Characterization of a 46.9 nm Ar soft x-ray laser

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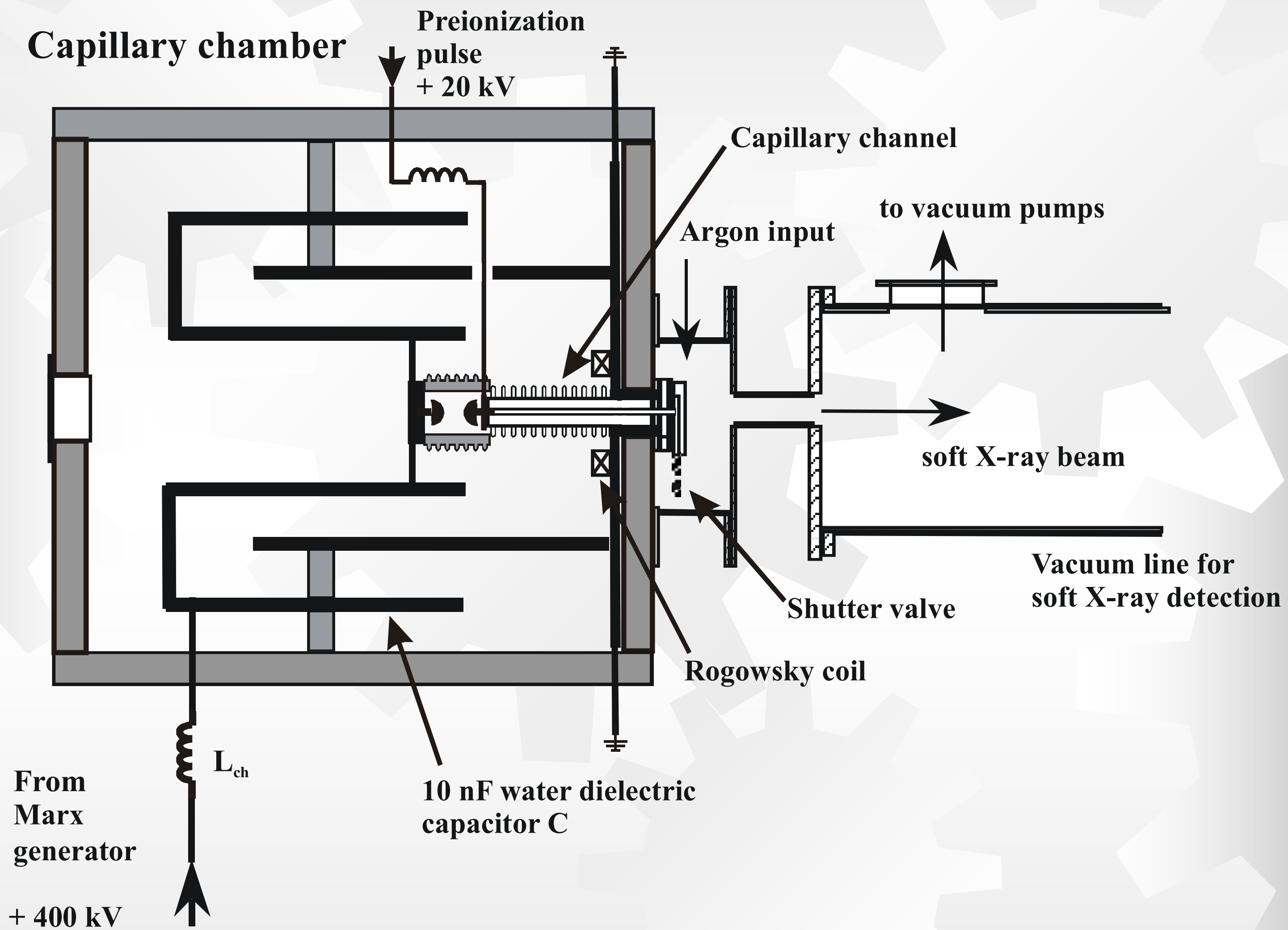
Objectives

- 1995 Decreasing the wavelength of the Ar^{+8} soft x-ray laser.
  - Generation of pure, high density and homogenous metal and dielectric vapor plasma by capillary discharge.
    - S.V. Kukhlevsky et al.: SPIE **3156**, 1997.
  - Double pulse excitation of x-ray capillary lasers.
    - S.V. Kukhlevsky et al.: SPIE **3156**, 1997.
- 1996 –2000 Investigation of ablative capillary discharges.
    - S.V. Kukhlevsky et al.: Apl. Phys Let., **74**, 1999.
    - S.V. Kukhlevsky et al.: Phys. Let. A, **258**, 1999.
- 2000 - 2001 Construction of a 46.9 nm soft x-ray laser.
    - S.V. Kukhlevsky et al.: Plasma S. Sci. & Tech. **10**, 2001.
    - G. Tomassetti et al.: Europ. Phys. J. D **19**, 2002.

Experimental apparatus



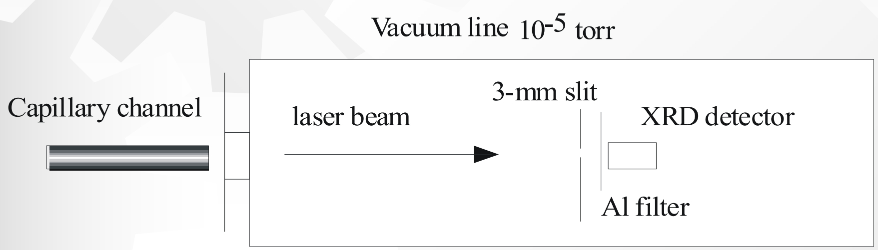
- G. Tomassetti et al.: Europ. Phys. J. D **19**, 2002.

Experimental conditions

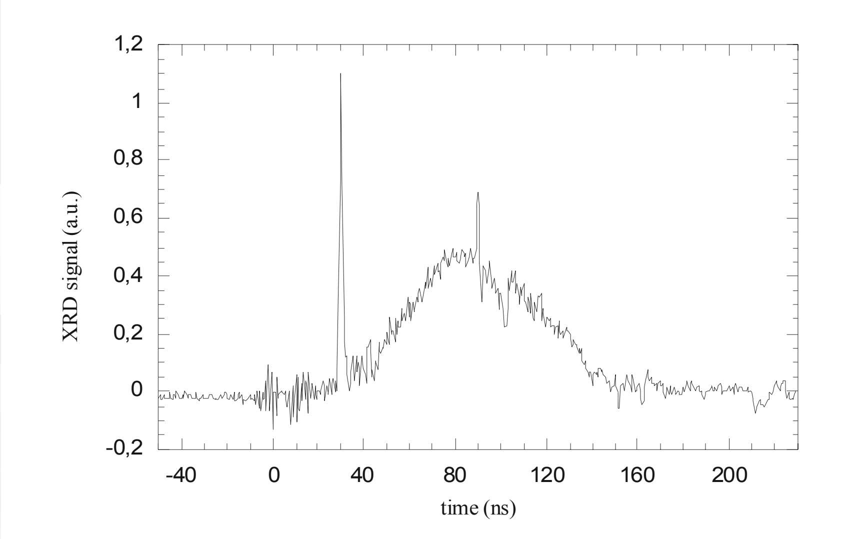
- Preionization current
  - 3 – 5 μs long, 20 A.
- Current pulse
  - Peak value 27 – 32 kA, half-cycle duration 150 ns rise time ~45 ns.
  - The current pulse was produced by discharging a 10 nF water dielectric capacitor. (Initially charged up to 200 kV.)
- Capillaries
  - 76 –200 mm long, 2.4 – 4 mm in diameter, both in alumina and polyacetal.
- Shutter valve
  - Separates the detection line from capillary channel.

Diagnostic methods

- Temporal evolution of the soft x-ray emission
  - Measurements with fast vacuum photodiode (XRD)

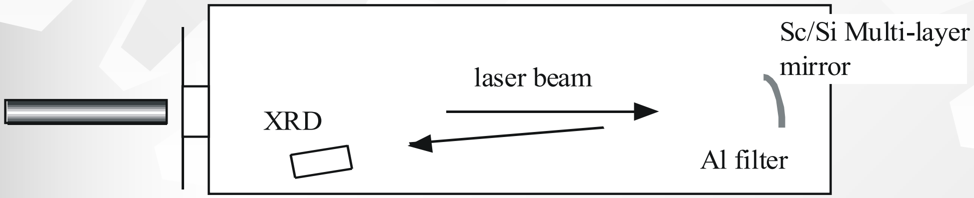


- Ar pressure 0.3 torr
- Capillary length 151 mm
- Capillary diameter 3 mm
- Current pulse amp. 32 kA



Temporal evolution of the soft x-ray emission

- Measurements with fast vacuum photodiode (XRD) after the reflection on Sc/Si multilayer mirror.



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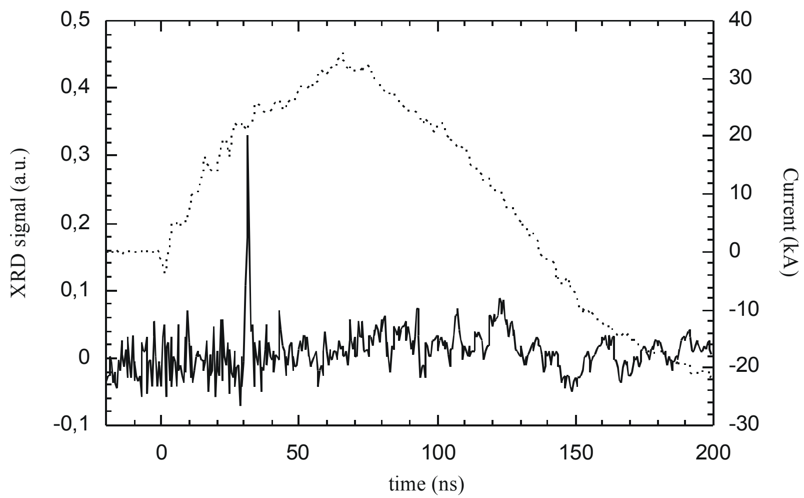
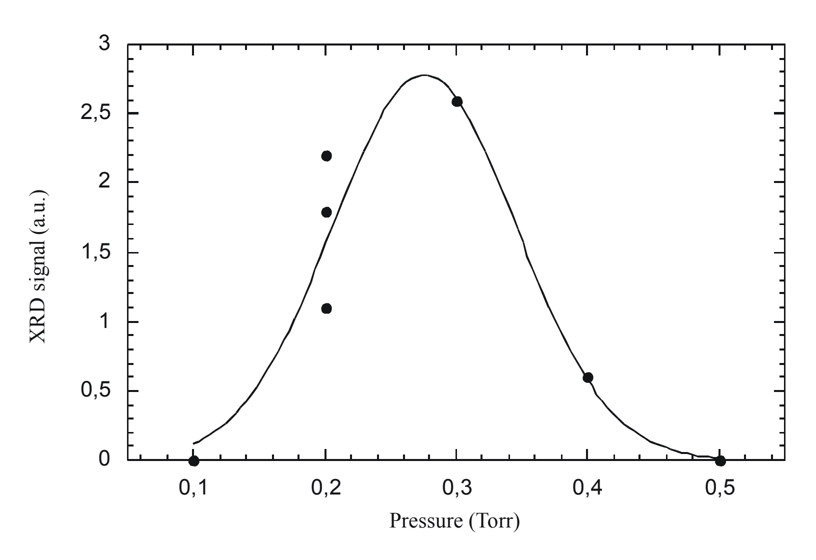
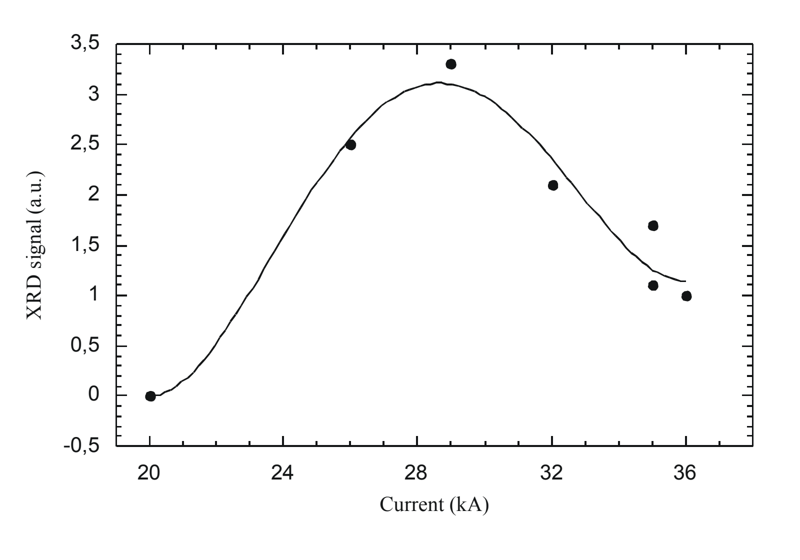


The divergence of the laser beam

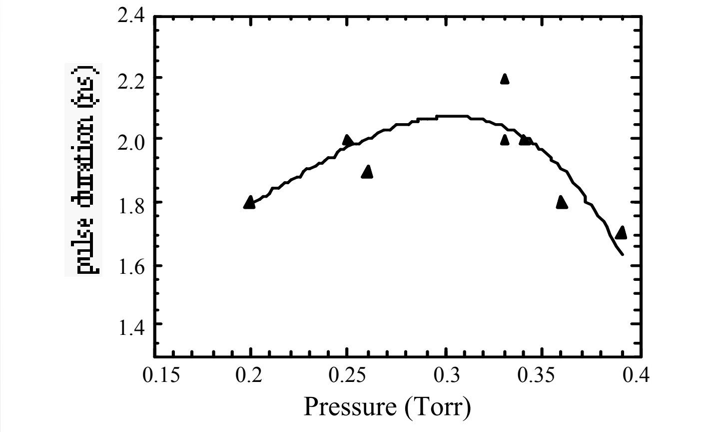
- The laser beam divergence was roughly estimated by putting the slit on the photodiode and moving in orthogonal direction of propagating the x-rays.
- We have estimated a divergence of about 4 mrad.

- Measurements of the laser intensity for different initial conditions





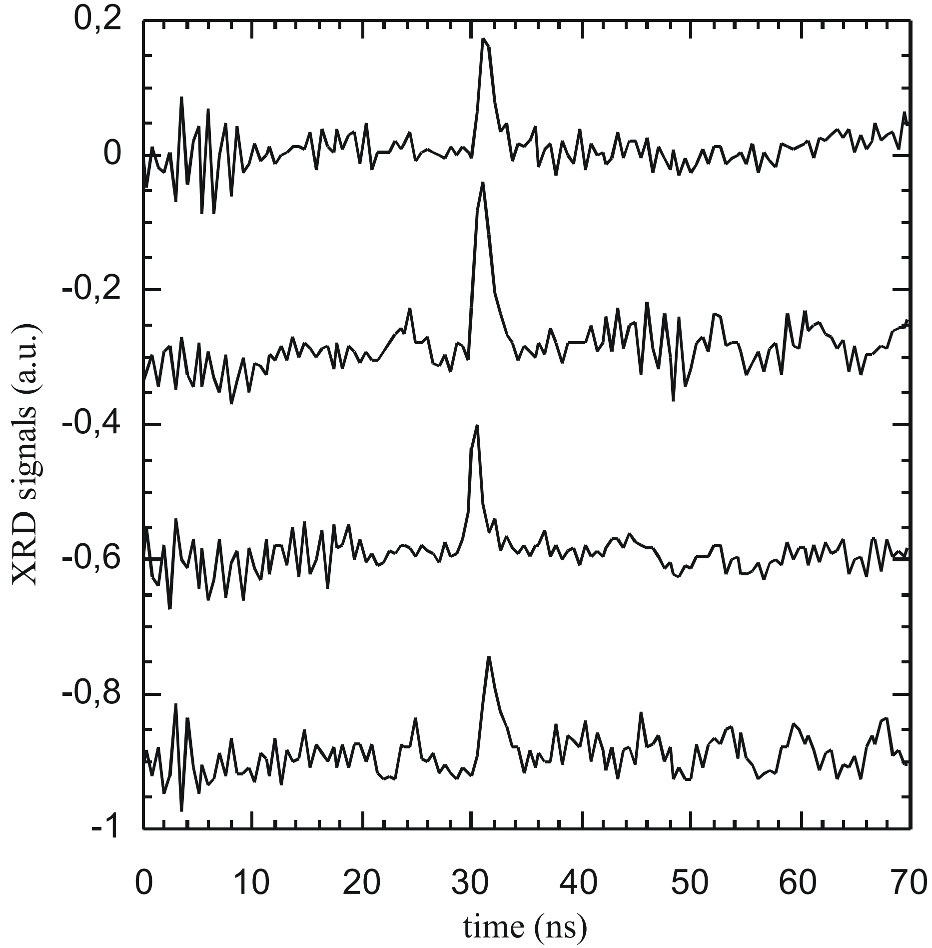
- Measurements of the pulse duration as a function of initially gas pressure



Maximum value:

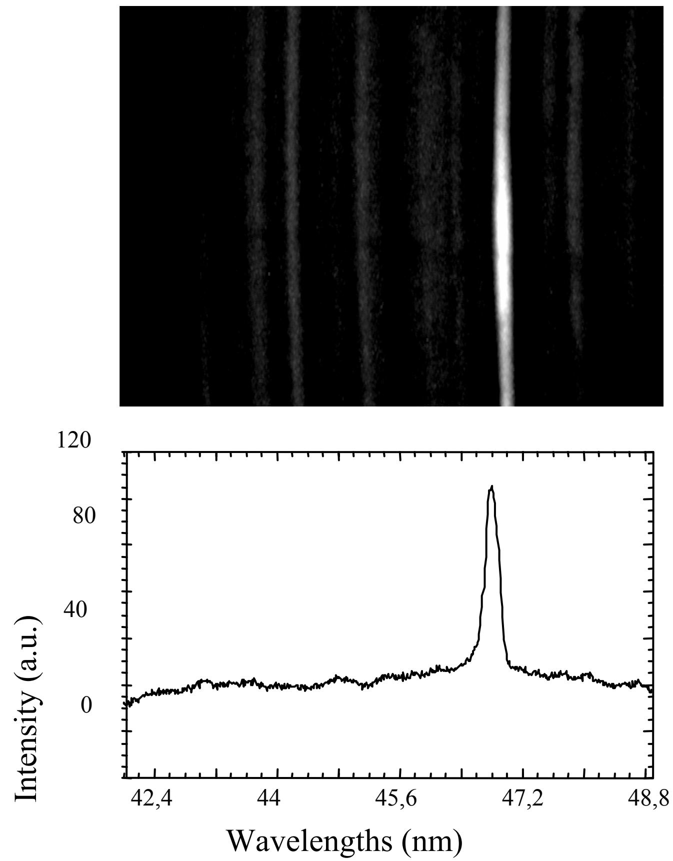
~2.2 ns at FWHM at 0.33 torr

Stability of the plasma compression



- Temporal evolution of laser emission obtained in four consequence pulses.
- The jitter of the laser spike is ~ 1 ns.

- Spectroscopic measurements
  - A 1 m grazing angle spectrometer equipped with a toroidal reflection grating with 500 g/mm and with a 100 μm entrance slit has been used. (Spectral resolution of about 2Å).

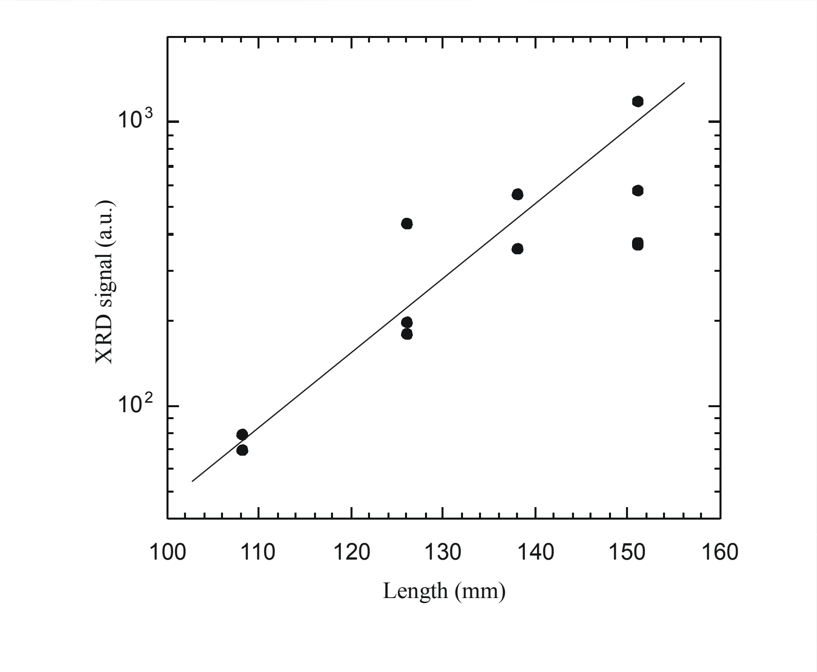


- Experimental parameters:

  Capillary diameter 3 mm,
  capillary length 200 mm,
  initial Ar pressure 0.32 torr,
  current pulse 30 kA.

Gain measurements

- The gain was measured changing the plasma column length. It was determined by fitting the experimental data by the Linford formula.



Experimental parameters:

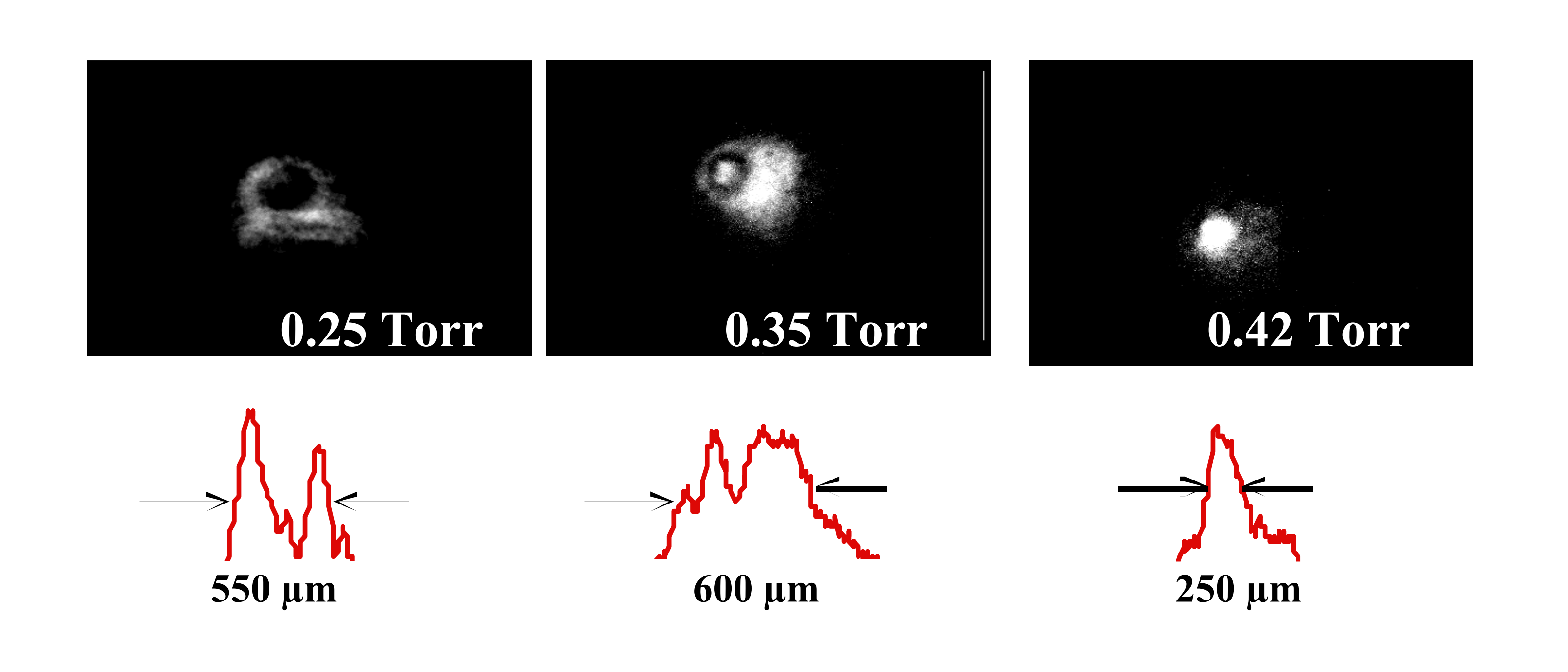
Capillary diameter 3 mm, initial Ar pressure 0.30 torr, current pulse 32 kA.

- The gain was studied also as a function of the initial gas pressure, it changes from 0.7 cm^{-1} at 0.25 torr up to 1 cm^{-1} at 0.33 torr.

Near field images of the laser beam

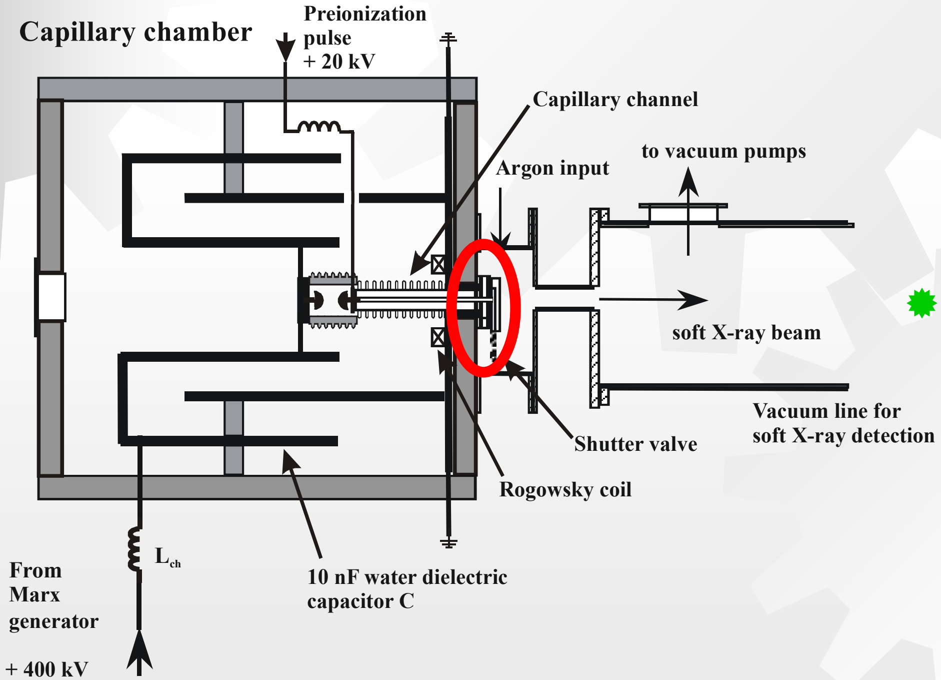
- The detection line consist of a couple of two 75 cm Sc/Si multilayer mirrors, positioned in order to reproduce on the detector a 1:1 image of the laser beam at the capillary output.
- The detector with a spatial resolution of about 20 μm consists of a MCP connected to the CCD camera.
- The MCP is gated with a 500 ns long voltage pulse – it acquires time-integrated images.
- The near filed images of the laser beam were analyzed as a function of the initial Ar pressure in 20 cm long alumina capillary channels.

Near field images of the laser beam



- The laser beam shape changes from an annular (ring-like) shape to the single peaked.
- The spot of the laser is two time bigger that reported by Rocca. Far field measurements can clarify if this can be attributed to the bigger gain region or an increased reflection of the beam.

- Laser beam energy
  - The laser output energy, with a 20 cm long plasma column and assuming a quantum efficiency of 10% for the copper photo-cathode, was estimated to be 5 μJ.
  - The energy can be effected by two factors:
    - The current rise time.
    - By re-absorption of the ~2 cm of neutral Ar, which is present between the end of the capillary tube and the shutter valve.



- The laser pulse energy does not change significantly with the capillary diameter from 2.4 up to 4 mm.
- Laser line is emitted at 20, 31 and 40 ns from the starting of the current pulse, with 2.4, 3.2 and 4 mm in diameter capillaries respectively.

Ongoing work

- Investigation of a laser pulse energy as a function of the current slope.
- Upgrade of the shutter.
- Upgrade of the set-up (more compact, ‘table-top’ device).
- Accomplishing the set-up with the metal and dielectric vapor generator, preliminary experiments with metal or dielectric vapors.
- Further improvements of the theoretical models for gain calculations and MHD simulations.
  - S.V. Kukhlevsky et al.: Contrib. Plasma Phys. **42**, 2002.
  - S.V. Kukhlevsky et al.: Plasma Sources Sci. & Tech. **10**, 2001.

Conclusion

- The realization and the characterization of a capillary discharge based soft x-ray laser operating at 46.9 nm in Ne-like Ar was shown.
- The laser uses relatively long current pulses (half cycle duration ~150 ns) with a peak value from 27 up to 32 kA.
- The measured gain was from 0.7 up to 1 cm^{-1}, at the initial gas pressure of 0.25 and 0.33 torr respectively.
- We achieved the saturation regime, the estimated energy of about 5 μJ in a 20 cm capillary was observed.
- Near field images of the laser beam were obtained.
- The measurements show a laser amplification in alumina capillary channels. For the same conditions lasing in polyacetal capillaries was no observed.

Acknowledgments

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