Execution plan (2006/10)

● Strategic Layout

1. Demonstrate high efficiency optical-field-ionization (OFI) collisional-excitation x-ray lasing in an optical-preformed plasma waveguide with gas mixture.

→ Ni-like Kr 32.8 nm

→ Ne-like Ar 46.9 nm

2. Demonstrate OFI recombination x-ray lasing in an optical-preformed plasma waveguide with gas mixture.

→ Na-like Ar 23.2 nm

→ Li-like N 24.7 nm

3. Achieve OFI recombination x-ray laser with gas mixture.

→ Li-like N 24.7 nm

→ Na-like Ar 23.2 nm

4. Achieve OFI inner-shell collisional-excitation x-ray laser.

→ Ne-like Ar 15.8 nm

● Logical layout

A. Demonstrate high efficiency OFI collisional-excitation x-ray laser in a plasma waveguide – Ni-like Kr 32.8 nm, Ne-like Ar 46.9 nm

a. Problems in Ni-like Kr 32.8 nm

1. low guiding efficiency

Problems in Ne-like Ar 46.9 nm

1. ionization intensity:

The laser intensity used to ionize Ar atoms to Ne-like Ar should be larger than 8.6×10^{16} W/cm^2. It is higher than that of Kr^{8+} and Xe^{8+} and makes the lasing difficult to be produced. This problem can be solved by using the plasma waveguide.

2. cluster effect:

The existence of clusters makes the electrons be overheated and inhibits the x-ray lasing. Using a prepulse to dissociate the clusters can avoid this effect. The ignitor and heater pulses play a role as the prepulse.

b. improvement

1. longer gain length – 1-cm plasma waveguide
   (1) Use 1-cm slit nozzle.
   (2) Generate a line focus longer than 1-cm length with an axicon.
   (3) Expand the probe beam to diagnose the 1-cm waveguide structure.

2. lower mixed ratio – maintain high guiding efficiency and prevent the generation of cold electrons
   (1) Reduce the mixed ratio from 1/11 to 1/4 (Kr/H_2 and Ar/H_2).

B. Optical-field-ionization inner-shell collisional-excitation x-ray laser

– Ne-like Ar 15.8 nm (inner-shell hole transition)

a. issue

1. Ref.: S. M. Hooker, Optics. Commun. **182**, 209 (2000)

   Ar pressure: 50 mbar

   gain length: 11 mm

   threshold intensity for generating Ne-like Ar: 7×10^{16} W/cm^2

   → 1-cm plasma waveguide with Ar:H_2 ~ 1:4

C. Optical-field-ionization recombination x-ray laser in a plasma waveguide

– Na-like Ar 23.2 nm and Li-like N 24.7 nm

Issues:

1. lower electron temperature:

   If the number of cold electrons increases, this will lead to higher three-body recombination rate. There are two ways to obtain higher cold electron number:

   (1) Increase the mixed ratio of hydrogen. (Ar:H_2 ~ 1:10 or 1:20)

   [From ref.: D. J. Spence, Optics. Commun. **249**, 501 (2005), the optimal mixed ratio is 1/130 (Ar/H).]

   (2) Use only the ignitor pulse to form the plasma waveguide.

   Prevent the pre-ionization of hydrogen.

D. Optical-field-ionization recombination x-ray laser

– Na-like Ar 23.2 nm, Li-like N 24.7 nm

Issues:

1. lower electron temperature:

   ATI heating increases with wavelength approximately as λ^2. So we use 400 nm pump pulse to produce lower electron temperature and higher three-body recombination rate.

   [Ref.: D. J. Spence, Optics. Commun. **249**, 501 (2005)]

   For 400 nm pump pulse,

   laser intensity: 6.3×10^{16} W/cm^2

   Ar^{8+} ionization intensity: 8.6×10^{16} W/cm^2 ~ 1.7×10^{18} W/cm^2

   N^{5+} ionization intensity: 4.2×10^{16} W/cm^2

   For 800 nm pump pulse,

   laser intensity: 1.3×10^{17} W/cm^2

   Ar^{8+} ionization intensity: 8.6×10^{16} W/cm^2 ~ 1.7×10^{18} W/cm^2

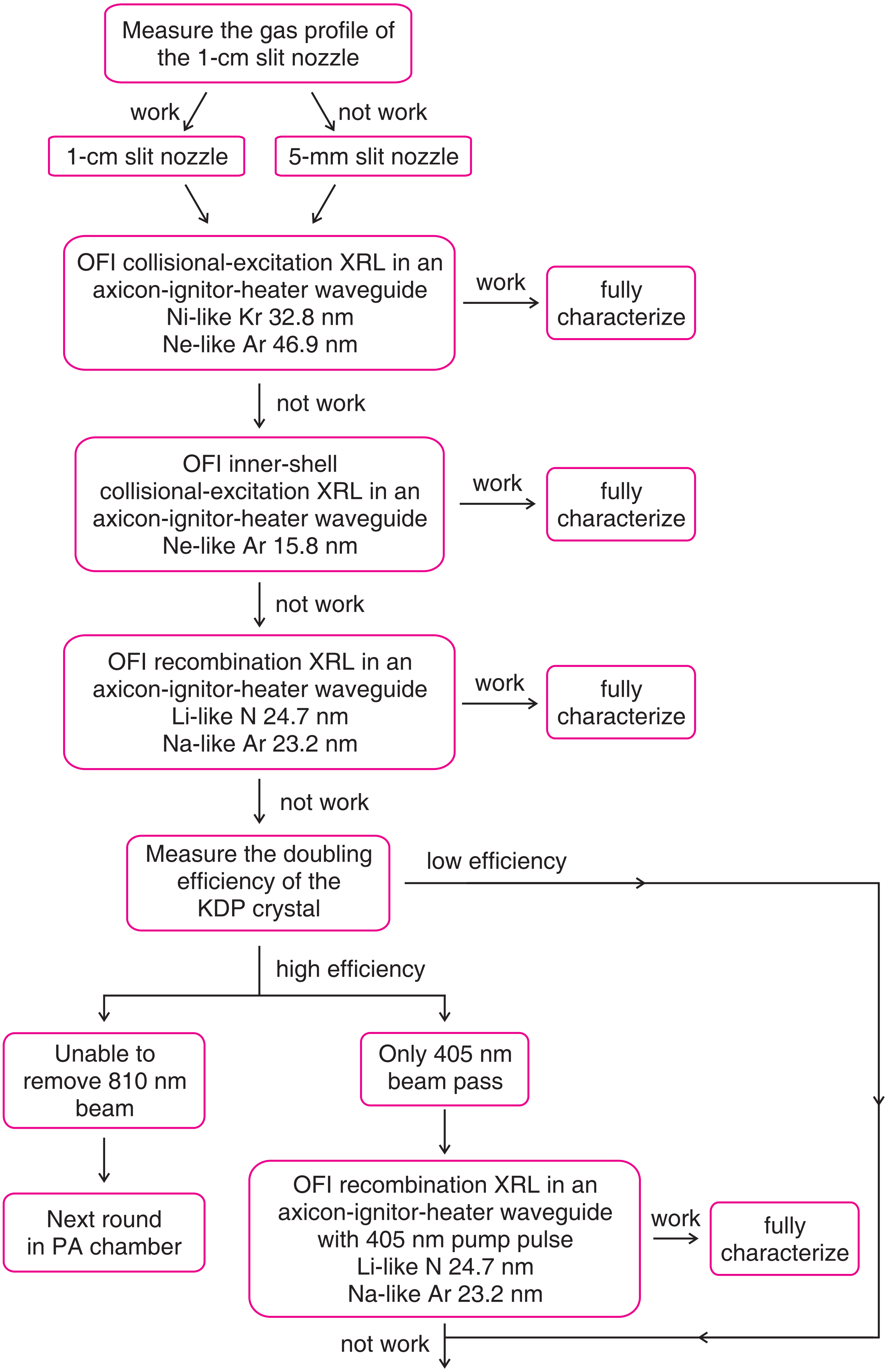
   N^{5+} ionization intensity: 4.2×10^{16} W/cm^2

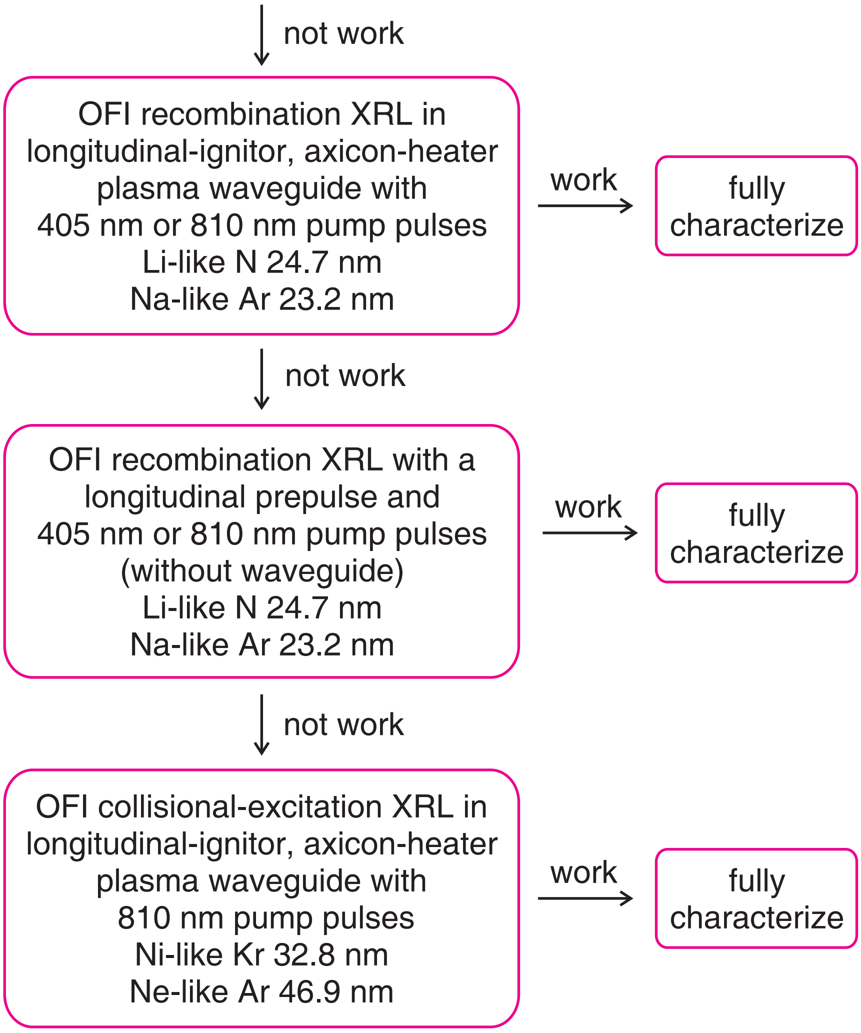
2. cluster effect:

   The existence of clusters makes the electrons be overheated and inhibits the x-ray lasing. Using a prepulse to dissociate the clusters can avoid this effect. We will use a longitudinal prepulse.

- Technical Issue and Temporal Layout

experimental flowchart




not work
OFI recombination XRL in longitudinal-ignitor, axicon-heater plasma waveguide with 405 nm or 810 nm pump pulses Li-like N 24.7 nm Na-like Ar 23.2 nm
work
fully characterize
not work
OFI recombination XRL with a longitudinal prepulse and 405 nm or 810 nm pump pulses (without waveguide) Li-like N 24.7 nm Na-like Ar 23.2 nm
work
fully characterize
not work
OFI collisional-excitation XRL in longitudinal-ignitor, axicon-heater plasma waveguide with 810 nm pump pulses Ni-like Kr 32.8 nm Ne-like Ar 46.9 nm
work
fully characterize

I. Measure the gas profile of the 1-cm slit nozzle.

a. Diagnostics:

side scattering image and interferogram.

b. Experimental conditions:

1. nozzle: 1-cm slit nozzle
2. pump pulse: 45 fs, 8 μm spot size (FWHM)
3. working gas: H_2

c. Procedure:

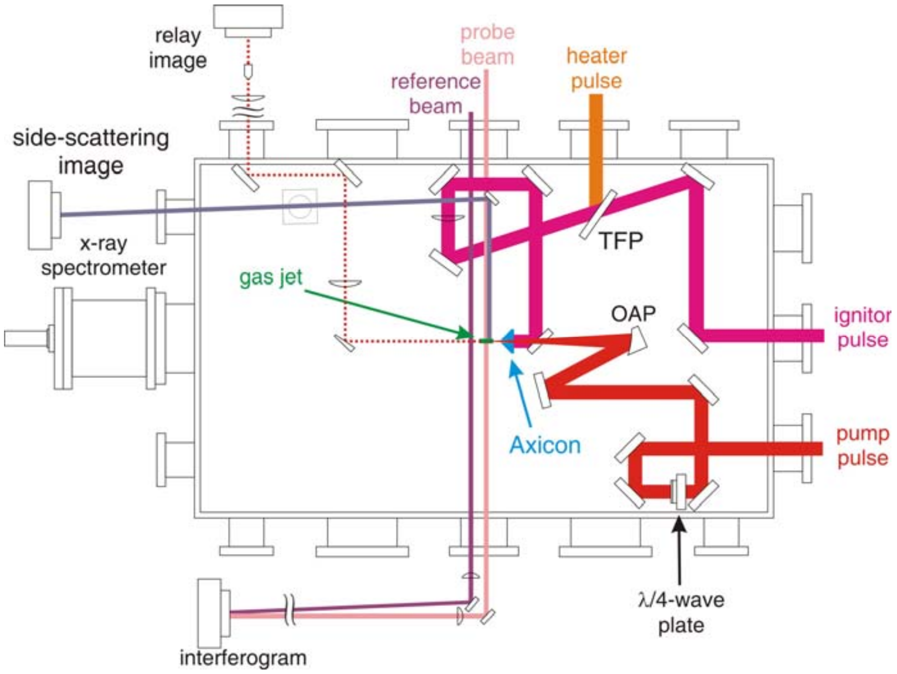
1. Rotate the 1-cm gas jet by 90 degree.
2. Use the pump pulse and move the gas jet in the transverse direction to scan the gas profile.

back to flowchart

II. OFI collisional-excitation XRL in an axicon-ignitor-heater waveguide

– Ni-like Kr 32.8 nm, Ne-like Ar 46.9 nm

a. Experimental Setup



b. Diagnostics:

flat-field spectrometer, relay image, side scattering image and interferogram.

c. Experimental conditions:

1. nozzle: 1-cm slit nozzle
2. pump pulse: 810 nm, 45 fs, 8 μm spot size (FWHM)
3. ignitor and heater energies: 50 mJ and 270 mJ
4. working gas: Kr:H_2 ~ 1:4 mixed gas
   Ar:H_2 ~ 1:4 mixed gas

d. Procedure:

1. Use Kr/H_2 (1/4) mixed gas. Fix the ignitor-heater separation at 200 ps and pump delay at 2.5 ns. Find the optimal focal position and measure the guiding efficiency in the 1-cm plasma waveguide.
2. Scan pump energy and pump polarization under good guiding conditions.
3. If the x-ray lasing can be produced, scan the focal position and pump energy to maximize the lasing signal.
4. Change the gas target to Ar/H_2 (1/4) mixed gas and repeat step 1~3.

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III. OFI inner-shell collisional-excitation XRL in an axicon-ignitor-heater waveguide

– Ne-like Ar 15.8 nm (inner-shell hole transition)

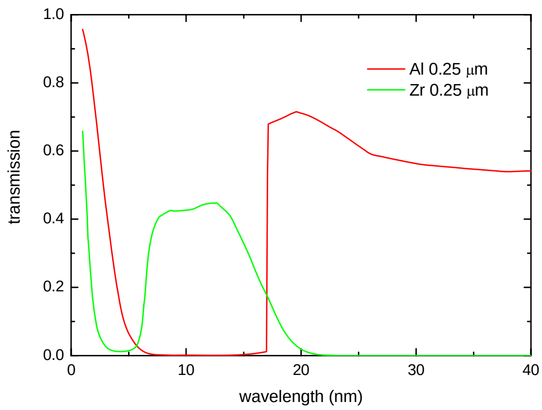
a. Experimental setup

The experimental setup is the same as that in Part II.

b. Diagnostics:

flat-field spectrometer, relay image, side scattering image and interferogram.

※ To measure the Ne-like Ar 15.8 nm signal, the x-ray filter should be the Zr filter.



c. Experimental conditions:

1. nozzle: 1-cm slit nozzle
2. pump pulse: 810 nm, 45 fs, 8 μm spot size(FWHM)
3. ignitor and heater energies: 50 mJ and 270 mJ
4. working gas: $Ar:H_2$ ~ 1:4 mixed gas

d. Procedure:

1. First, adjust the grating angle and the x-ray CCD position and change the x-ray filter for measuring the 15.8 nm signal.
2. Scan pump energy and pump polarization under good guiding conditions found in Part II.
3. If the x-ray lasing can be produced, scan the focal position and pump energy to maximize the lasing signal.

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IV. OFI recombination XRL in an axicon-ignitor-heater waveguide

– Na-like Ar 23.2 nm and Li-like N 24.7 nm

a. Experimental setup

The experimental setup is the same as that in Part II.

b. Diagnostics:

flat-field spectrometer, relay image, side scattering image and interferogram.

c. Experimental conditions:

1. nozzle: 1-cm slit nozzle
2. pump pulse: 810 nm, 45 fs, 8 μm spot size (FWHM)
3. ignitor and heater energies: 50 mJ and 270 mJ
4. working gas: $Ar:H_2$ ~ 1:11 and 1:20 mixed gases
   $N_2:H_2$ ~ 1:11 and 1:20 mixed gases

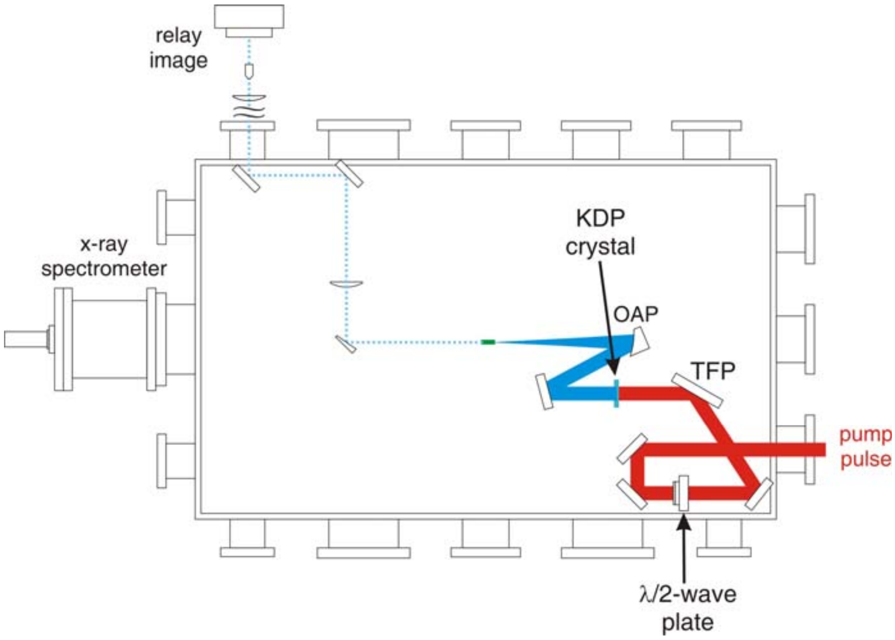
d. Procedure:

1. Use Ar/H_2 (1/11) mixed gas. Fix the ignitor-heater separation at 200 ps and pump delay at 2.5 ns. Find the optimal focal position and measure the guiding efficiency in the 1-cm plasma waveguide.
2. Scan linearly-polarized pump energy under good guiding conditions.
3. If the x-ray lasing can be produced, scan the focal position and pump energy to maximize the lasing signal.
4. Turn off the heater pulse and repeat step 1~3.
5. Change the gas target to Ar/H_2 (1/20) mixed gas and repeat step 1~4.
6. Change the gas target to N_2/H_2 (1/11) mixed gas and repeat step 1~4.
7. Change the gas target to N_2/H_2 (1/20) mixed gas and repeat step 1~4.

back to flowchart

V. Measure the doubling efficiency of the KDP crystal.

a. Experimental setup



b. Diagnostics:

relay image and power meter

c. Experimental conditions:

1. KDP crystal size: 76 mm diameter, 4 mm thickness

d. Procedure:

1. Measure the energy of the 405 nm beam with low laser energy by power meter in air and record the relay image.
2. Calculate the relation between the recorded values measured by power meter and relay image system.
3. Measure the energy of the 405 nm beam with full energy by relay image system. Then use the relation from step 2 to calculate the doubling efficiency.

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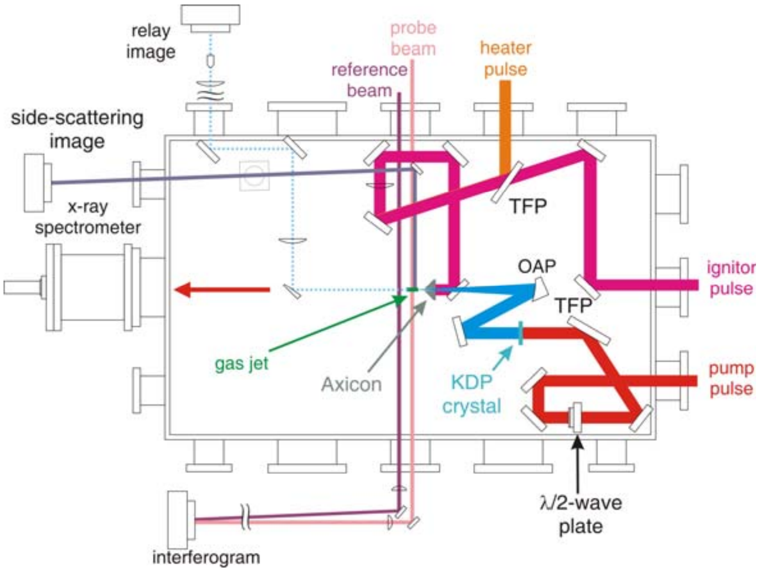
VI. OFI recombination XRL in an axicon-ignitor-heater waveguide with 405 nm pump pulse – Na-like Ar 23.2 nm and Li-like N 24.7 nm

a. Experimental setup



b. Diagnostics:

flat-field spectrometer, relay image, side scattering image and interferogram.

c. Experimental conditions:

1. nozzle: 1-cm slit nozzle
2. pump pulse: 405 nm, 45 fs, 8 μm spot size (FWHM)
3. ignitor and heater energies: 50 mJ and 270 mJ
4. working gas: $Ar:H_2$ ~ 1:11 and 1:20 mixed gases
   $N_2:H_2$ ~ 1:11 and 1:20 mixed gases

d. Procedure: (the same as that in Part IV)

1. Use Ar/H_2 (1/11) mixed gas. Fix the ignitor-heater separation at 200 ps and pump delay at 2.5 ns. Find the optimal focal position and measure the guiding efficiency in the 1-cm plasma waveguide.
2. Scan linearly-polarized pump energy under good guiding conditions.
3. If the x-ray lasing can be produced, scan the focal position and pump energy to maximize the lasing signal.
4. Turn off the heater pulse and repeat step 1~3.
5. Change the gas target to Ar/H_2 (1/20) mixed gas and repeat step 1~4.
6. Change the gas target to N_2/H_2 (1/11) mixed gas and repeat step 1~4.
7. Change the gas target to N_2/H_2 (1/20) mixed gas and repeat step 1~4.

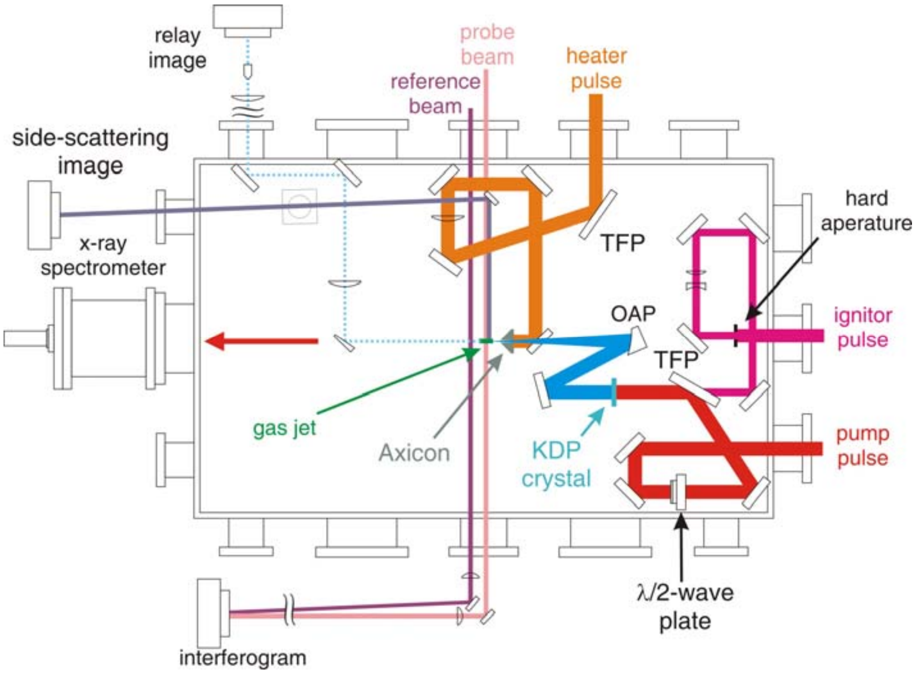
back to flowchart

VII. OFI recombination XRL in longitudinal-ignitor, axicon-heater plasma waveguide with 405 nm and 810 nm pump pulses

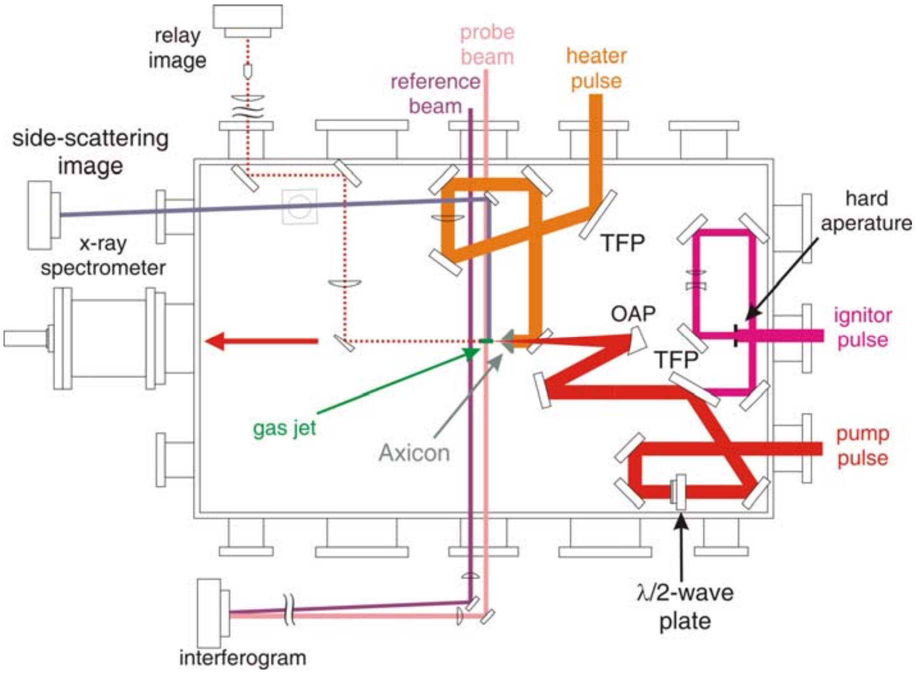
– Na-like Ar 23.2 nm and Li-like N 24.7 nm

a. Experimental setup

for 405 nm pump pulse



for 810 nm pump pulse



b. Diagnostics:

flat-field spectrometer, relay image, side scattering image and interferogram.

c. Experimental conditions:

1. nozzle: 1-cm slit nozzle
2. pump pulse: 405 nm and 810 nm, 45 fs, 8 μm spot size (FWHM)
3. heater energy: 270 mJ
4. working gas: $Ar:H_2$ ~ 1:11 and 1:20 mixed gases
   $N_2:H_2$ ~ 1:11 and 1:20 mixed gases

d. Procedure:

1. Use Ar/H_2 (1/11) mixed gas. In order to make the longitudinal ignitor passing through the whole gas region, we should optimize the focal position and energy of it with the side scattering image and the interferogram.
2. Fix the ignitor-heater separation at 200 ps and pump delay at 2.5 ns. Also fix the longitudinal ignitor at the optimal focal position and energy found in step 1. Find the optimal focal position of pump pulse and measure the guiding efficiency in the 1-cm plasma waveguide.
3. Scan 400 nm, linearly-polarized pump energy under good guiding conditions.
4. If the x-ray lasing can be produced, scan the focal position and pump energy to maximize the lasing signal.
5. Change the gas target to Ar/H_2 (1/20) mixed gas and repeat step 1~3.
6. Change the gas target to N_2/H_2 (1/11) mixed gas and repeat step 1~3.
7. Change the gas target to N_2/H_2 (1/20) mixed gas and repeat step 1~3.
8. If there is no lasing, use the 810 nm pump pulse and repeat step 1~7.

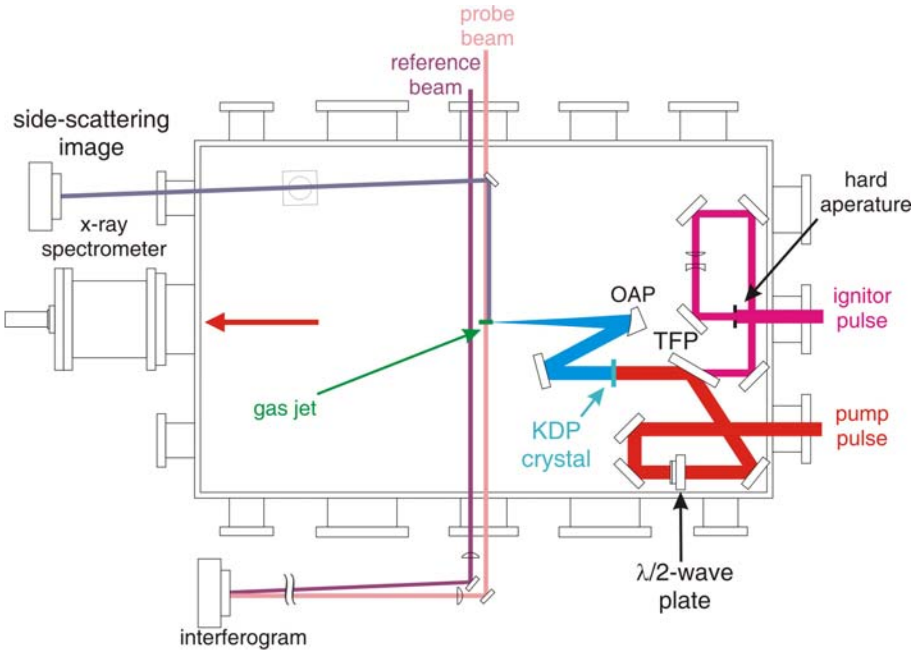
back to flowchart

VIII. OFI recombination XRL with a longitudinal prepulse and 405 nm and 810 nm pump pulses (without waveguide)

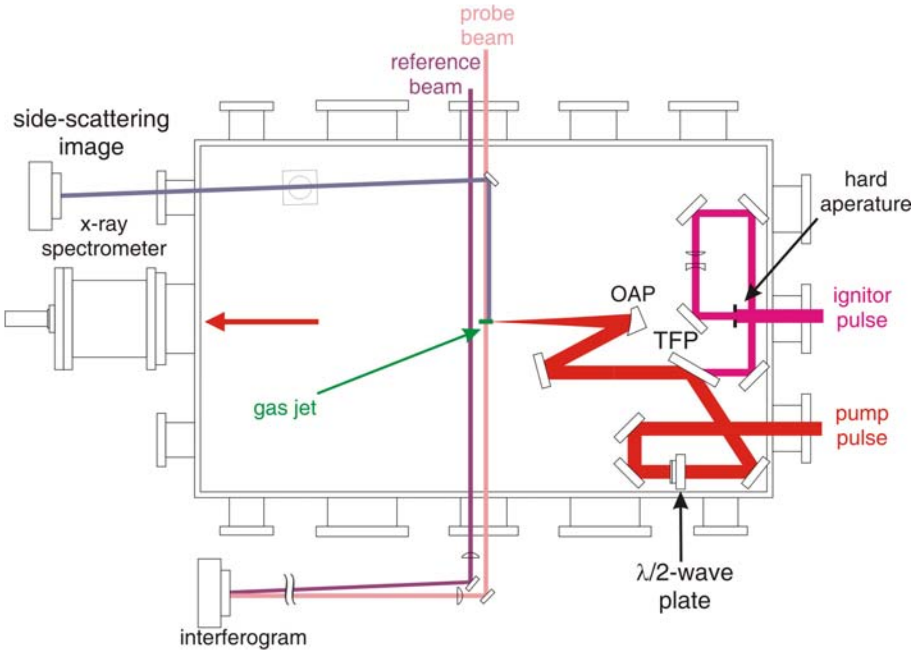
– Na-like Ar 23.2 nm and Li-like N 24.7 nm

a. Experimental setup

for 405 nm pump pulse



for 810 nm pump pulse



b. Diagnostics:

flat-field spectrometer, relay image, side scattering image and interferogram.

c. Experimental conditions:

1. nozzle: 5-mm slit nozzle
2. pump pulse: 405 nm and 810 nm, 45 fs, 8 μm spot size (FWHM)
3. working gas: Ar:H_2 ~ 1:11 and 1:20 mixed gases
   N_2:H_2 ~ 1:11 and 1:20 mixed gases

d. Procedure:

1. Use Ar/H_2 (1/11) mixed gas. Fix the longitudinal prepulse at the optimal focal position and energy found in step 1 of Part VII and fix the delay at 2.7 ns.
2. Use the 405nm, linearly-polarized pump pulse and scan the focal position of the pump pulse and the backing pressure.
3. Turn off the prepulse and scan the focal position of the pump pulse and the backing pressure.
4. If the x-ray lasing can be produced, scan the focal position and pump energy to maximize the lasing signal.
5. Change the gas target to Ar/H_2 (1/20) mixed gas and repeat step 1~4.
6. Change the gas target to N_2/H_2 (1/11) mixed gas and repeat step 1~4.
7. Change the gas target to N_2/H_2 (1/20) mixed gas and repeat step 1~4.
8. If there is no lasing, use the 810 nm pump pulse and repeat step 1~7.

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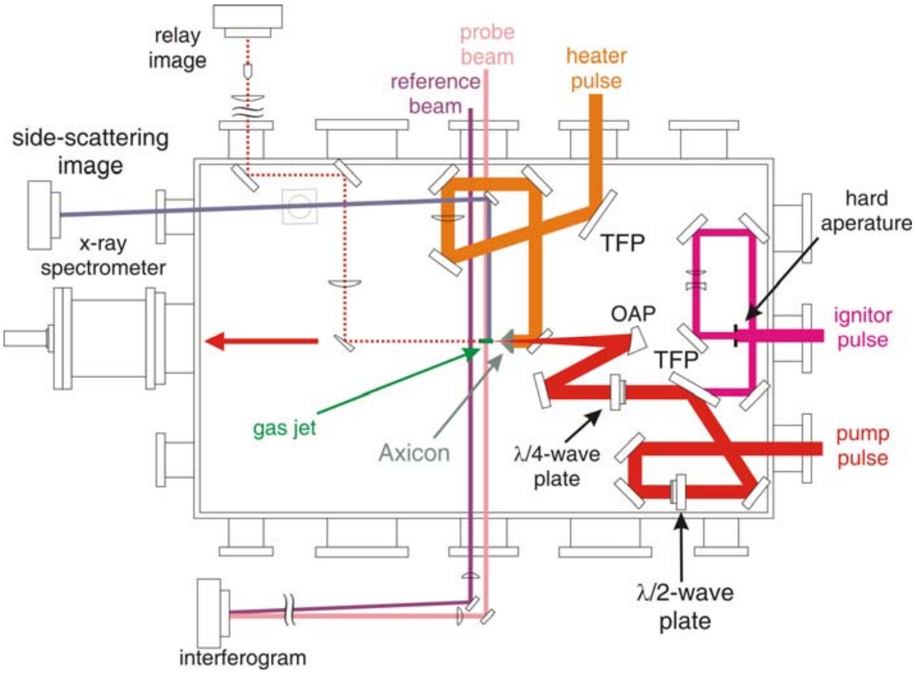
IX. OFI collisional-excitation XRL in longitudinal-ignitor, axicon-heater plasma waveguide with 810 nm pump pulses

– Ni-like Kr 32.8 nm, Ne-like Ar 46.9 nm

a. Experimental setup



b. Diagnostics:

flat-field spectrometer, relay image, side scattering image and interferogram

c. Experimental conditions:

1. nozzle: 1-cm slit nozzle
2. pump pulse: 810 nm, 45 fs, 8 μm spot size (FWHM)
3. working gas: Ar:H_2 ~ 1:4 mixed gas

   Kr:H_2 ~ 1:4 mixed gas

d. Procedure:

1. Use Ar/H_2 (1/4) mixed gas. In order to make the longitudinal ignitor passing through the whole gas region, we should optimize the focal position and energy of it with the side scattering image and the interferogram.
2. Fix the ignitor-heater separation at 200 ps and pump delay at 2.5 ns. Also fix the longitudinal ignitor at the optimal focal position and energy found in step 1. Find the optimal focal position of pump pulse and measure the guiding efficiency in the 1-cm plasma waveguide.
3. Scan pump energy and pump polarization under good guiding conditions.

4. If the x-ray lasing can be produced, scan the focal position and pump energy to maximize the lasing signal.
5. Change the gas target to Kr/H_2 (1/4) mixed gas and repeat step 1~4.