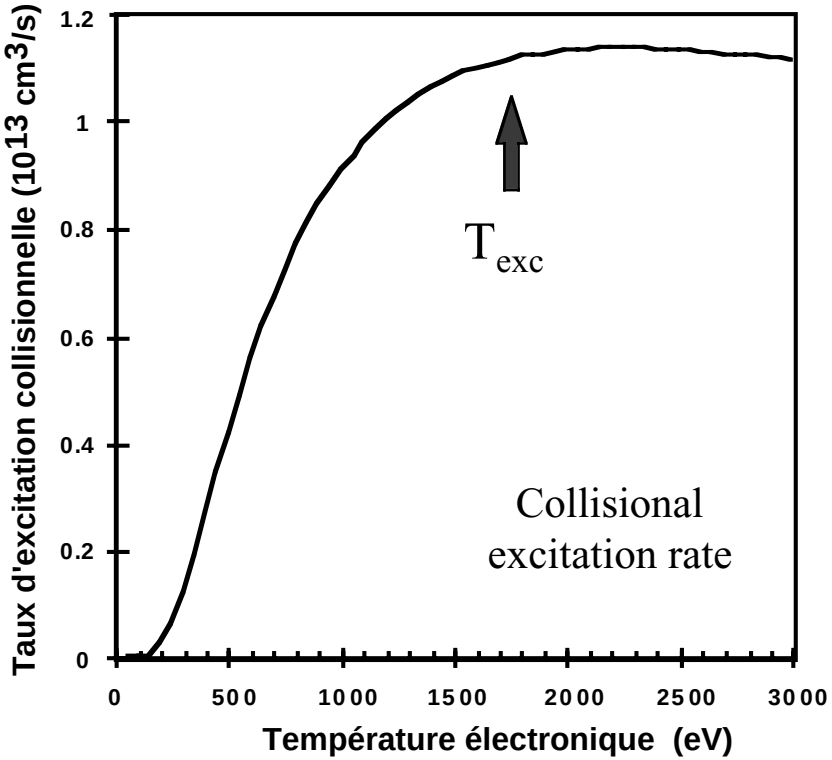
$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 3d^{10}$

Strong 2p-3p or 3d-4d collisional excitation requires high electron temperature ($kTe \sim \Delta E_{exc}$)

the duration of the pump pulse was shown to have a critical influence on gain

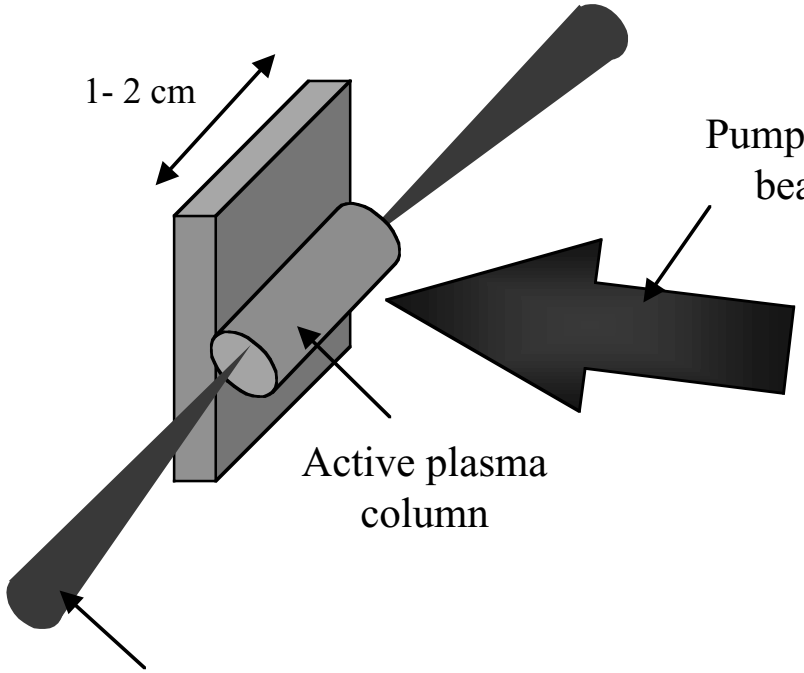
Non-stationary ionisation of the plasma is required





- $T_{Ne} << T_{exc}$ => **fast heating** to avoid overionisation
  => short pump pulse are better

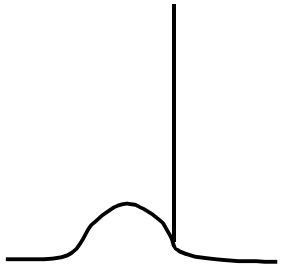
Different regimes of pumping collisional X-ray lasers have been investigated



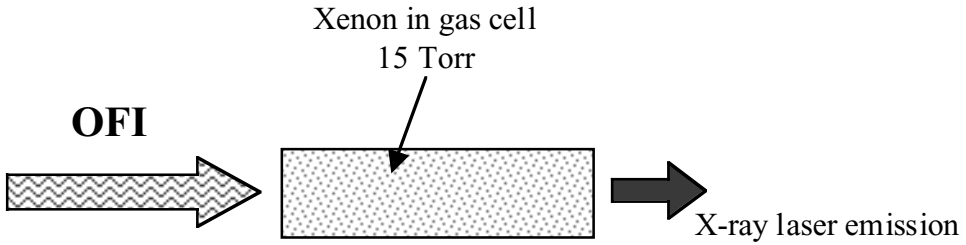
X-ray laser beam

E = 10 μJ - 1 mJ
τ = 2 ps - 80 ps
λ = 13.9; 21.2; 25 nm

QSS: 100 - 600 ps
+ low energy prepulse



Transient: ~ 1 ps
+ preformed plasma



LOA

Saturated X-ray lasers demonstrated at LSAI/LULI

QSS regime

600 ps ---------- Ne-like Zn @21,2 nm E ~ 1 mJ; τ ~ 80 ps
gain ~ 5 cm^{-1}
half-cavity;
several applications demonstrated

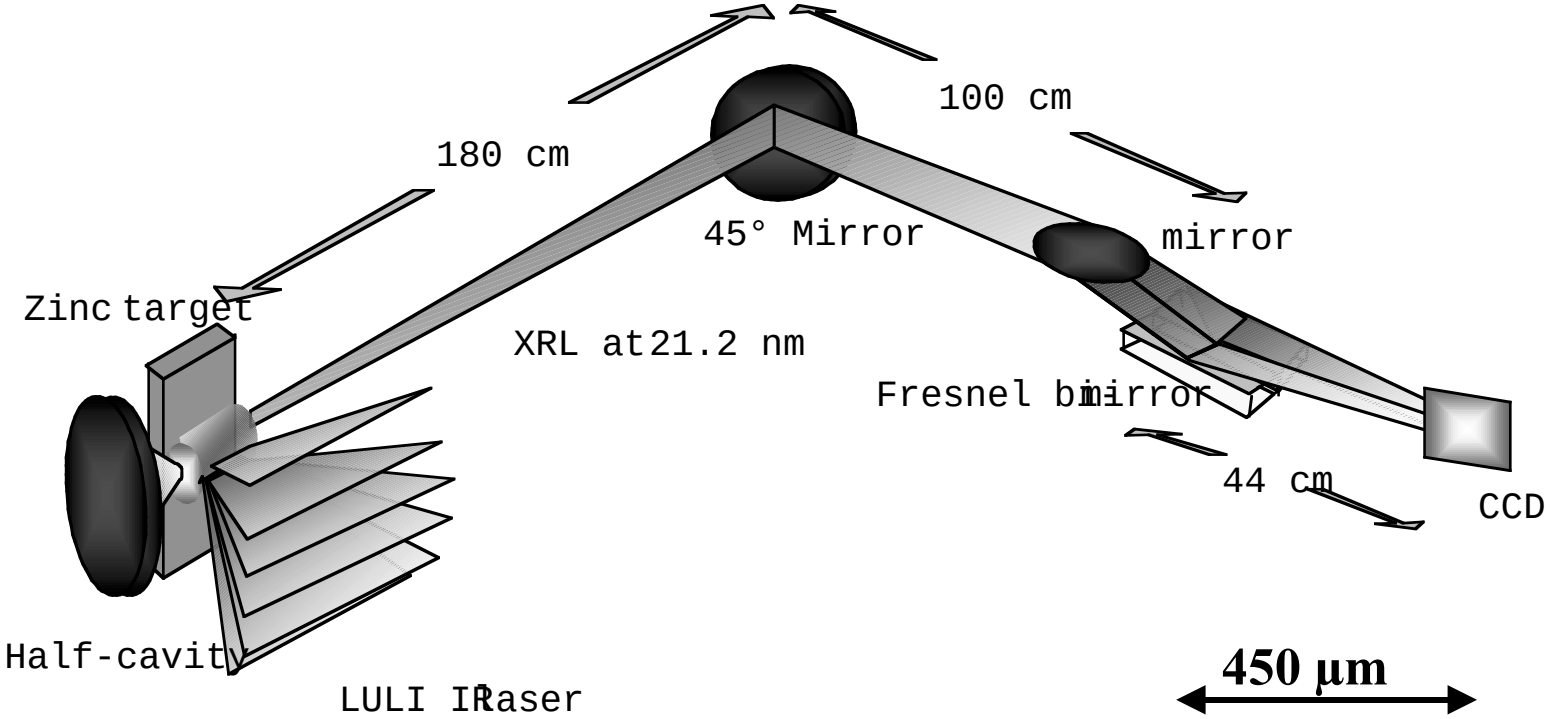
130 ps---------- Ni-like Ag @13,9 nm; E ~ 40 µJ; τ ~ 50 ps
gain ~ 8 cm^{-1}
wavelength optimal for Mo/Si optics;
applications under development

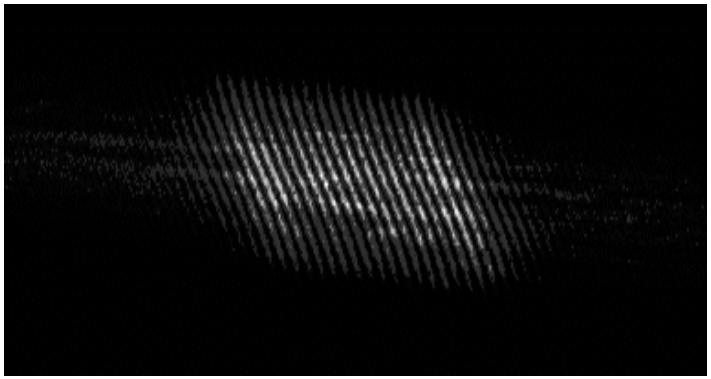
Ne-like Fe @25,5 nm; E ~100µJ; τ ~ 50 ps
gain ~ 15 cm^{-1}
sequential pumping for cavity
operation under investigation

transient regime

0,5 ps ---------- Ni-like Ag @13,9 nm; E ~10 µJ; τ ~ 2 - 5 ps
gain ~ 30 cm^{-1}
substantial reduction of pump energy
and duration of X-ray laser pulse

XRL interferometry : set up



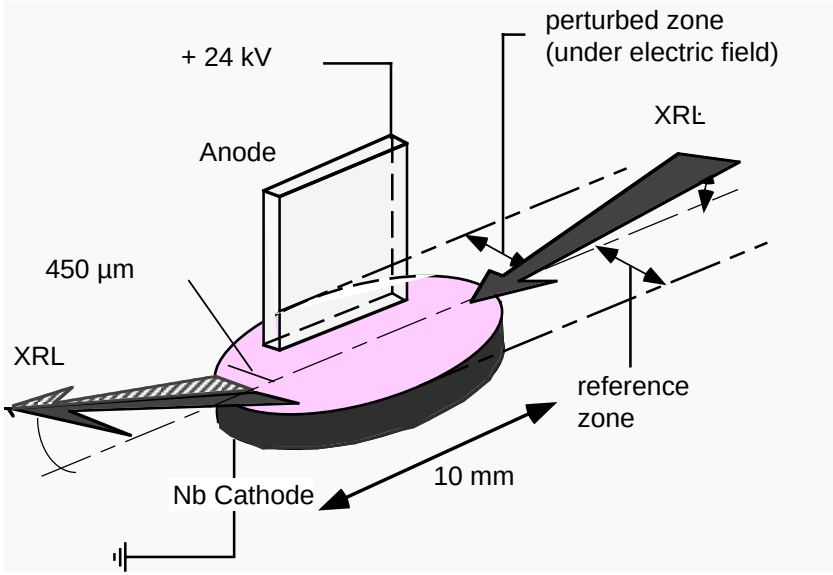


LSAI /IOTA

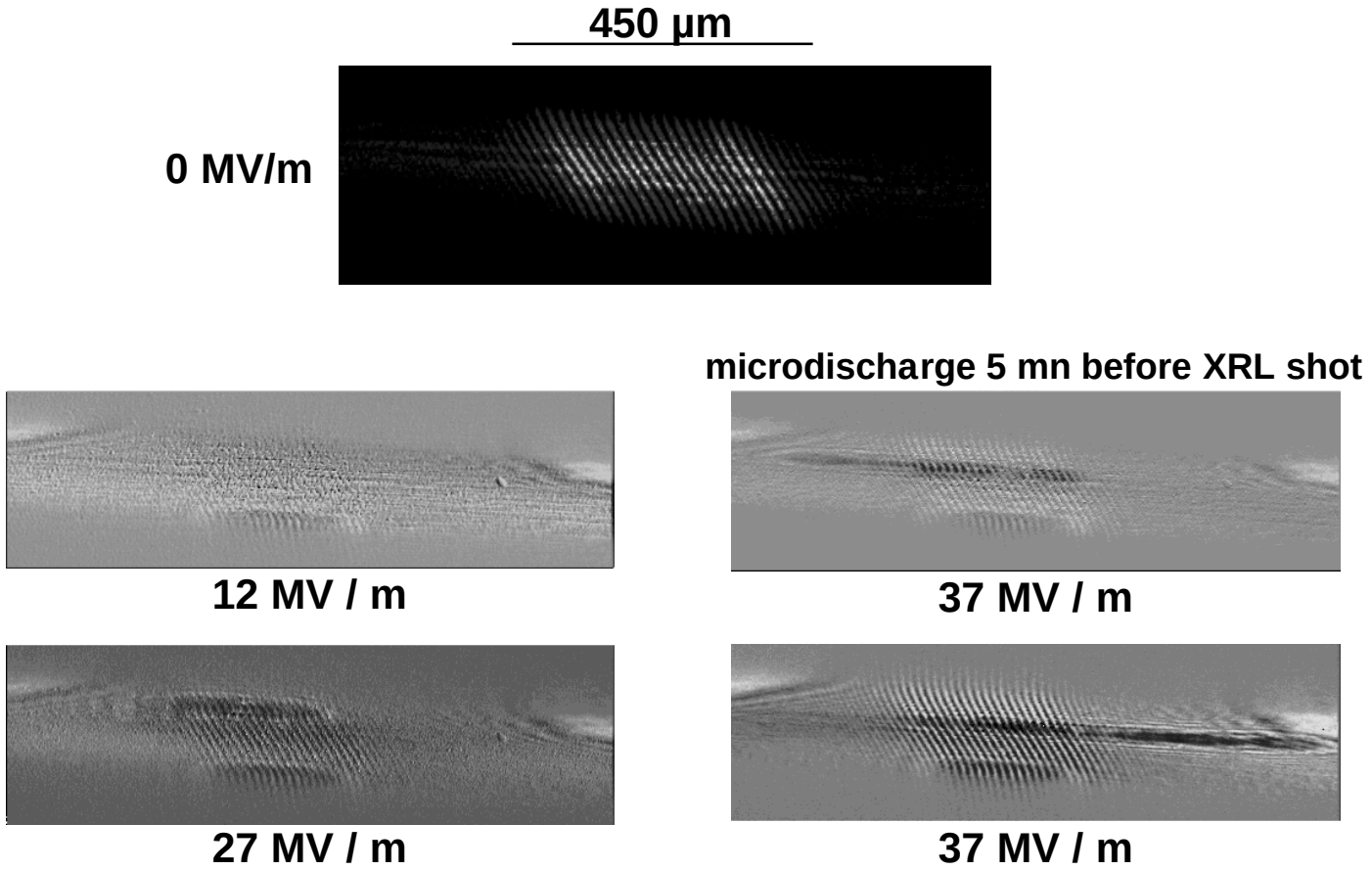
B. Rus et al., Phys; Rev. A 55 (1997) 3858
*F. Albert et al, Optics Comm. **142** (1997)184*

XRL interferometry of a surface under high electric field

Arrangement of niobium cathode and anode



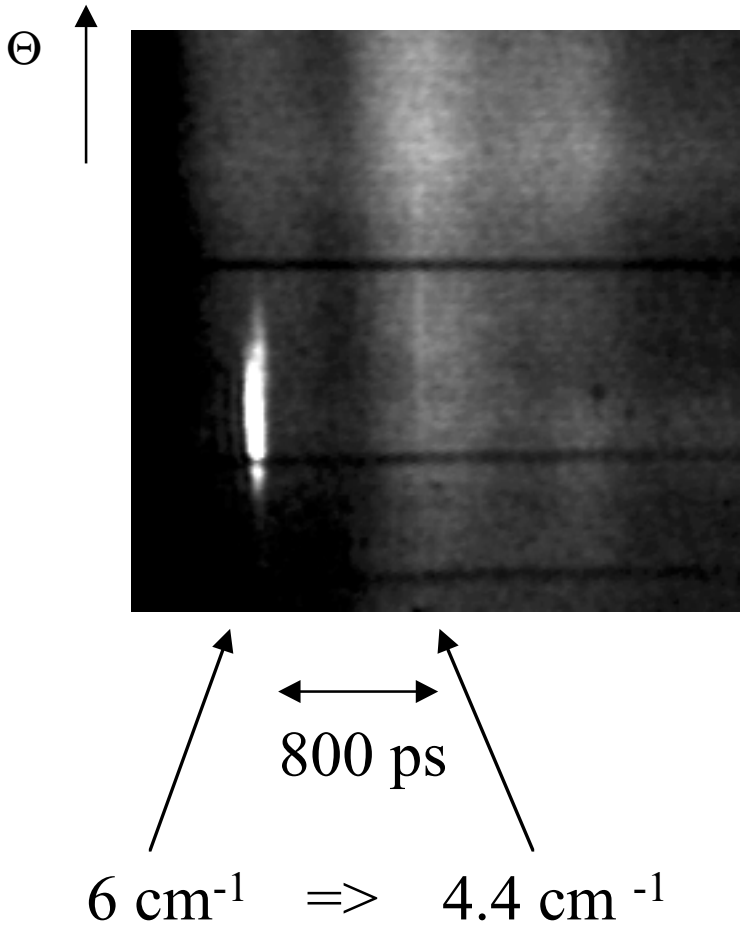
Modification of cathode surface due to electric field



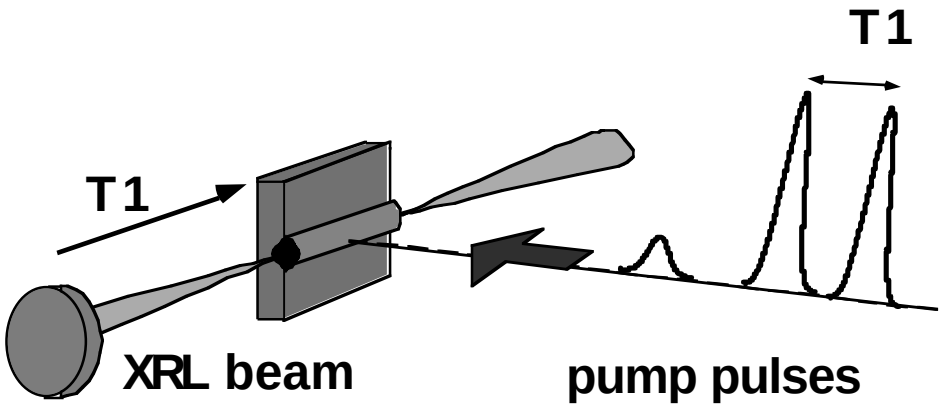
LSAI / IOTA / CEA-DSM

F. Albert et al. Phys. Rev. B 60 (1999) 11089

100 ps pump pulses allow to generate lasing in Ni-like Ag at 13.9 nm

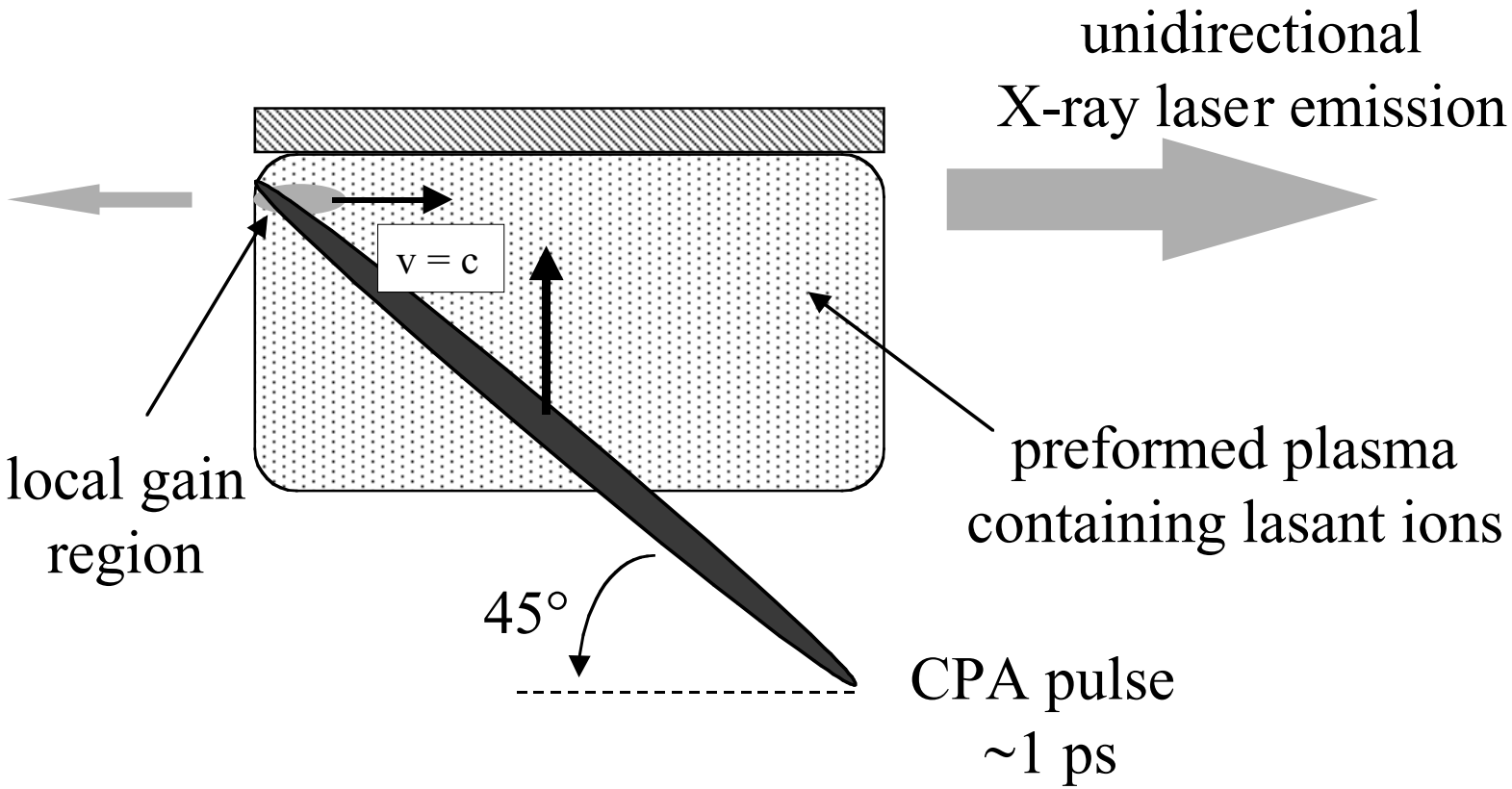


- very short XRL pulse duration: <50ps (limit of Streak resolution)
- Wavelength is optimal for Mo:Si optics (lithography)



*A. Klisnick et al., X-Ray Lasers 1998, IOP Conf. Series **159**, 107 (1999)*

Transient collisional X-ray lasers require traveling-wave pumping

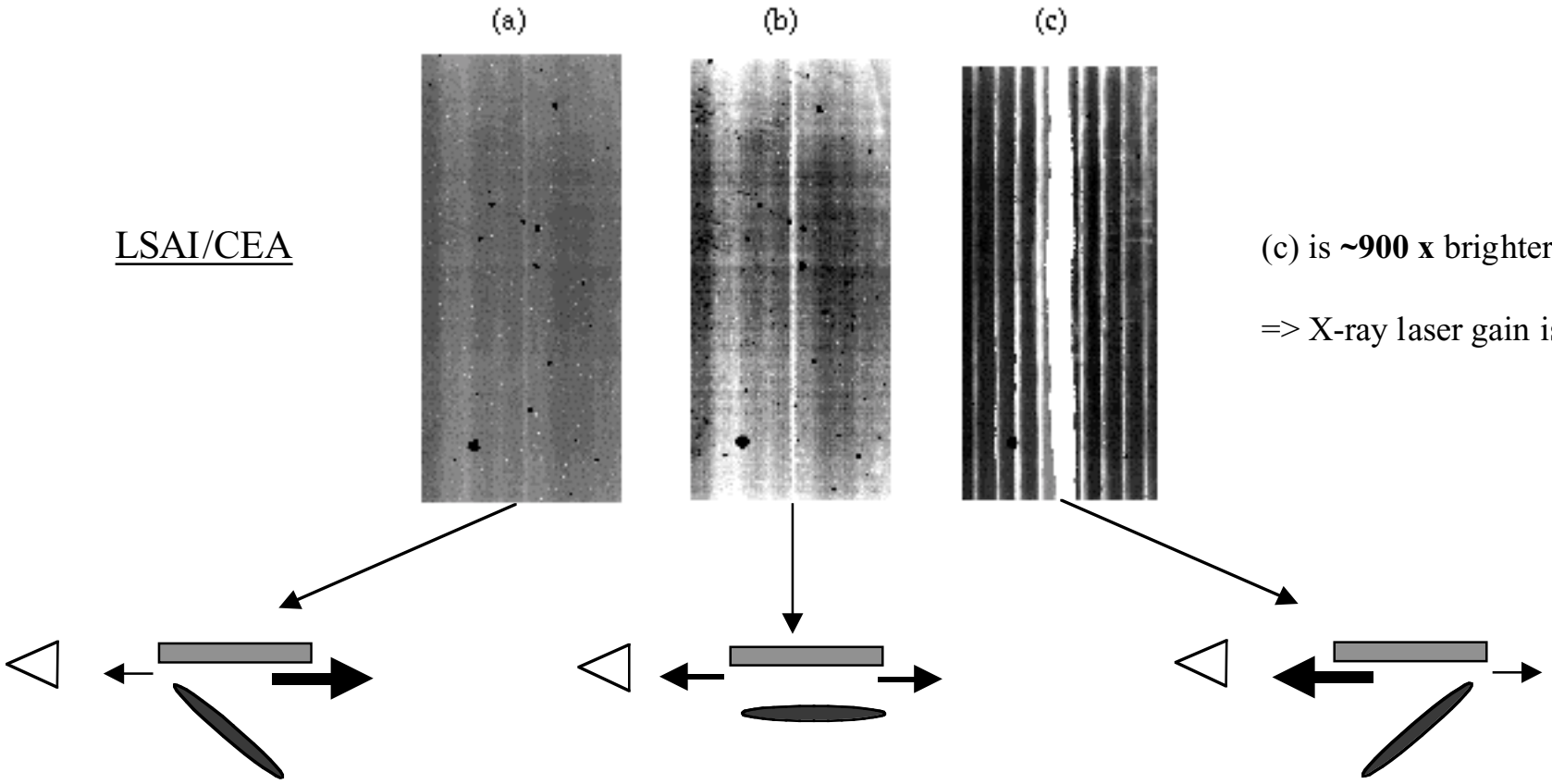


*A Klisnick et al. JOSA B **17** (2000) 1093*

*J C Chanteloup et al. JOSA B **17** (2000) 151*

Demonstration of traveling-wave pumping at 13.9 nm with the CEA-P102 laser

LSAI/CEA



(c) is **~900 x** brighter than (a)

=> X-ray laser gain is short-lived

(a) TW backward relative to spectrometer

(b) no TW (v=∞)

(c) TW towards the spectrometer

*J Kuba, A Klisnick, et al., Phys. Rev A **62** (2000) 043808*

Conclusions - Future work

- The reduction of the pump pulse duration has allowed:
  - Significant reduction of the pump laser energy (500 J → 30 J)
  - Significant increase of the gain coefficients on lasing lines ($5cm^{-1}$ → ~$30\ cm^{-1}$)
  - Reduction of the duration of the X-ray laser pulse:
    2 ps demonstrated -> presentation by J. Kuba
  - but the energy contained in the X-ray laser pulse is also decreased (1 mJ → 10-50 μJ)

- The temporal behaviour of the 13.9 nm transient laser will be further investigated at LULI in January 2001

- Applications to interferometry of perturbed surfaces will be continued at PALS in 2001, in collaboration with B. Rus et al.