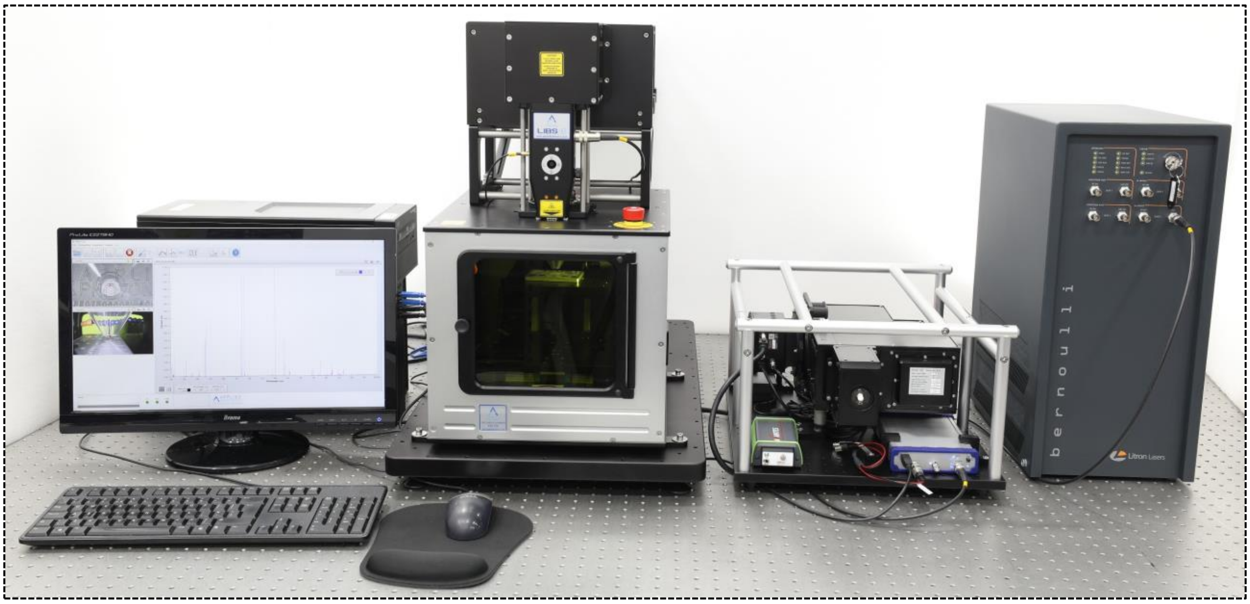
APPLIED PHOTONICS
LASER SPECTROSCOPY SOLUTIONS

Modular LIBS System Test Report
Example Configuration 2

June 2022

Customer: XXXXXXX **End User:** XXXXXXX



System Information	**Laser Information**
LIBS-6 (6-channel, 266 nm) Serial No: XXXX, Manufactured: June 2020 LIBS-6 (6-channel, 1064 nm) Serial No: XXXX, Manufactured: June 2020 AP-B-266 Serial No: XXXX, Manufactured: June 2020 AP-B-1064 Serial No: XXXX, Manufactured: June 2020	Litron Bernoulli G 200-20 Laser head Serial No: XXXX LPU550B Serial No: XXXX LUCI Serial No: XXXX
Sample Chamber Information	**Spectrometer Information**
XYZ-750 Serial No: XXXX Manufactured: June 2020	- Echelle Spectrograph, Model: EMU-120/65 UV-VIS-NIR, Serial No: XXXX (Catalina Scientific Instruments LLC) - EMCCD Camera, Model: Falcon 285, Model Number: FA285B-CL-OEM2, Serial No: XXXX (Raptor Photonics Ltd) - Digital delay pulse generator, Model: Sapphire Plus, Model number: 9212+, Serial No: XXXX (Quantum Composers Inc)
Software	**Fibre Information**
LIBSoft 2020	1 off FC-UV400-2-ME-SR Length 2 m 1 off FC-UV400-0.5-ME-SR Length 0.5m
Optional Extras	
IMG-HR High-resolution camera imaging kit (x3)	AvaLight-CAL-Mini Mercury Argon Calibration lamp Serial No: XXXX
SpecLine AM Software V 2.1 Serial No: XXXX	Coherent LabMax TOP, Serial No: XXXX EnergyMax sensor, J50MB-YAG, Serial No: XXXX

Telephone +44 (0)1756 708900 Facsimile +44 (0)1756 708909 Email mail@appliedphotonics.co.uk Web www.appliedphotonics.co.uk

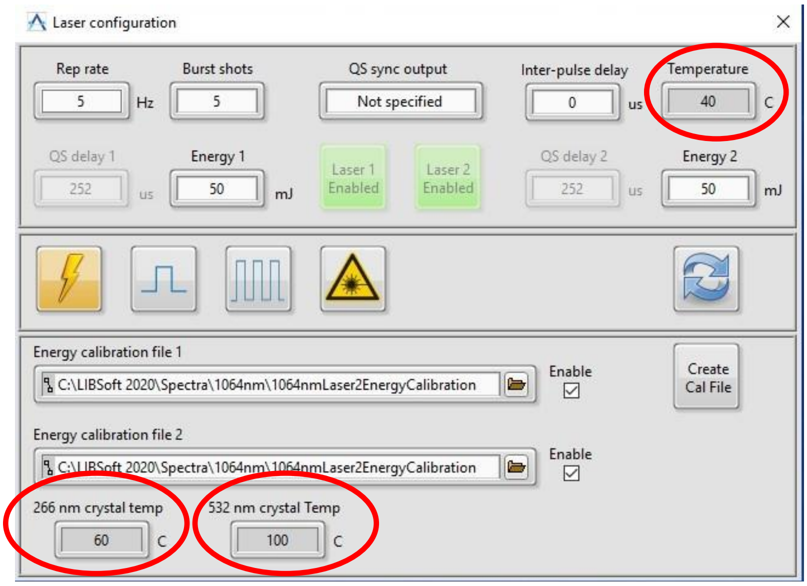
Applied Photonics Limited - Registered No. 3617150 - Registered Office: Unit 8, Carleton Business Park, Skipton, North Yorkshire BD23 2DE

Laser Energy Calibration

The laser beam energy was measured using a calibrated laser energy meter (Coherent LabMax TOP Laser Power/Energy meter with J-50MB-YAG detector head). The laser pulse energy was measured at the output of the LIBS-6, with the transparent nozzle aperture removed and the detector head positioned close to the optics array so that the laser beam diameter is relatively large (so as not to damage the detector). The energy measurements are therefore representative of the laser pulse energy at the sample. The laser energy calibration was performed by varying the Flashlamp-Q-Switch (FL-QS) delay (FL-QS Delay values: 125 µs - 340 µs) and measuring the average, minimum and maximum energy as well as standard deviation of 50 shots. The repetition rate was set to 5 Hz. Prior to the measurements and for laser warm up/stabilization purposes, the flashlamp was operating without lasing (i.e. Q-Switch off) for 10 min. The laser coolant temperature during the laser energy calibration measurements ranged from 40 to 42 ºC. **For optimum laser performance, the coolant temperature should reach a minimum of 30°C when the laser is configured for 1064 nm. This is achieved by firing the flashlamp with the Q-Switch disabled until this temperature is reached. If the laser is configured for 266 nm, the coolant temperature should be allowed to reach a minimum of 40°C for optimum performance.**

For both configurations 266 nm and 1064 nm, the harmonic generator crystal temperatures inside the laser head should reach their optimum values, 100°C for the 532 nm crystal and 60°C for the 266 nm crystal.

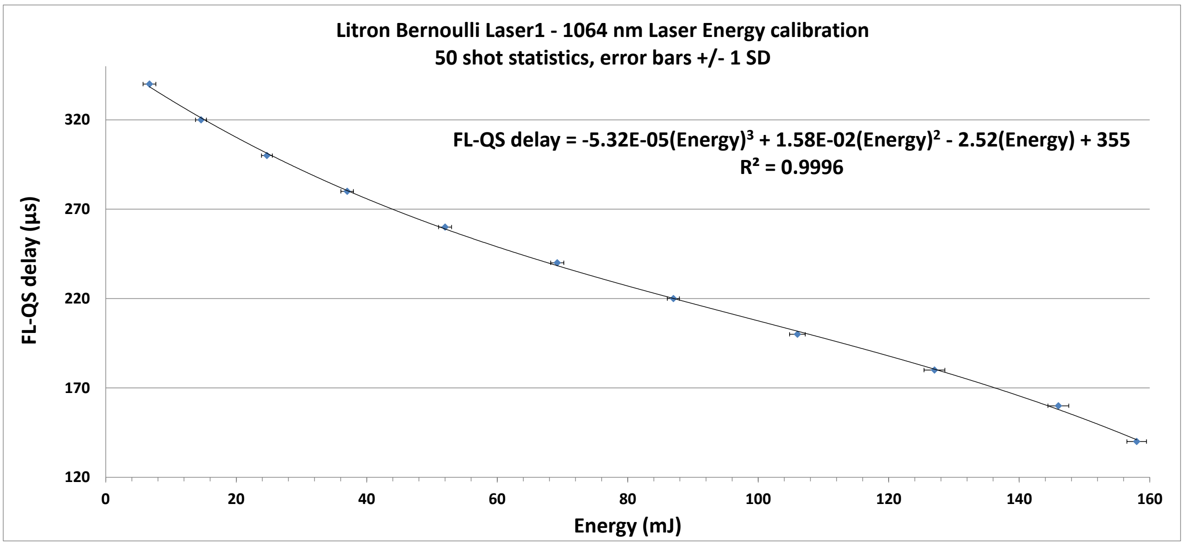
The temperature readings of the laser coolant and the crystals are reported in LIBSoft in the laser configuration window.

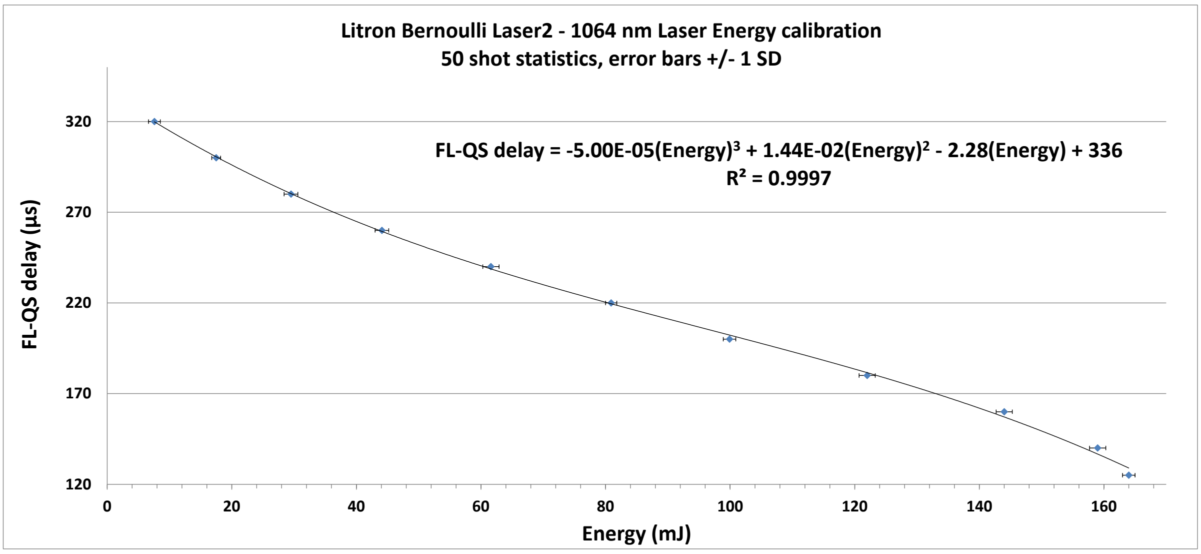


<u>1064 nm configuration</u>

Important. Attach the laser head to the 1064 nm adaptor platform, the 1064 nm mirror module and the 1064 nm LIBS-6 module (each item is labelled accordingly). Please refer to the User's Manual for further guidance on configuring the hardware. Note that using the laser in the 1064 nm configuration with the 266 nm mirror module and/or the 266 nm LIBS-6 module will lead to damage of the optics and possibly also the laser head.

FL-QS Delay (µs)	Laser 1 Energy					Laser 2 Energy				
	Mean (mJ)	SD (mJ)	RSD (%)	Min. (mJ)	Max. (mJ)	Mean (mJ)	SD (mJ)	RSD (%)	Min. (mJ)	Max. (mJ)
125	159	1.3	0.8	157	162	164	1.0	0.6	161	166
140	158	1.5	0.9	155	162	159	1.3	0.8	155	162
160	146	1.6	1.1	141	149	144	1.3	0.9	141	147
180	127	1.6	1.3	122	129	122	1.3	1.1	120	126
200	106	1.2	1.1	104	109	99.9	1.0	1.0	97.6	100
220	87.0	0.93	1.1	84.7	88.8	80.9	0.91	1.1	78.7	83.0
240	69.2	1.0	1.4	66.9	71.2	61.6	1.3	2.1	57.2	64.3
260	52.0	1.0	1.9	49.6	54.1	44.1	1.1	2.5	41.8	46.7
280	37.0	0.96	2.6	34.8	39.2	29.5	1.1	3.7	26.4	31.8
300	24.7	0.83	3.4	22.8	26.0	17.5	0.71	4.1	15.5	18.9
320	14.6	0.83	5.7	12.7	16.8	7.58	0.95	12	5.16	9.35
340	6.71	0.98	15	3.63	6.98	--	--	--	--	--

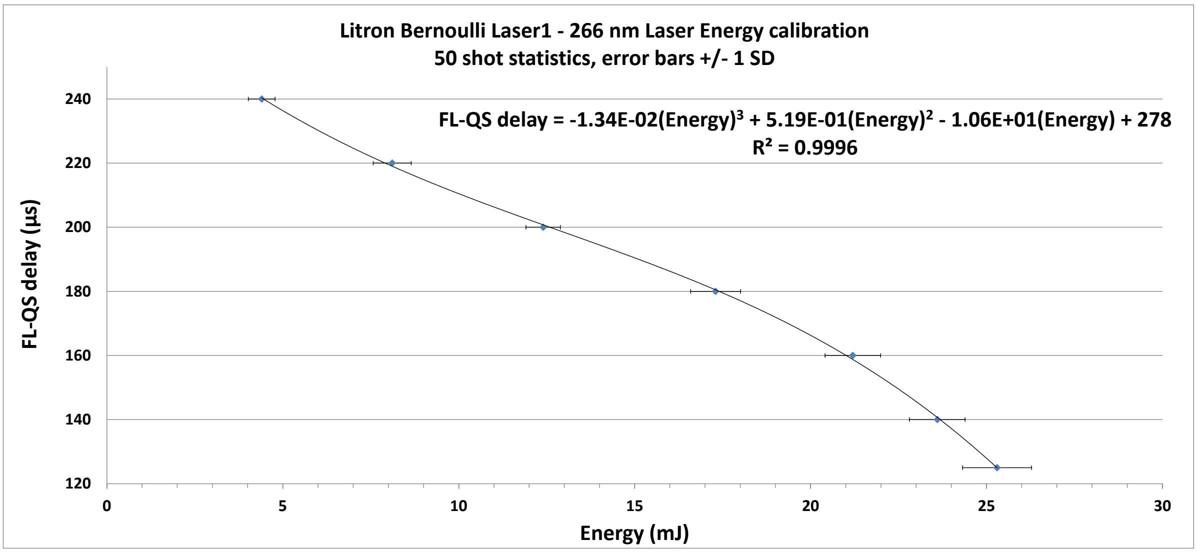


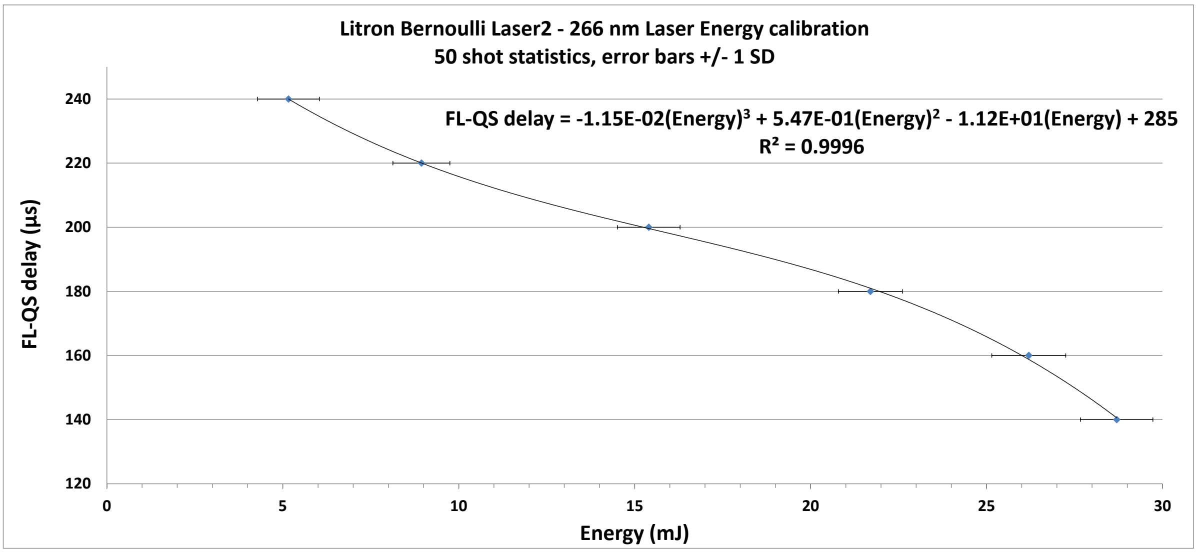


266 nm configuration

Important. Attach the laser to the 266 nm adaptor platform, the 266 nm mirror module and the 266 nm LIBS-6 module (each item is labelled accordingly). Please refer to the User's Manual for further guidance on configuring the hardware. Note that using the laser in the 266 nm configuration with the 1064 nm mirror module and/or the 1064 nm LIBS-6 module will lead to damage of the optics and possibly also the laser head.

FL-QS Delay (µs)	Laser 1 Energy					Laser 2 Energy				
	Mean (mJ)	SD (mJ)	RSD (%)	Min. (mJ)	Max. (mJ)	Mean (mJ)	SD (mJ)	RSD (%)	Min. (mJ)	Max. (mJ)
125	25.3	0.98	3.9	22.1	27.4	28.7	1.03	3.6	26.0	30.6
140	23.6	0.79	3.3	21.8	25.3	28.7	1.05	3.7	25.7	30.9
160	21.2	0.79	3.7	19.9	23.1	26.2	0.91	3.5	24.0	28.4
180	17.3	0.71	4.1	15.8	19.1	21.7	0.89	4.1	18.8	23.7
200	12.4	0.49	4.0	11.7	13.5	15.4	0.81	5.3	13.3	17.2
220	8.11	0.54	6.7	6.99	9.14	8.94	0.88	9.8	7.33	10.8
240	4.40	0.38	8.6	3.61	5.39	5.16	0.58	11	4.05	6.21



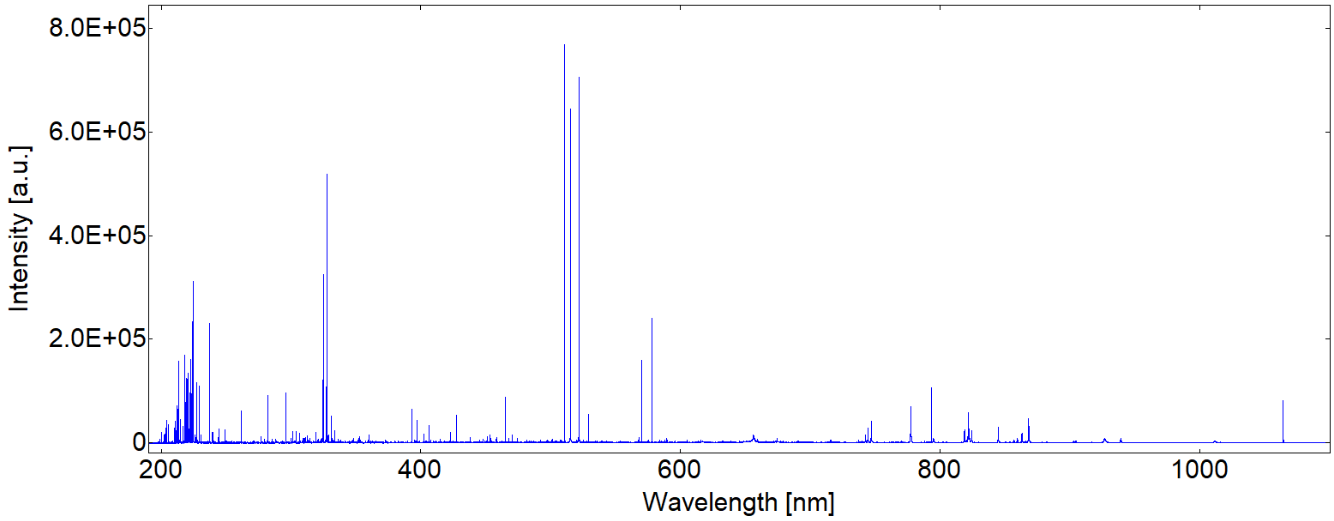


Test spectra 1064 nm configuration (UV3 Echelle dispersion cassette)

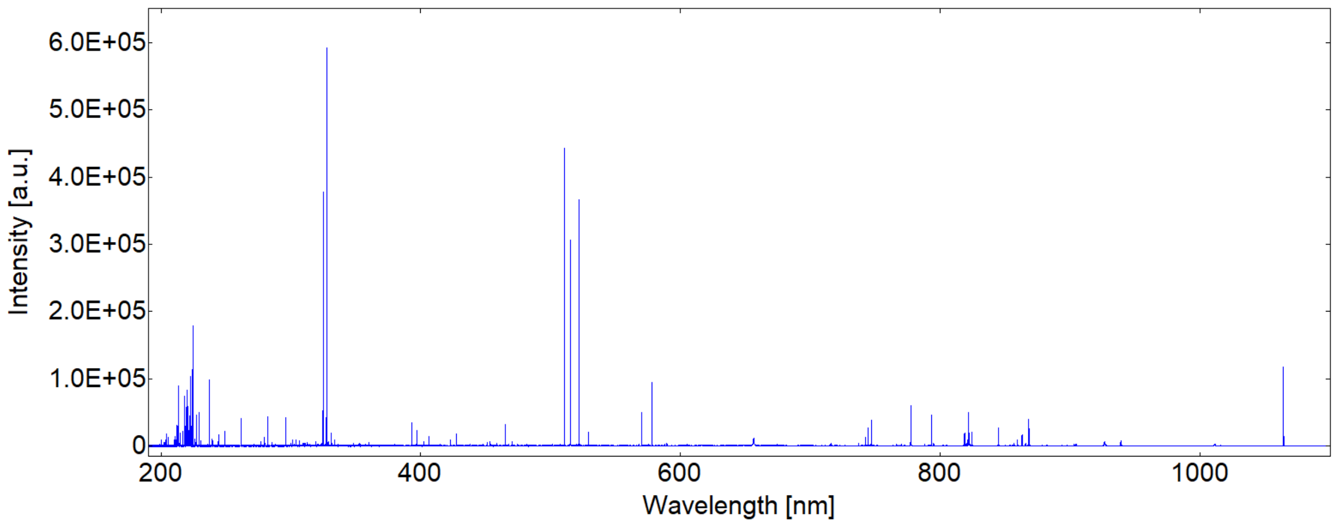
The spectra were acquired using the following parameters:

- Echelle dispersion cassette: UV3 (≈ 26,600 average resolving power), Slit size: 9 x 30 µm, Aperture Stop: 16 mm
- EMCCD Gain = 2800
- Wavelength step = 0.004 nm
- Wavelength range 190-1100 nm
- Integration time = 100 µs
- Integration delay = as stated in each spectrum
- Laser energy at the sample= approx. 50 mJ (unless otherwise stated, only one laser was fired while the other one remained off)
- Accumulation/Acquisition shots = 25
- Conditioning / Cleaning shots = 25
- Purge gas: Air or Argon (stated in each spectrum)

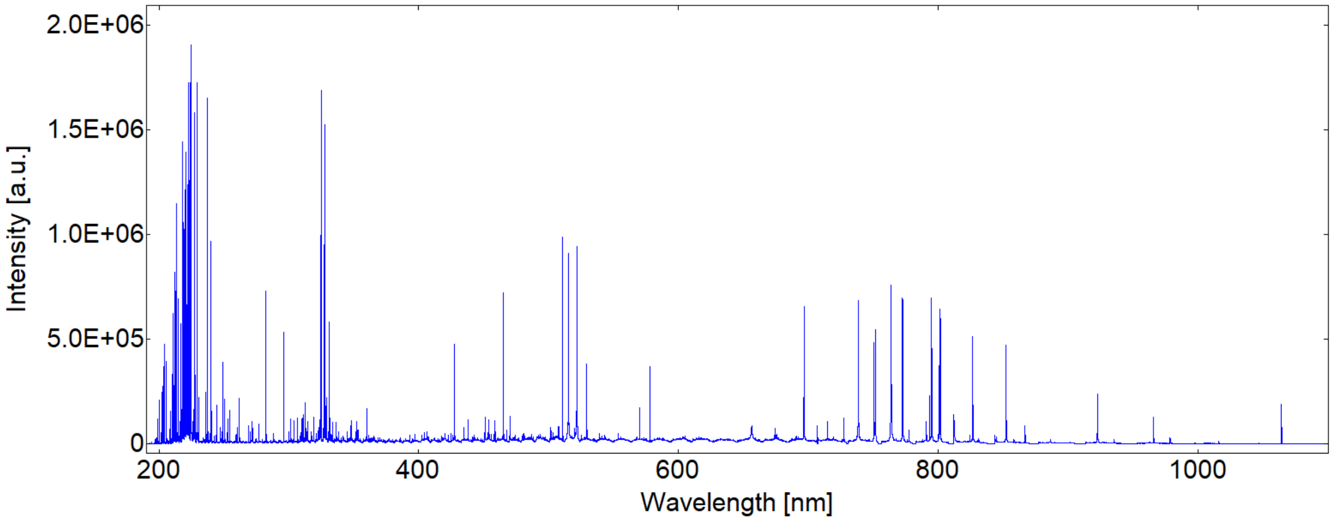
High purity copper (Air) 1µs integration delay



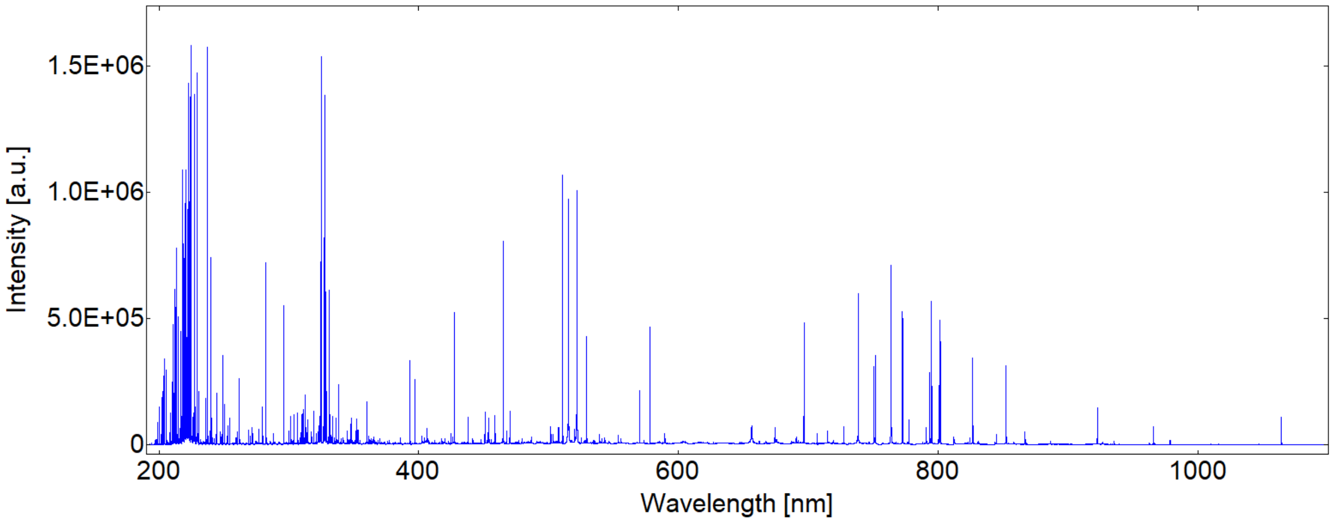
High purity copper (Air) 3 µs integration delay



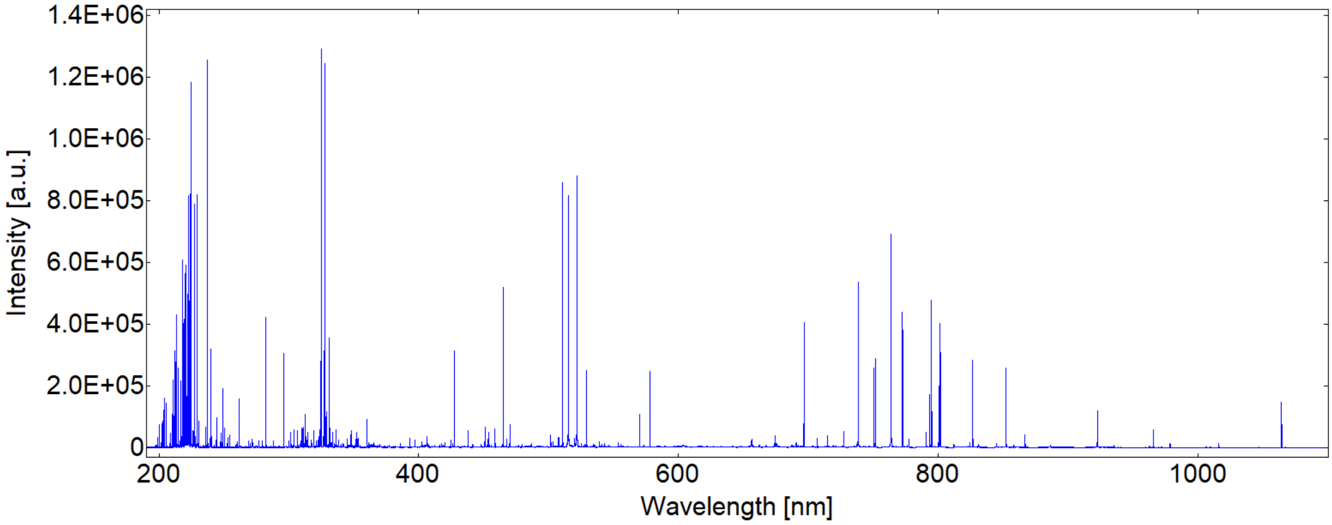
High purity copper (Argon) 1 µs integration delay



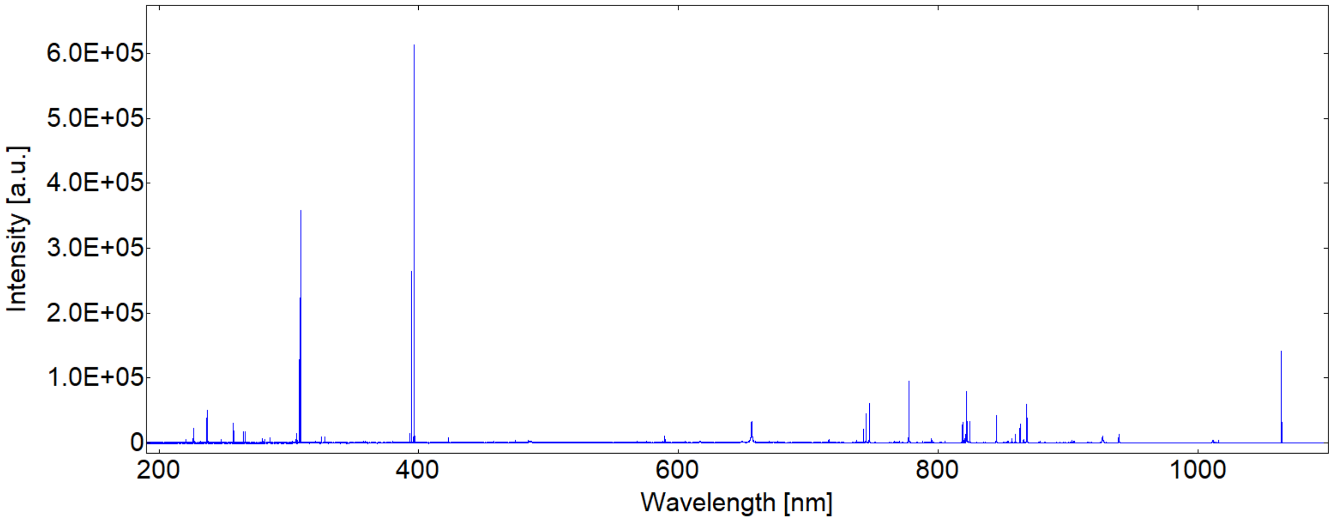
High purity copper (Argon) 3 µs integration delay



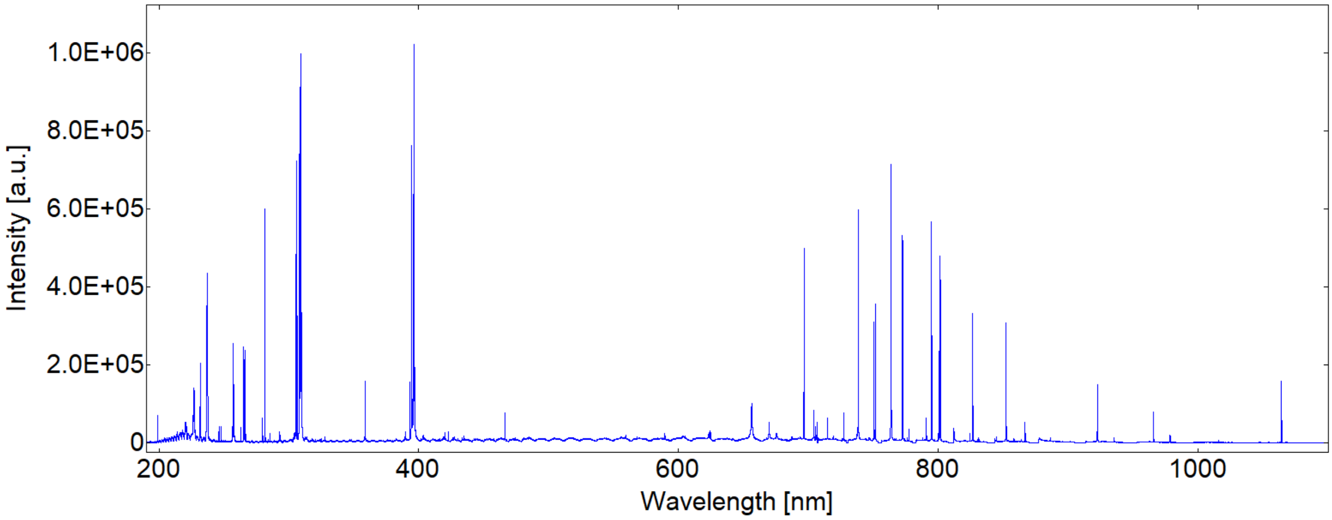
High purity copper (Argon) 10 µs integration delay



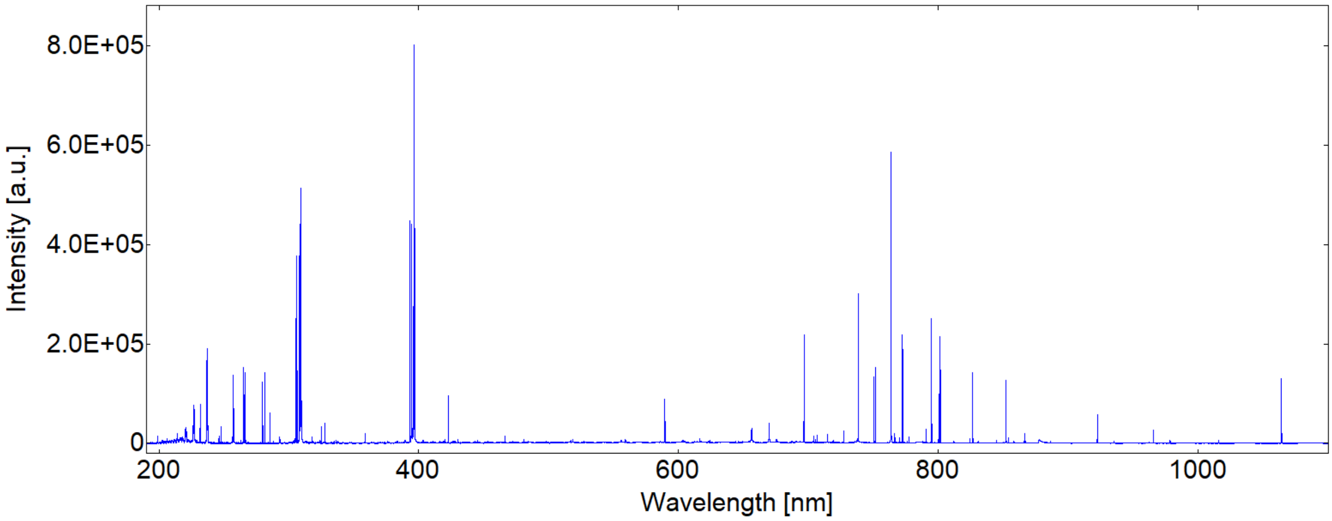
High purity aluminium (Air) 3 µs integration delay



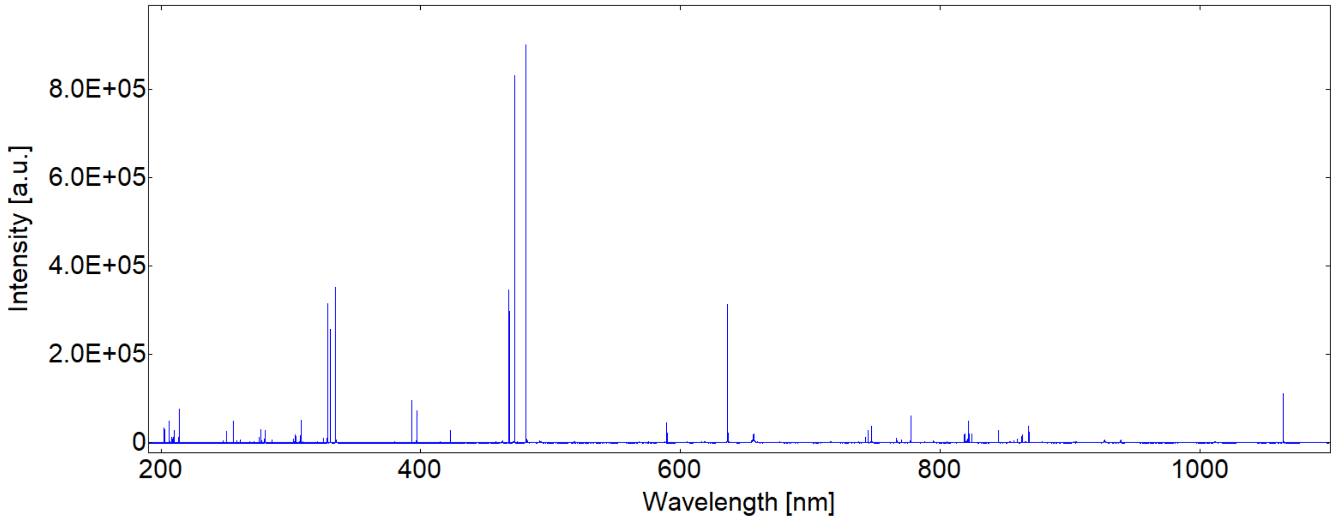
High purity aluminium (Argon) 3 µs integration delay



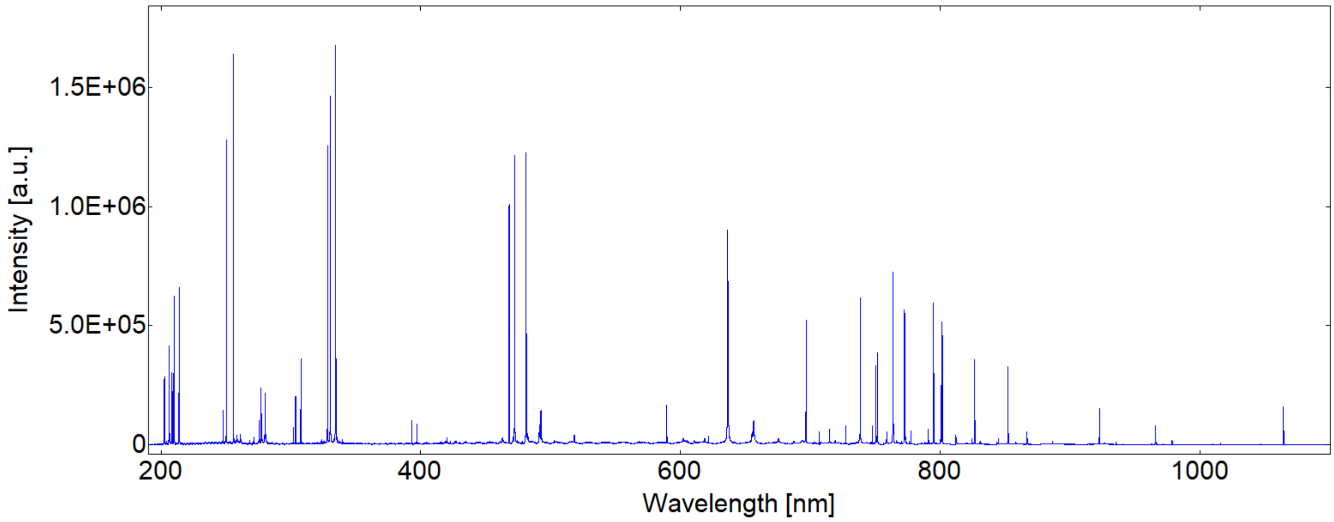
High purity aluminium (Argon) 10 µs integration delay



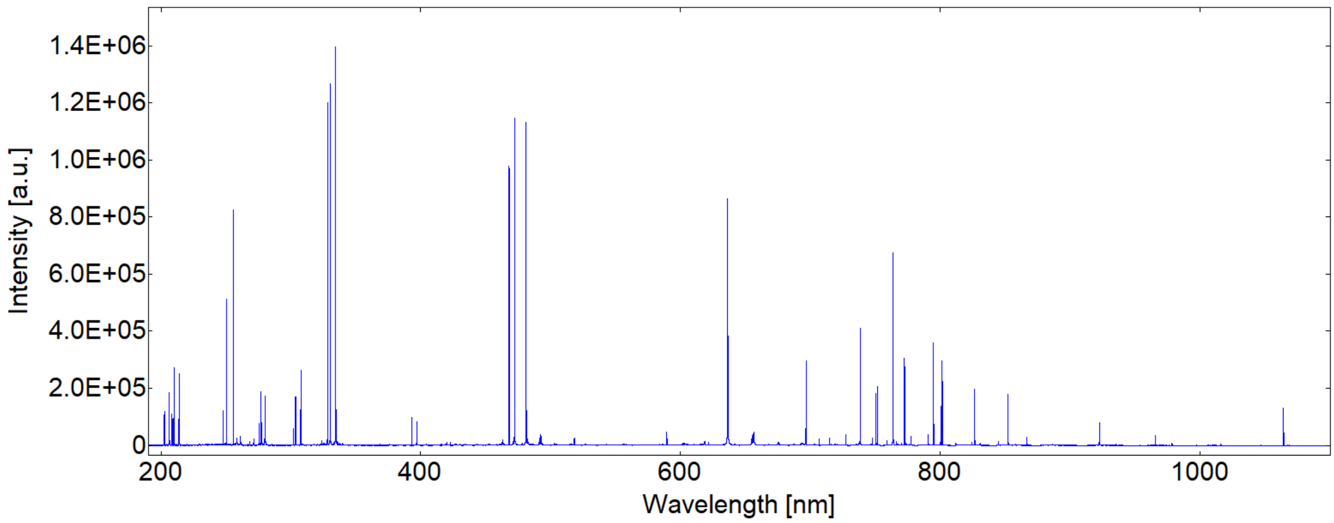
High purity zinc (Air) 3 µs integration delay



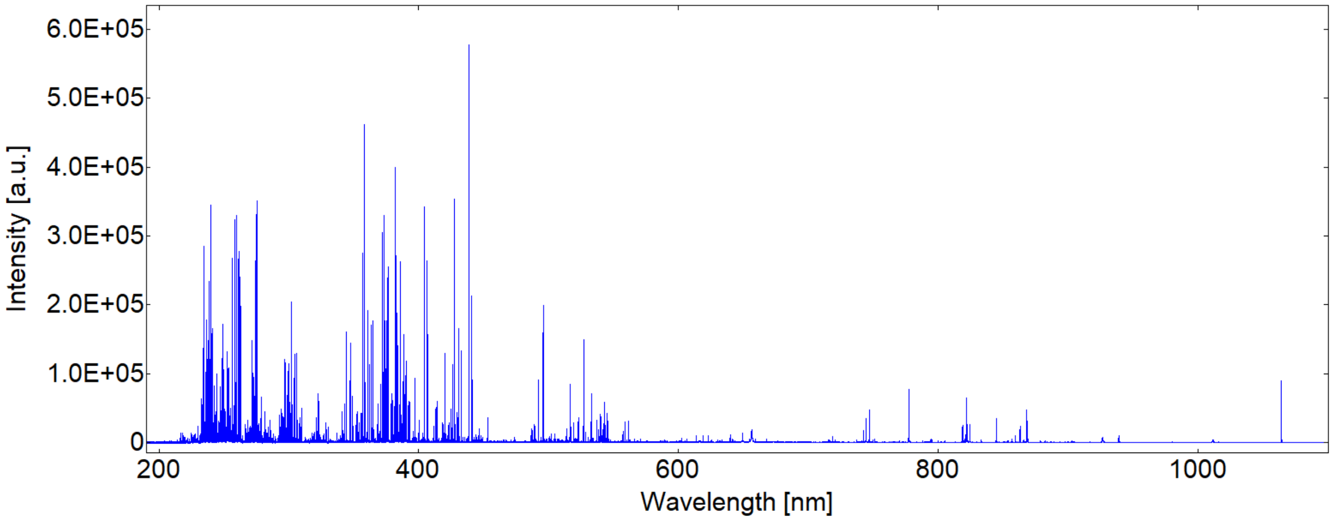
High purity zinc (Argon) 3 µs integration delay



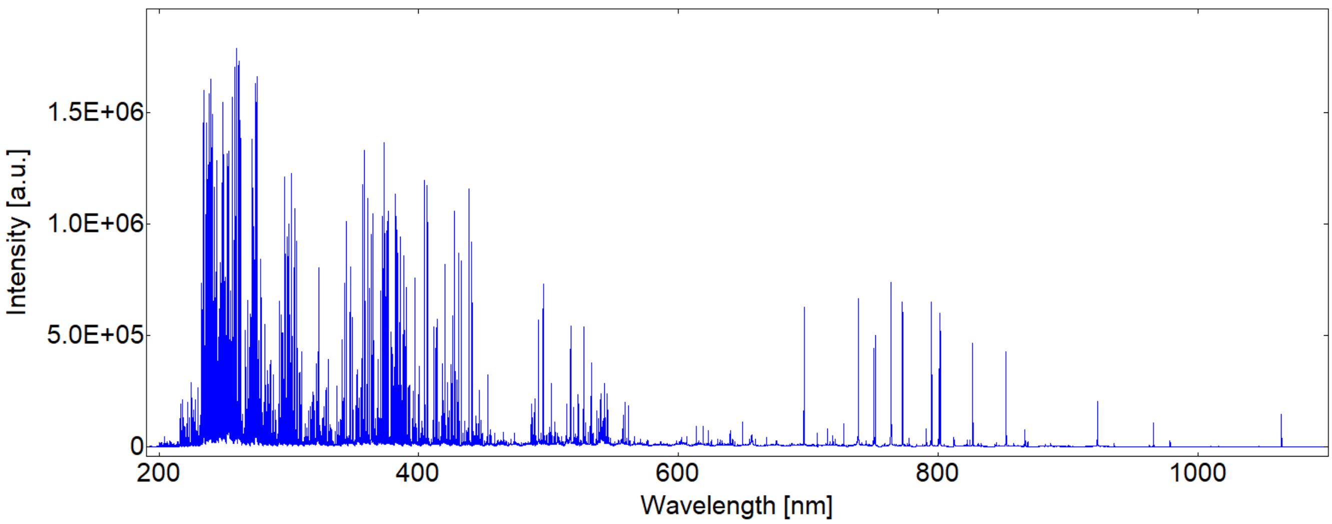
High purity zinc (Argon) 10 µs integration delay



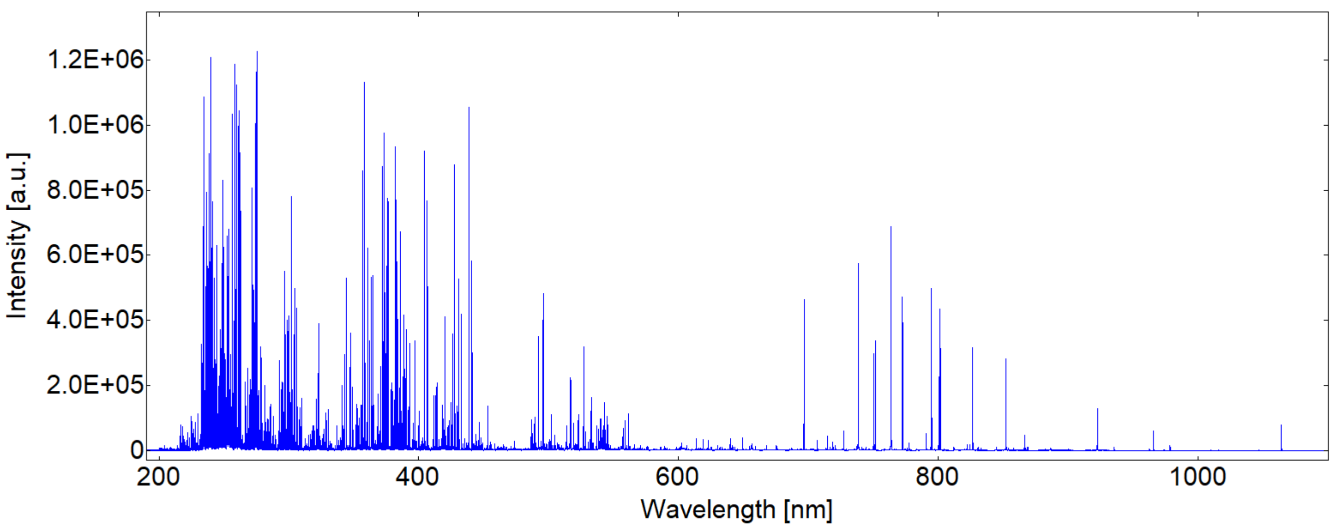
High purity iron (Air) 3 µs integration delay



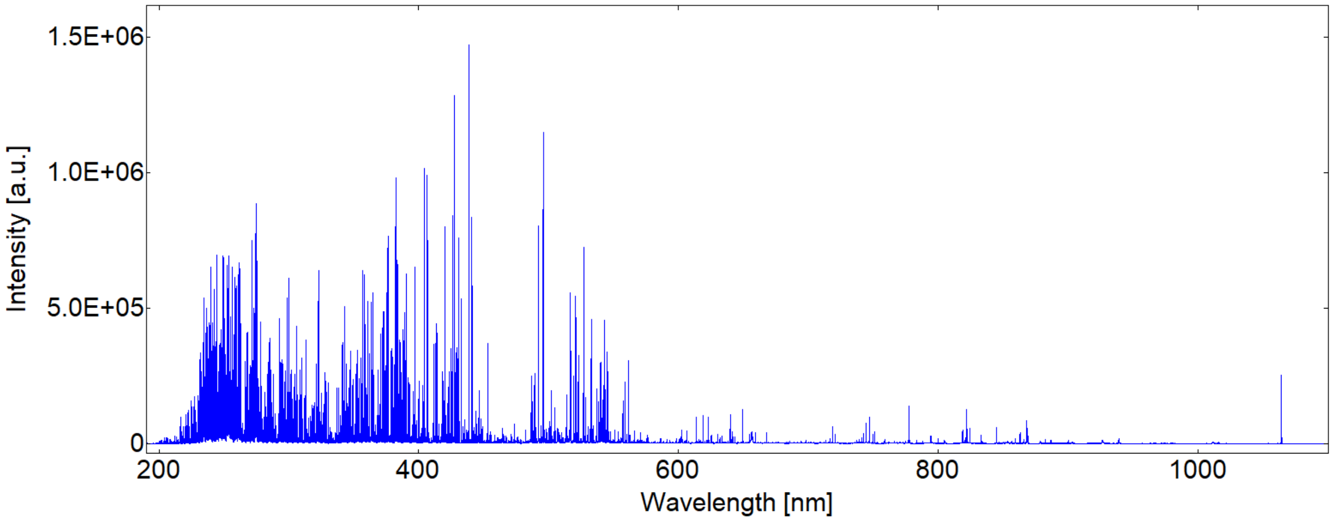
High purity iron (Argon) 3 µs integration delay



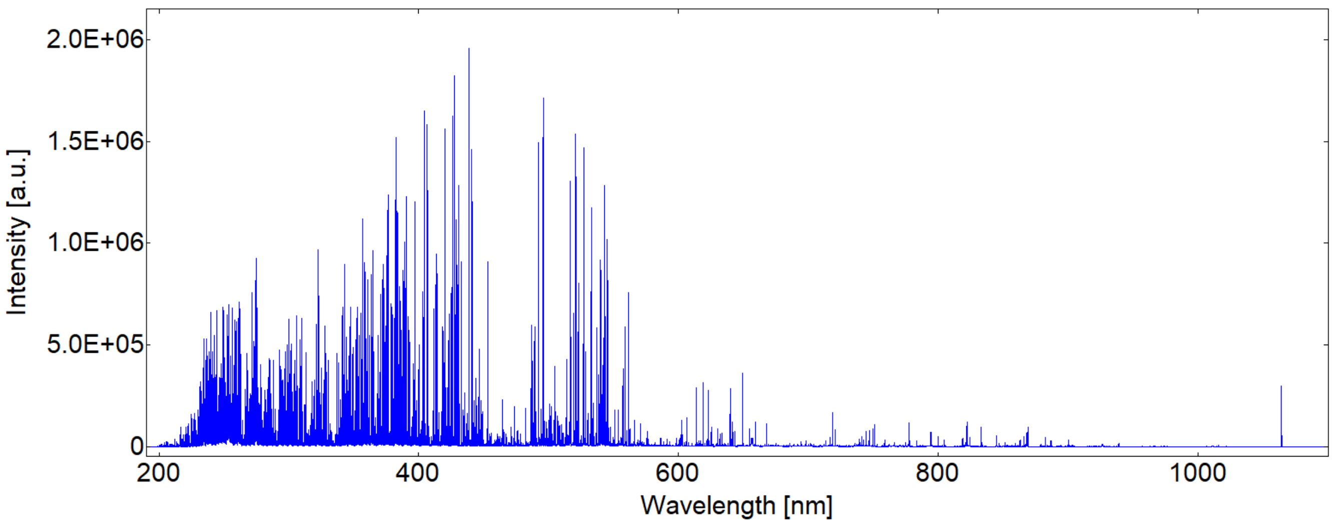
High purity iron (Argon) 10 µs integration delay



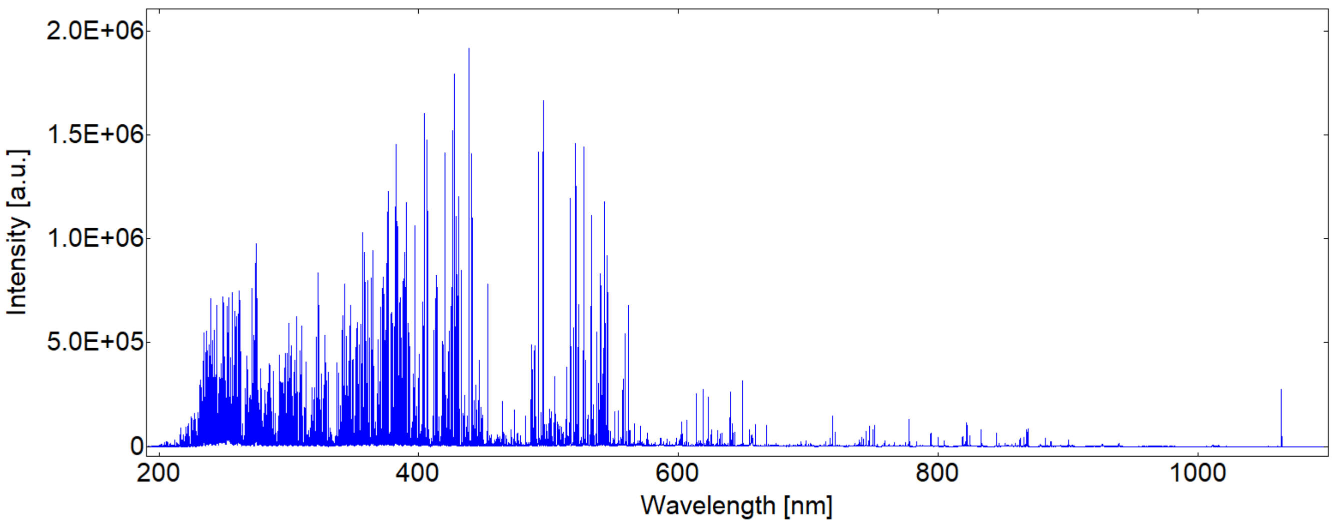
Double pulse spectrum, Interpulse Delay= 0 µs (Laser1 Energy= 50 mJ, Laser2 Energy 50mJ)
Low alloy steel sample (Air) 3 µs integration delay (Q-Switch sync signal from Laser2 was used as trigger)



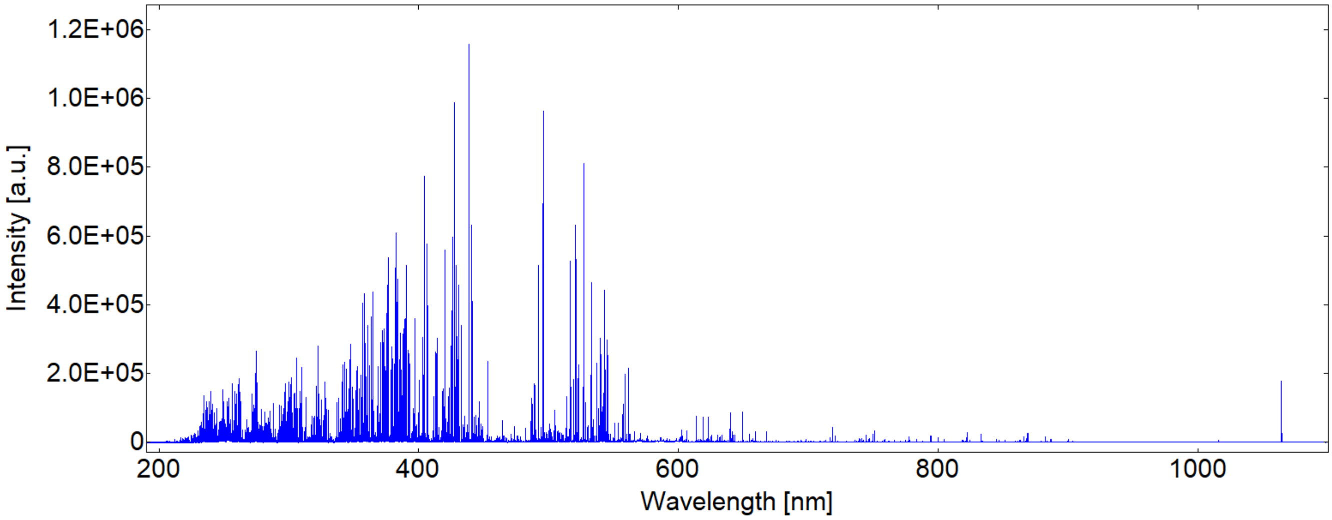
Double pulse spectrum, Interpulse Delay= 1 µs (Laser1 Energy= 50 mJ, Laser2 Energy 50mJ)
Low alloy steel sample (Air) 3 µs integration delay (Q-Switch sync signal from Laser2 was used as trigger)



Double pulse spectrum, Interpulse Delay= 5 µs (Laser1 Energy= 50 mJ, Laser2 Energy 50mJ)
Low alloy steel sample (Air) 3 µs integration delay (Q-Switch sync signal from Laser2 was used as trigger)



Double pulse spectrum, Interpulse Delay= 50 µs (Laser1 Energy= 50 mJ, Laser2 Energy 50mJ)
Low alloy steel sample (Air) 3 µs integration delay (Q-Switch sync signal from Laser2 was used as trigger)

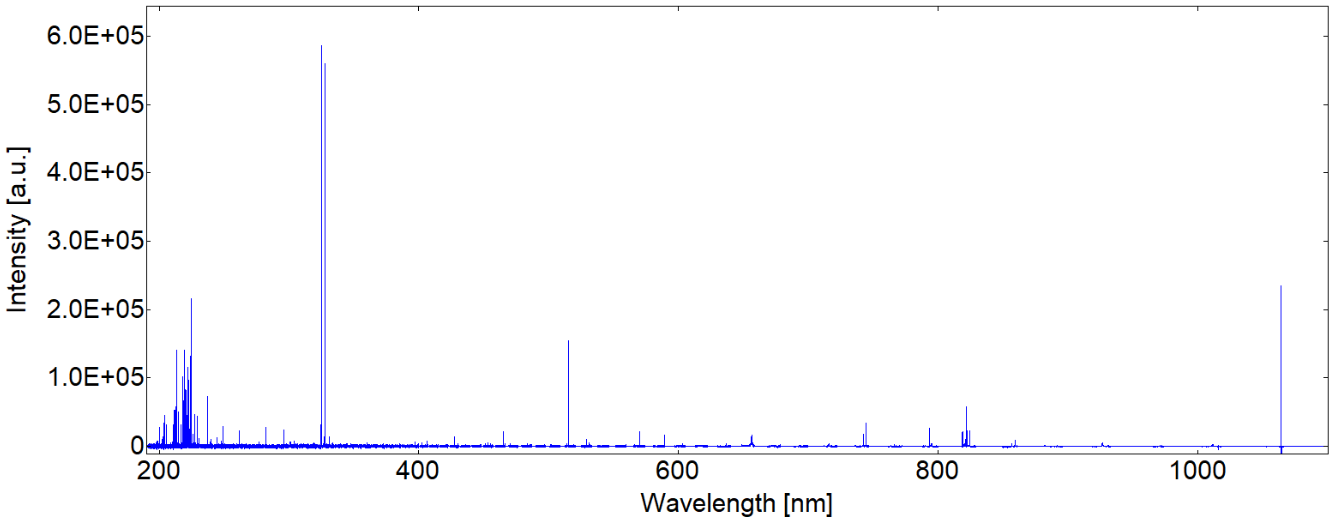


Test spectra 1064 nm configuration (IX1 Echelle dispersion cassette)

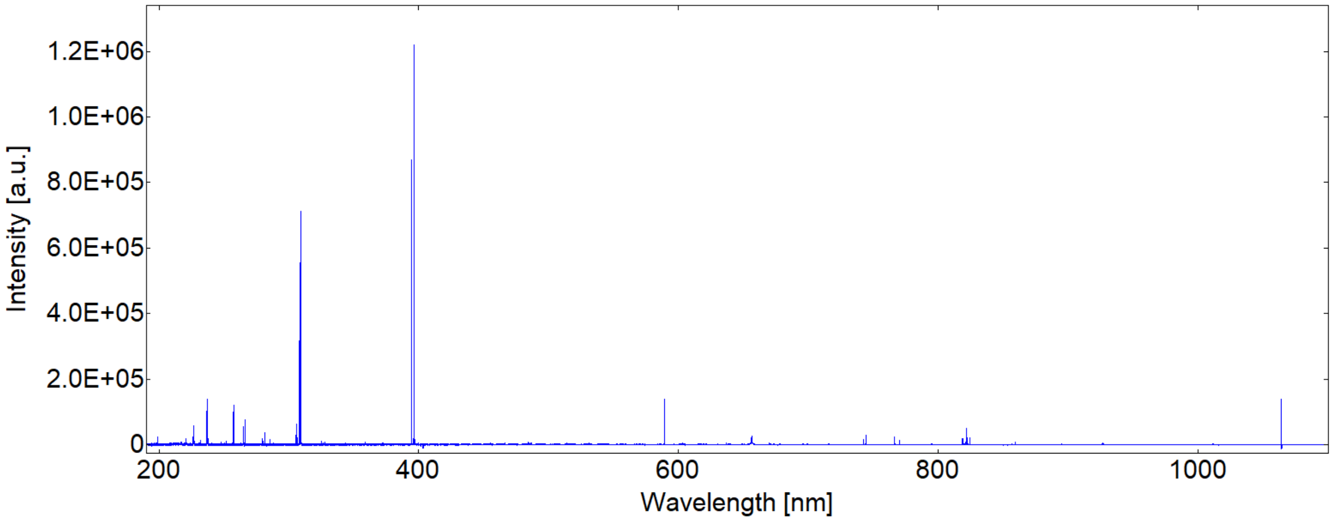
The spectra were acquired using the following parameters:

- Echelle dispersion cassette: IX1 (≈ 44,200 average resolving power), Slit size: 10 x 30 µm, Aperture Stop: 16 mm
- EMCCD Gain = 2800
- Wavelength step = 0.004 nm
- Wavelength range 190-1100 nm
- Integration time = 100 µs
- Integration delay = 3 µs
- Laser energy at the sample= approx. 50 mJ (only one laser was fired while the other one remained off)
- Accumulation/Acquisition shots = 25
- Conditioning / Cleaning shots = 25
- Purge gas: Air

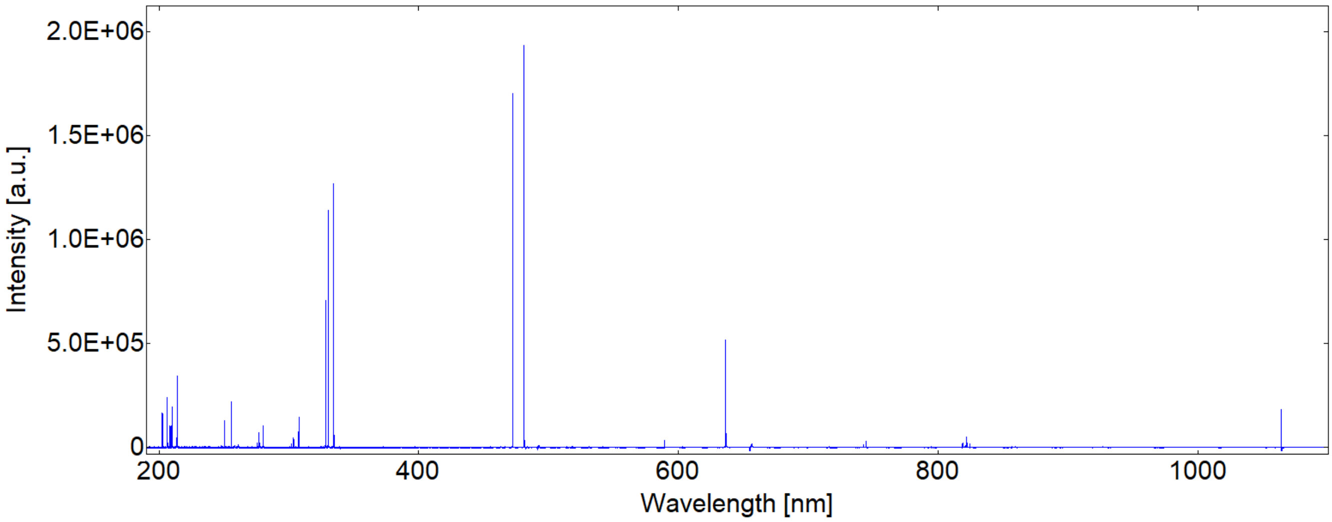
High purity copper (Air) 3 µs integration delay



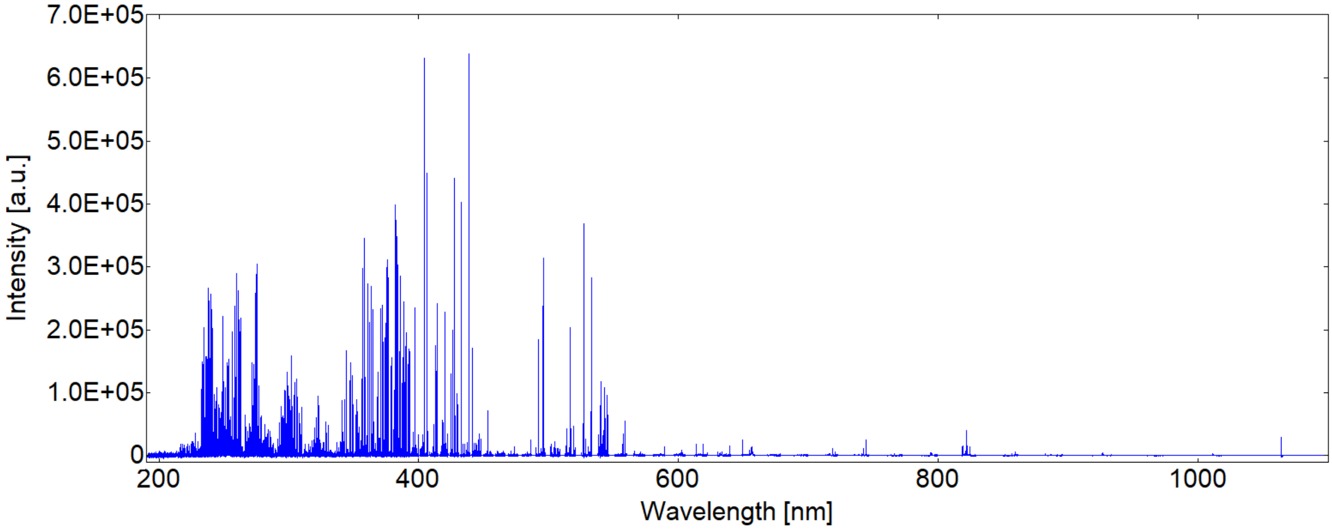
High purity aluminium (Air) 3 µs integration delay



High purity zinc (Air) 3 µs integration delay



High purity iron (Air) 3 µs integration delay

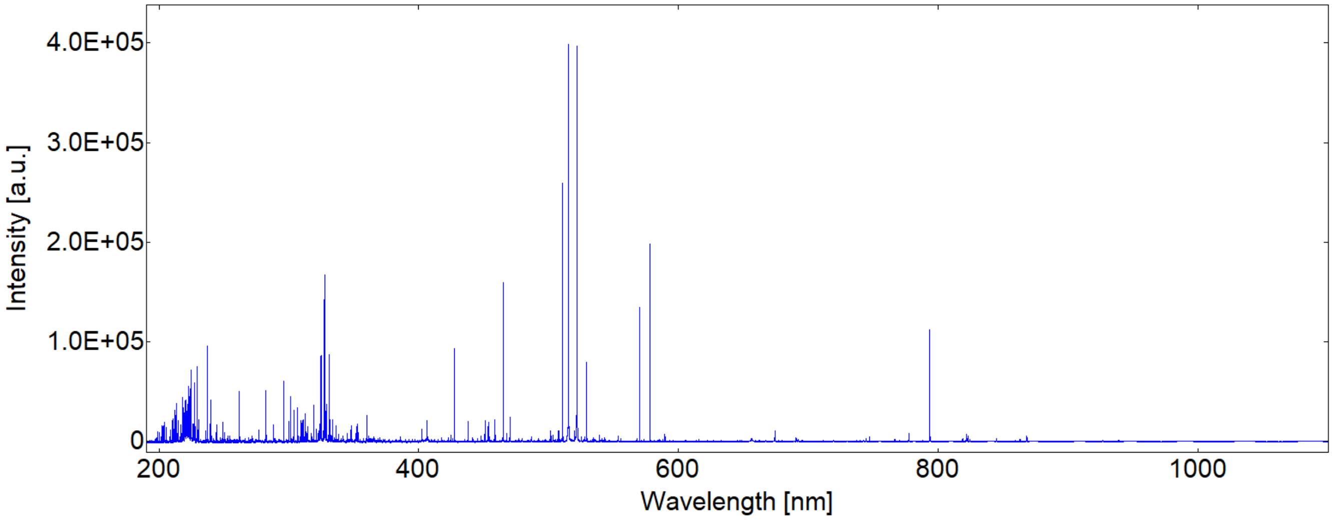


Test spectra 266 nm configuration (UV3 Echelle dispersion cassette)

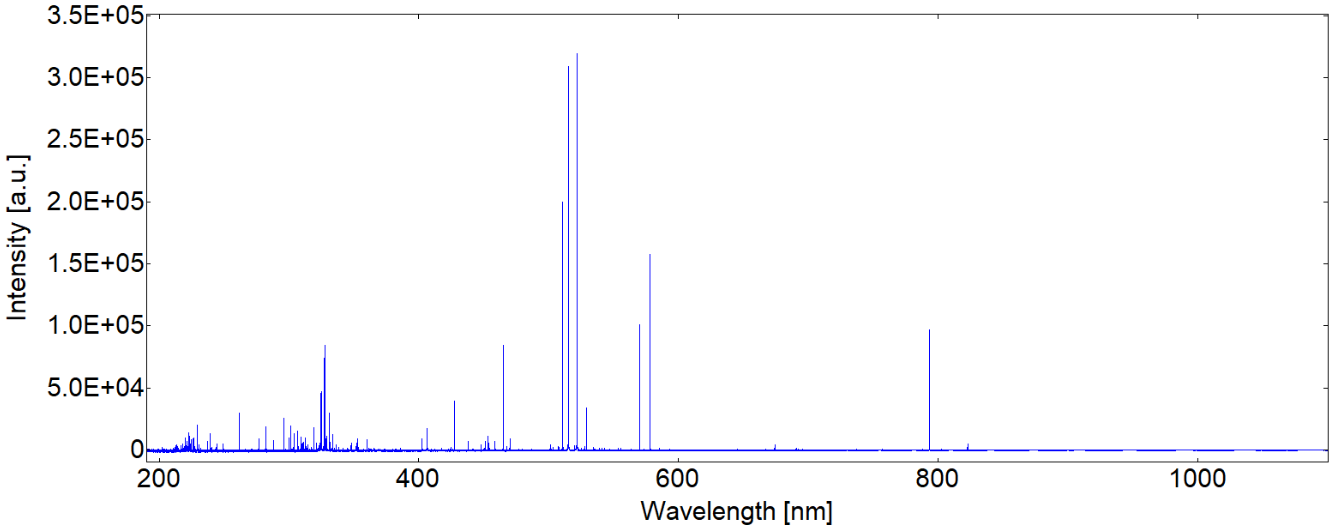
The spectra were acquired using the following parameters:

- Echelle dispersion cassette: UV3 (≈ 26,600 average resolving power), Slit size: 9 x 30 µm, Aperture Stop: 16 mm
- EMCCD Gain = 2800
- Wavelength step = 0.004 nm
- Wavelength range 190-1100 nm
- Integration time = 100 µs
- Integration delay = 3 µs
- Laser energy at the sample= approx. 25 mJ (only one laser was fired while the other one remained off)
- Accumulation/Acquisition shots = 25
- Conditioning / Cleaning shots = 25
- Purge gas: Air or Argon (stated in each spectrum)

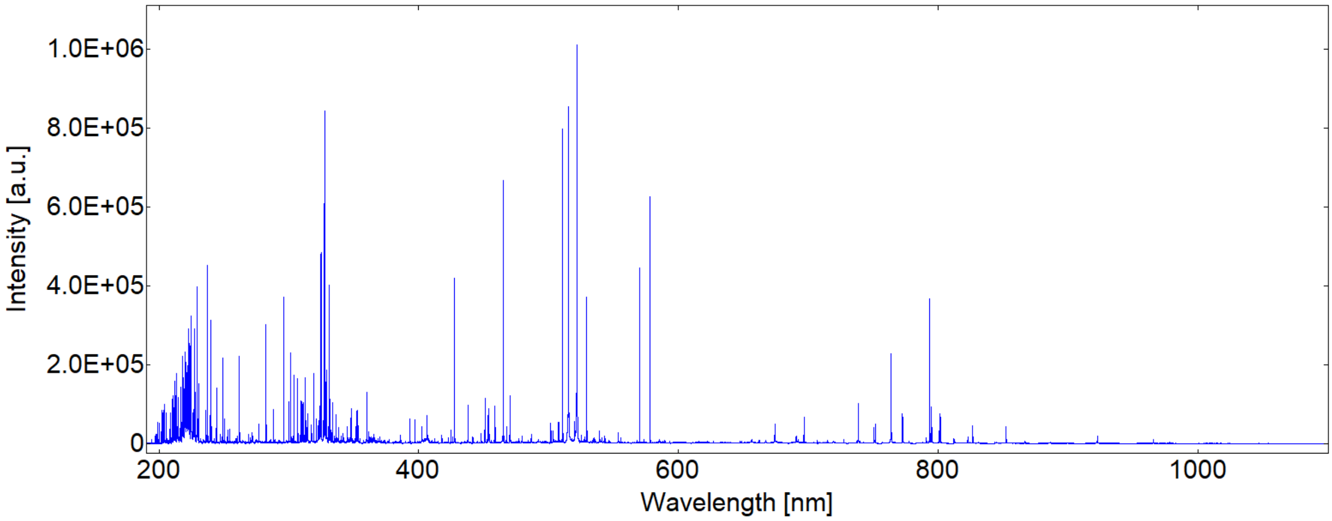
High purity copper (Air) 1 µs integration delay



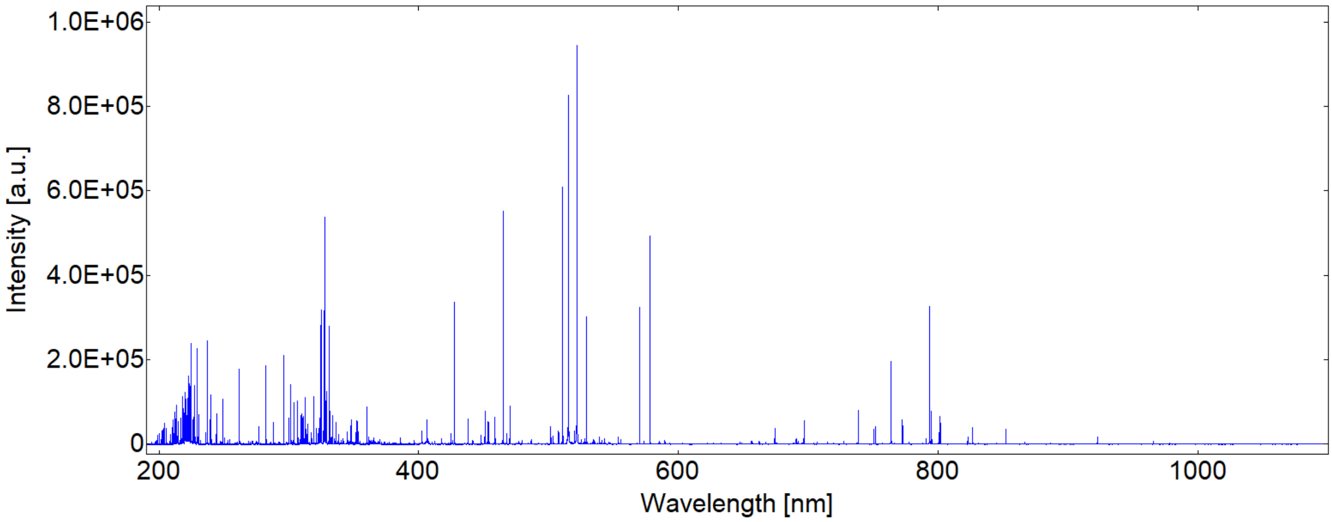
High purity copper (Air) 3 µs integration delay



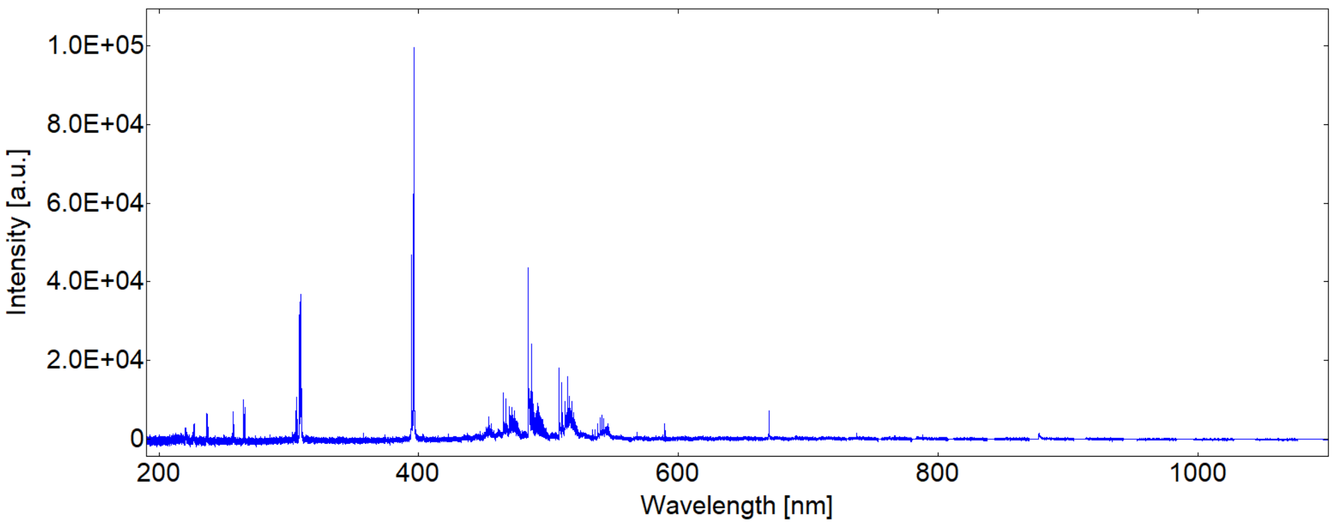
High purity copper (Argon) 1 µs integration delay



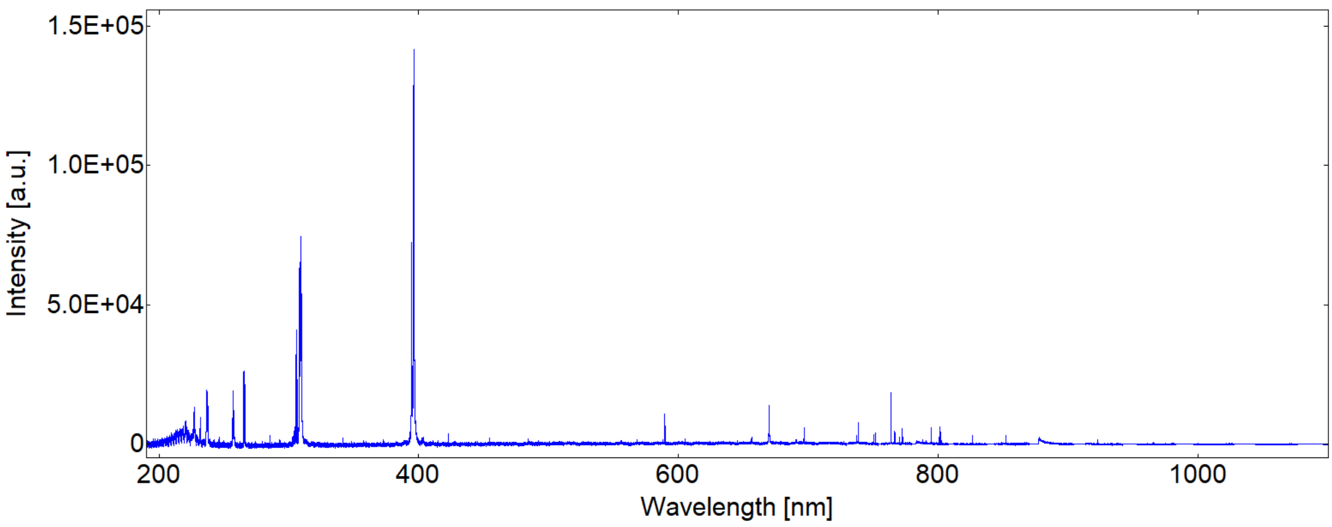
High purity copper (Argon) 3 µs integration delay



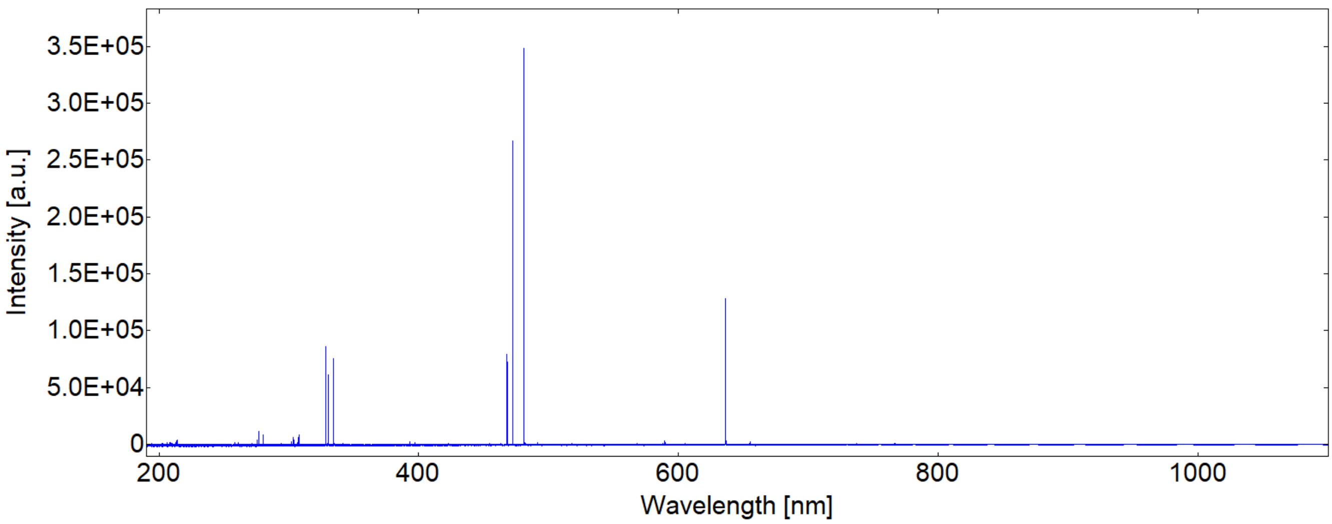
High purity aluminium (Air) 3 µs integration delay



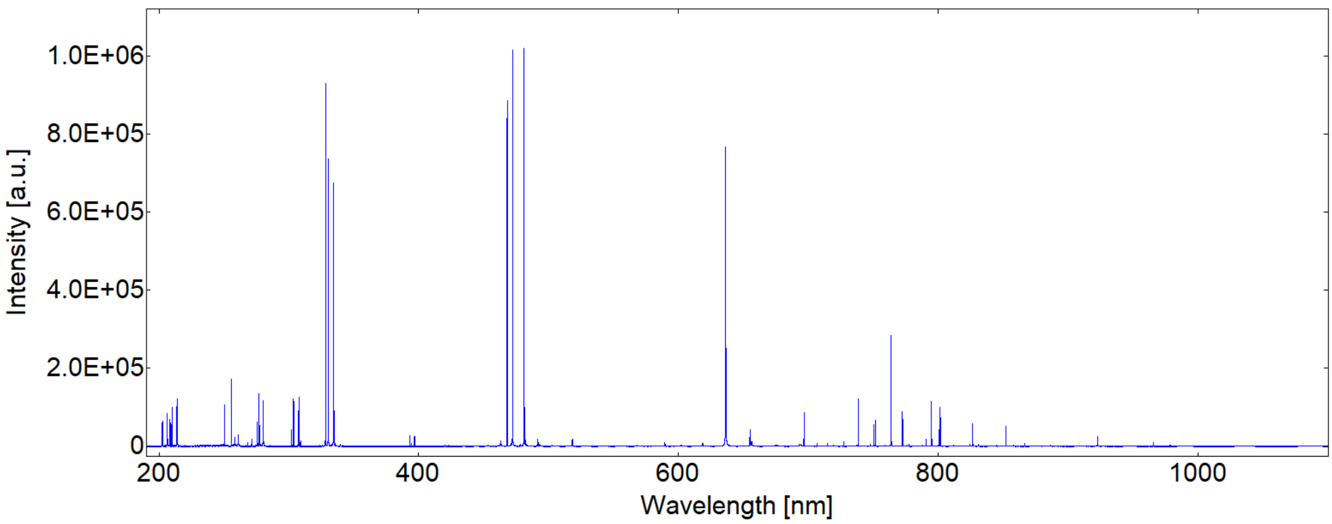
High purity aluminium (Argon) 3 µs integration delay



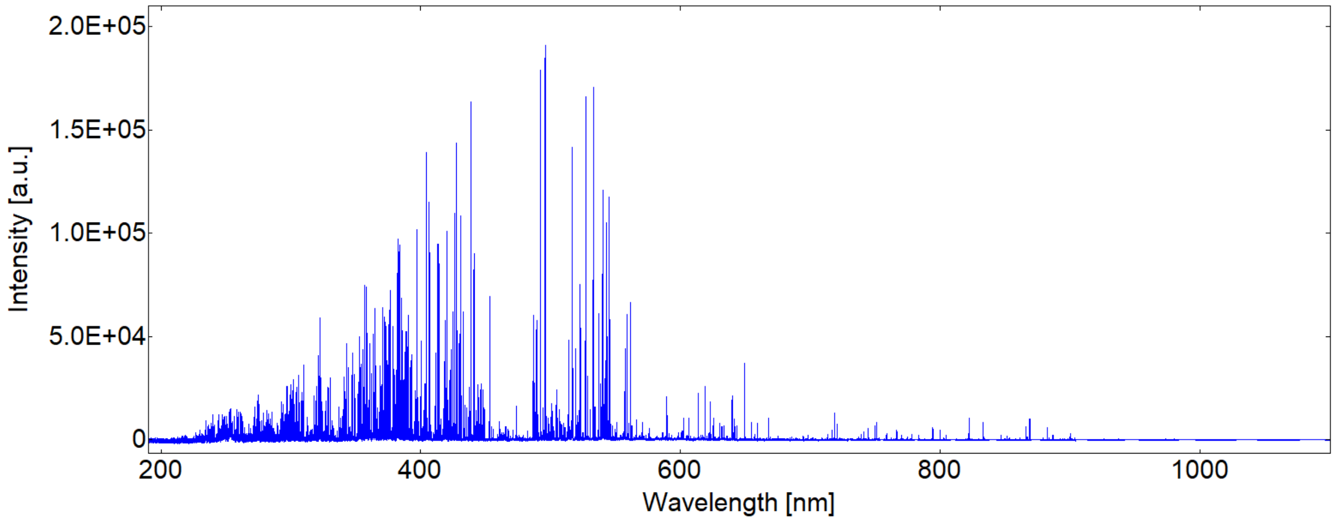
High purity zinc (Air) 3 µs integration delay



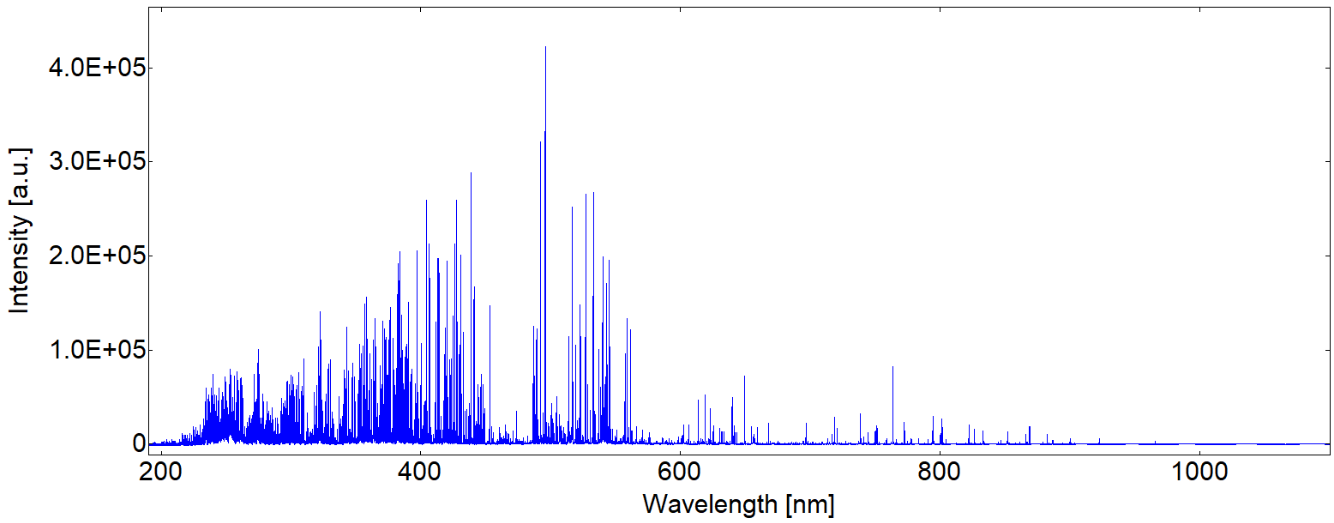
High purity zinc (Argon) 3 µs integration delay



High purity iron (Air) 3 µs integration delay



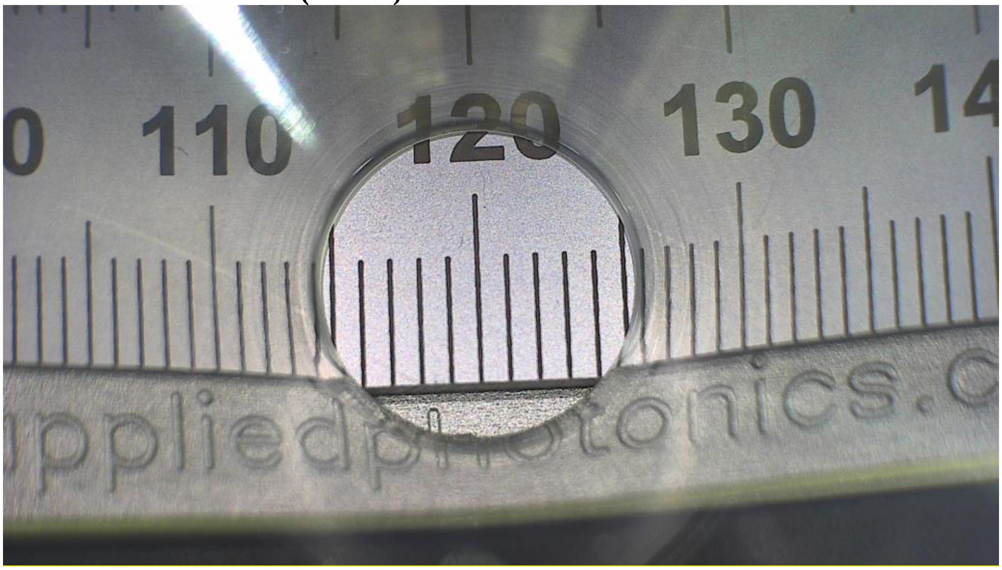
High purity iron (Argon) 3 µs integration delay



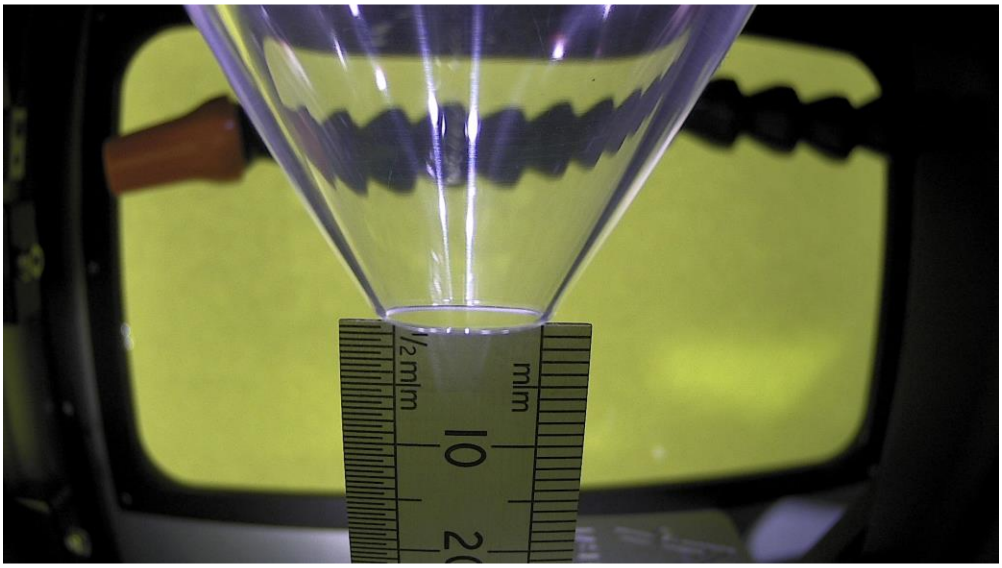
Test of sample imaging cameras

LIBS-6 (1064 nm) Camera Screenshot from LIBSoft

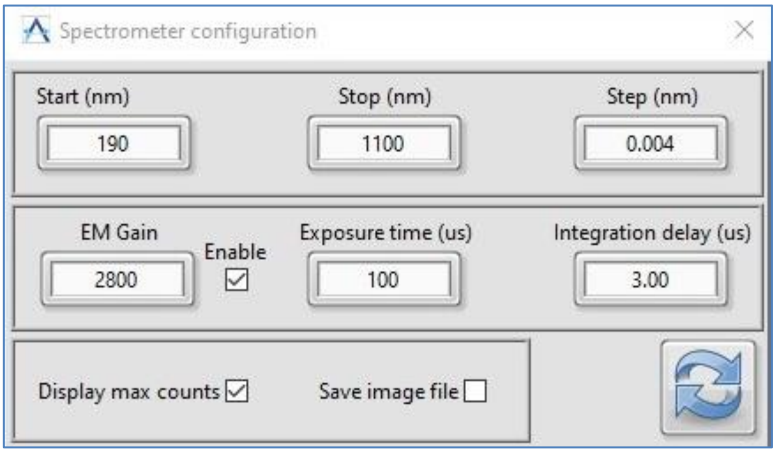
LIBS-6 (266 nm) Camera Screenshot from LIBSoft



XYZ-750 Camera Screenshot from LIBSoft



EMU configuration screen



End of Test Report