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COMPRESSOR FREE HYBRID (SOLID/GAS) FS SYSTEM

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Photochemically Driven Active Media: New Strategy in the Development of Ultra-high Power Fs Systems

OUTLINE

- **Main properties of broadband photochemically driven active media**
- **Architecture of a hybride multiterawatt systems**
- **XeF(C-A)-amplifier optically driven by the 172 nm radiation from an e-beam pumped flash-lamp**
- **Recompression of fs pulses**
- **Conclusions**

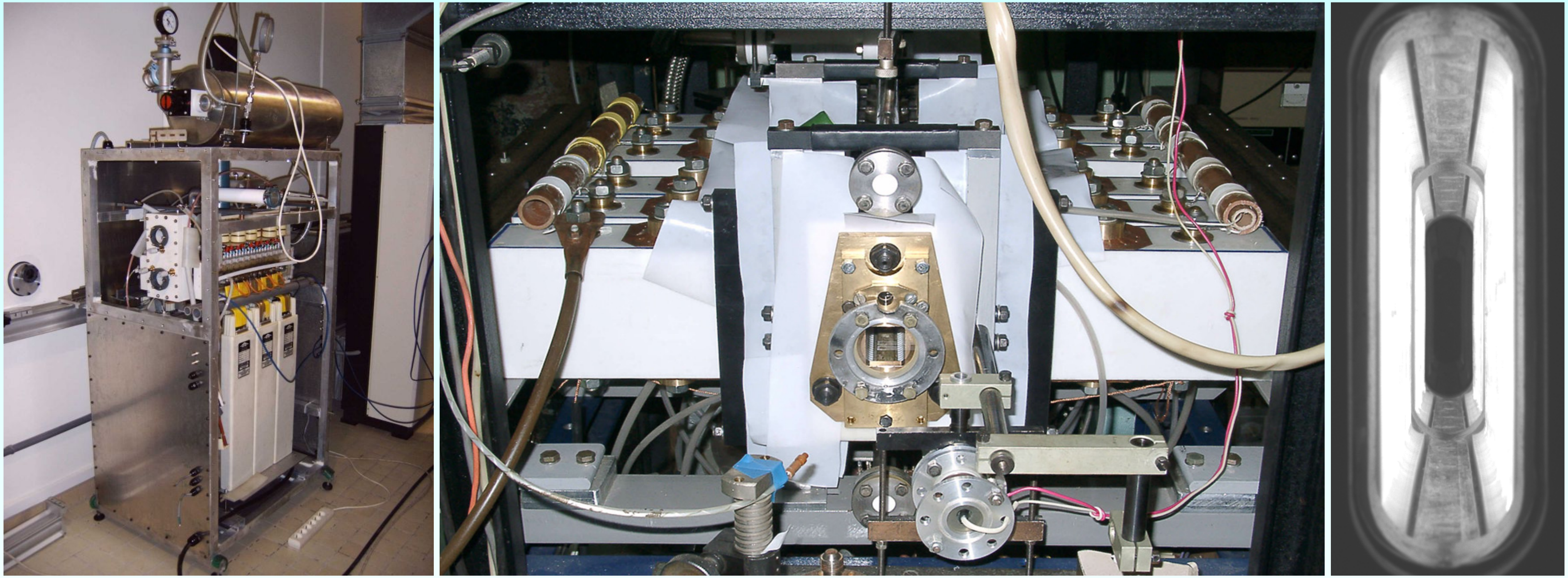
Advantages of gaseous optically pumped active media: **Low optical nonlinearity → CPA in subps time domain**
Scalability to very large volumes
Low cost of realization
High temporal contrast (>10^{10})

Photochemically driven broadband active media for the fs optical pulse amplification

Transition	XeF(C-A) /1/	Kr_2F (4 $^2\Gamma$-1,2 $^2\Gamma$) /2/	Xe_2Cl (4 $^2\Gamma$-1,2 $^2\Gamma$) /3/
λ_{max}, nm	474	405	485
$\Delta\lambda$, nm	60-100	80	100
τ_{lim}, fs	8-12	7	8
τ_{sp}, ns	100	181	245
σ_{st}, cm^2	10^{-17}	2.3×10^{-18}	2.8×10^{-18}
ε_{sat}, J/cm^2	0.05	0.2	0.15
I , TW/cm^2 (τ = 25 fs)	2	8	6

1. L.D.Mikheev, D.B.Stavrovskii, V.S.Zuev: J. Rus. Las. Res., v.16, 427 (1995)
2. N.G.Basov,V.S.Zuev,A.V.Kanaev,L.D.Mikheev,D.B.Stavrovskii: Kvantovaya Elektron.(Moscow) v.7, 2660 (1980)
3. N.G.Basov, V.S.Zuev, A.V.Kanaev, L.D.Mikheev: Kvantovaya Elektron. (Moscow) v.12, 1954 (1985)

XeF(C-A) amplifier pumped by radiation from a surface discharge



a) b) c)

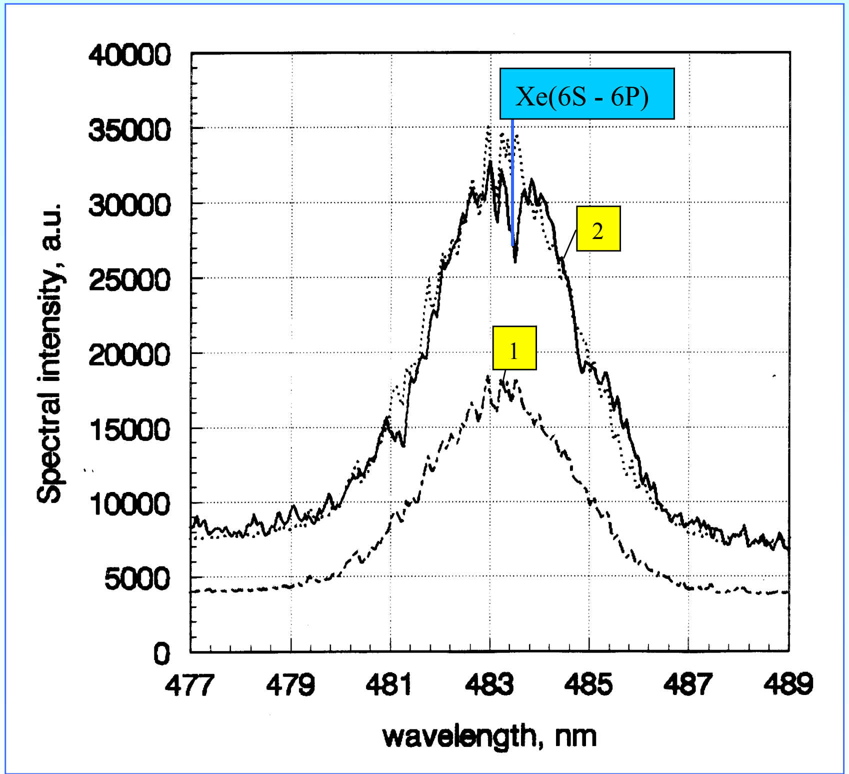
Photos of the photolytical XeF(C-A) amplifiers: a) LP3 of Marseille Univ.(active volume: 5×18×40 cm^3); b) P.N.Lebedev Inst. (active volume: 3×11×50 cm^3); c) XeF(C-A) amplifier viewed from its front when surface discharge is initiated.

Small-signal gain: 2×10^{-3} cm^{-1}
Total amplification factor: 10^2

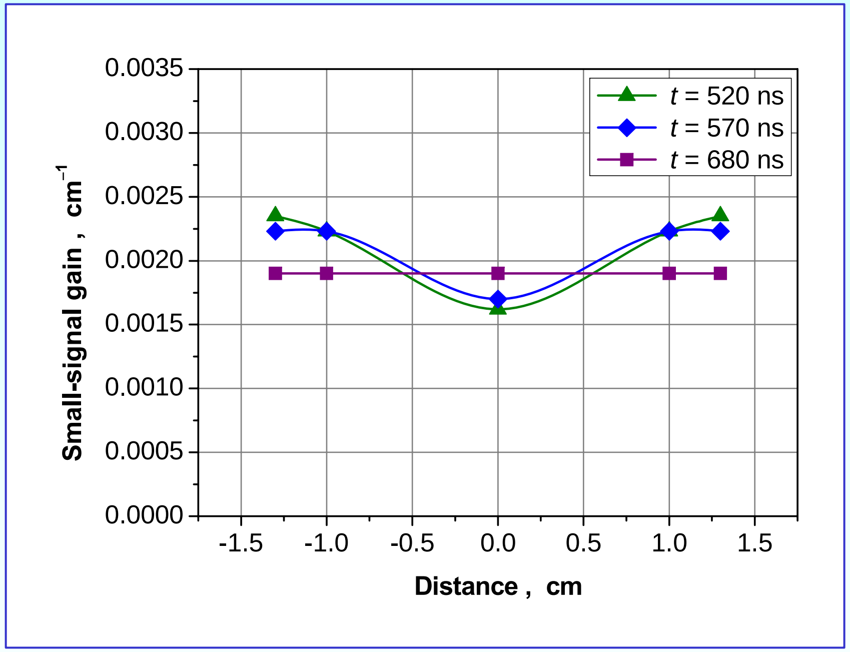
Surface discharge is promising up to 100 TW

XeF(C-A) amplifier photochemically driven by radiation from a surface discharge. Experimental results.

Total small signal gain of the multipass amplifier 10^2

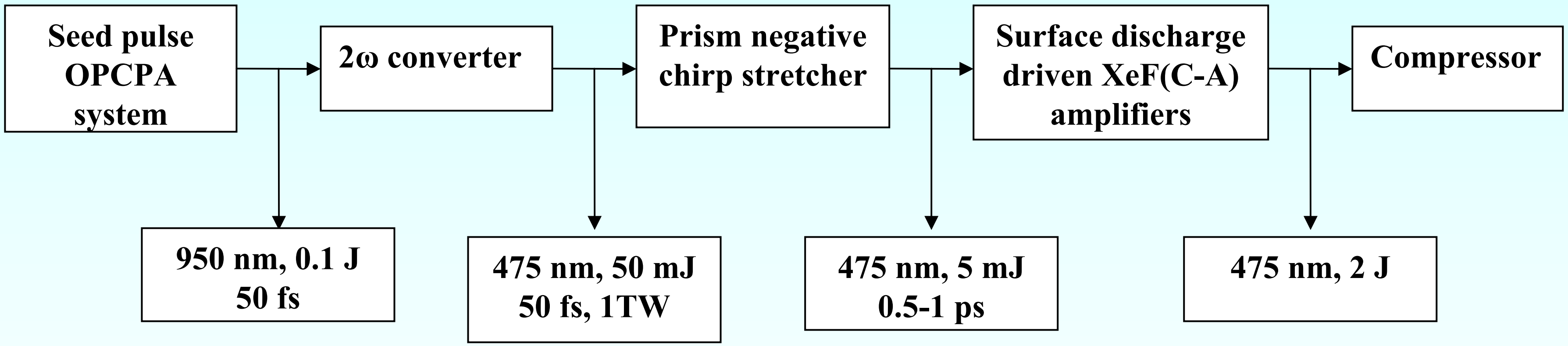


Spectra of fs pulse before (1) and after (2) amplification



Gain distributions versus the distance from the central plane of the amplifier at different instants of time

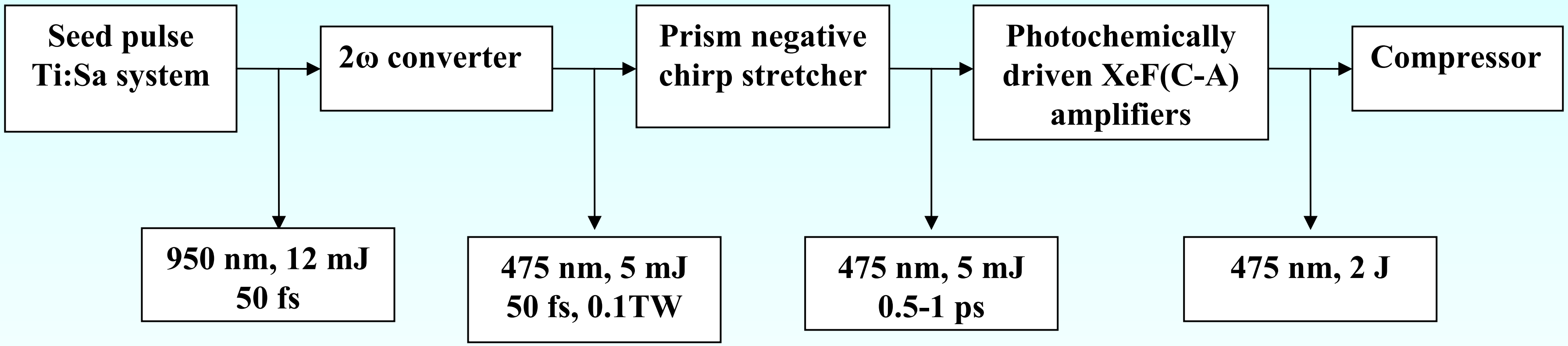
Architecture of a 10 Tw hybrid fs XeF(C-A) system at LP3 (Marseille University)



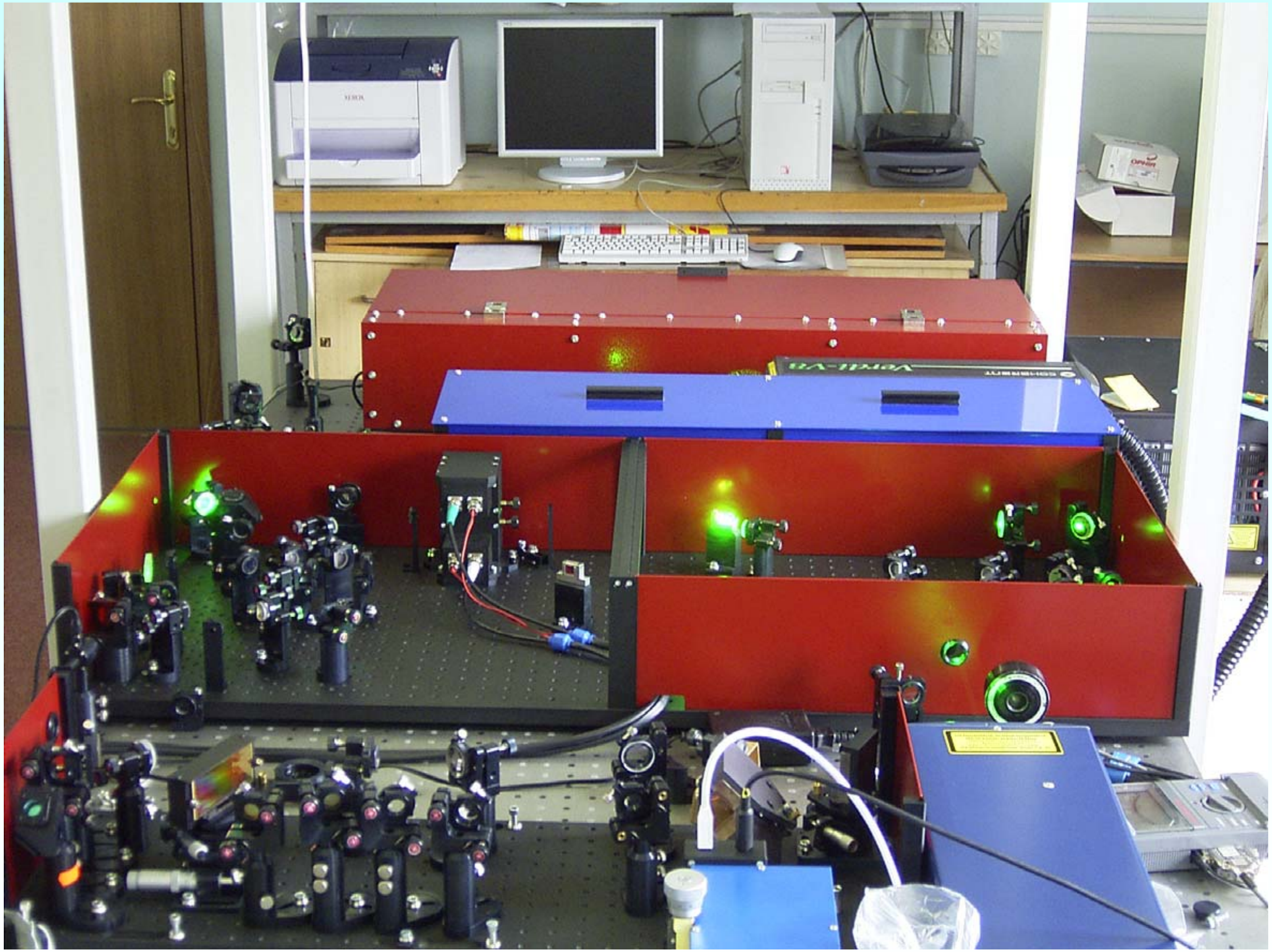
R.Clady, G.Coustillier, M.Gastaud, M.Sentis, P.Spiga, V.Tcheremiskine, O.Uteza, L.D.Mikheev, V.Mislavskii, J.P.Chambaret, G.Chẻriaux.

Appl. Phys. B, **82**, 347-358 (2006).

Architecture of a 100 TW hybrid fs XeF(C-A) system at P.N.Lebedev Inst. (Moscow)



Ti:Sa front end (Avesta Project Ltd)



λ_{ω} = 950 nm

$\lambda_{2\omega}$ = 475 nm

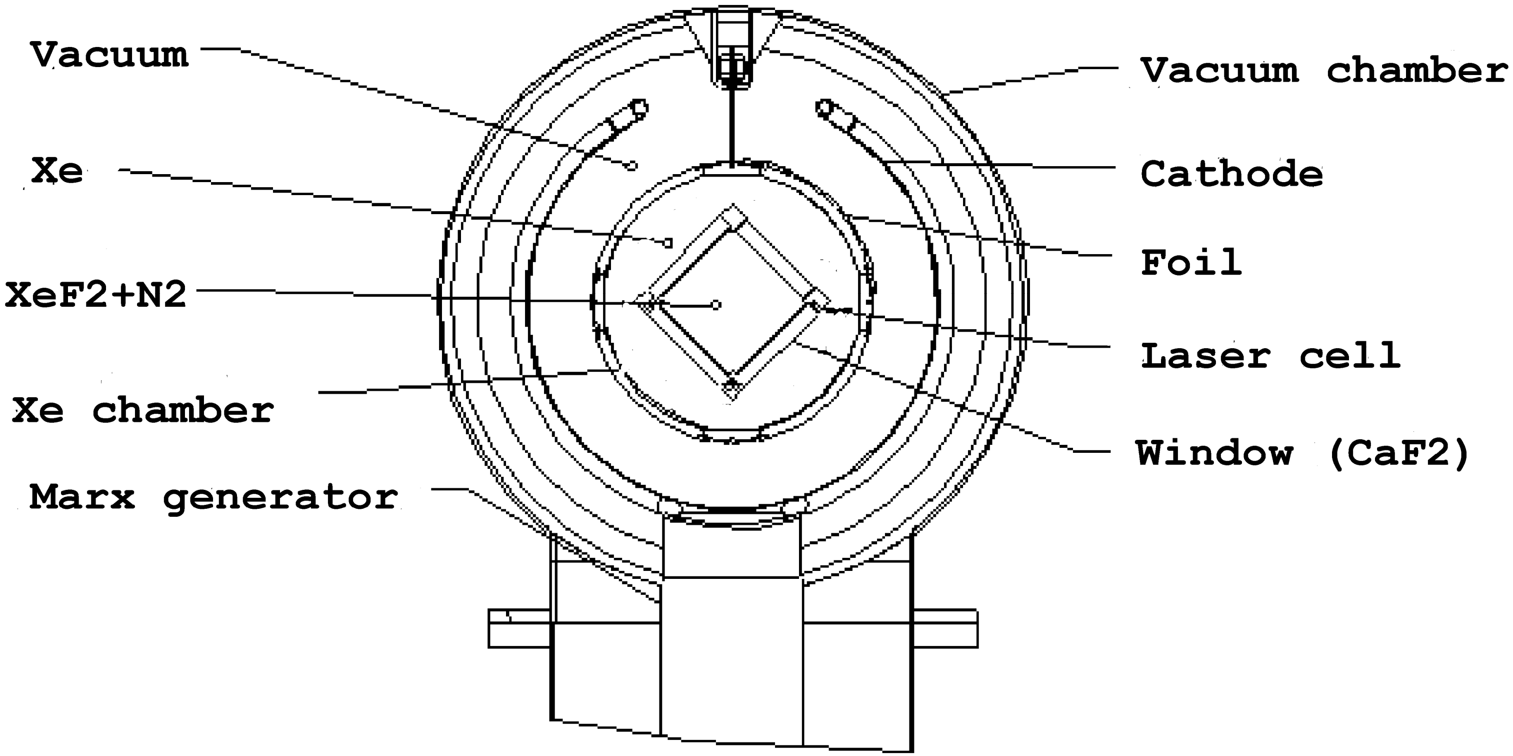
τ = 45-50 fs

E = 5 mJ

f = 10 Hz

Final XeF(C-A) amplifier photochemically driven by 172 nm radiation from an e-beam pumped Xe converter

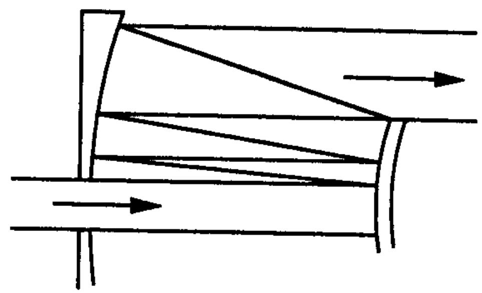
Active medium length - 1.2 m, clear aperture - 12 cm.
E-beam: I=80 кA, U_e= 420 keV, pulse-width – 400 ns.
Xe_2 fluorescence efficiency related to e-beam energy is 30-40%



XeF(C-A) amplifier (IHCE, Tomsk)

Experiment:
Small signal gain
2.6×10^{-3} cm^{-1}

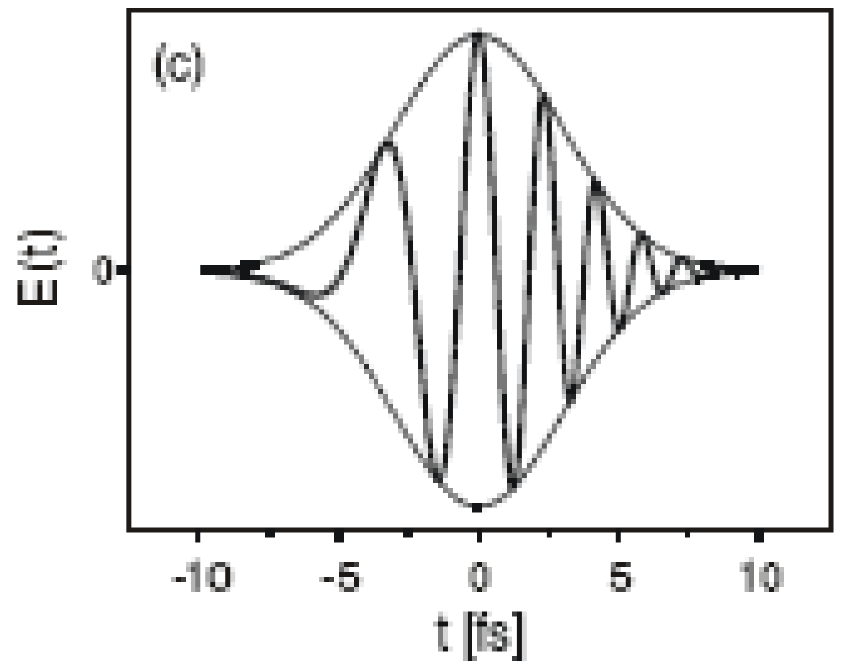
Theory:
Small signal gain
5×10^{-3} cm^{-1}
E_{stor} = 6 J
E_{out} = 2-2.5 J
P_{out} = 50 TW
τ = 50 fs



Recompression of downchirped fs pulses in bulk materials (physical insight)

PW systems – recompression in bulk materials in linear regime
Is it possible to do it in output window (nonlinear interaction)?
Gaseous active media ⇒ W_{out} ~ (1-4) TW/cm^2 << W_{dam} (balk glass, gas)

Self-phase modulation
$\Delta\omega \sim (-\,dn/dt)$
Kerr effect: $dn/dt > 0$, $\Delta\omega<0$
Electron plasma: $dn/dt < 0$, $\Delta\omega>0$



Recompression of downchirped fs pulses in bulk materials (physical insight)

$$\Delta n = n_2 I h\nu + \sqrt{n_0^2 - \frac{\omega_p^2}{\omega^2}} - n_0 \approx n_2 I h\nu - \frac{1}{2n_0}\frac{\omega_p^2}{\omega^2} = n_2 I h\nu - \frac{1}{2n_0}\frac{\rho^e}{\rho^e_{crit}}$$

$n_2 = 3.5\times10^{-16}$ cm^2/W is the fused silica nonlinear refractive index,

I [phot/cm^{2}s] is the intensity of the electric field,

$\omega_p = \sqrt{\dfrac{\rho^e e^2}{\varepsilon_0 n_0^2 m}}$ is the plasma frequency, ω is the carrier frequency,

$m = 0.635 m_e$ denotes the reduced mass of the electron and the hole,

ρ^e stands for the electron plasma density,

$\rho^e_{crit} = \varepsilon_0 n_0^2 m\omega^2/e^2 \approx 4.2\times10^{21}$ cm^{-3} is the critical plasma density at 480 nm

Recompression of downchirped fs pulses in bulk materials (physical insight)

Electron plasma generation in fused silica

(U_i = 7.5-9 eV, hν (480 nm) = 2.5 eV, U_i / hν=3–4, W_{out} ~ (1-4) TW/cm^2):

1. Multiphoton ionization (MPI)
2. Tunneling ionization – minor due to $\gamma=\omega(mU_i)^{1/2}/eE >> 1$
3. Avalanche ionization – minor?

MPI: $\rho^e \approx \sigma_k I^k N_a \tau_p$, k=3,4

$\sigma_3 = 6\times10^{-81}$ cm^{6}c^2 (S.C.Jones et al., Opt.Eng. 28, 1039 (1989))

$\sigma_4 = 2\times10^{-114}$ cm^{8}c^3 (S.C.Jones et al., Opt.Eng. 28, 1039 (1989))

$N_a = 2.2\times10^{22}$ cm^{-3}, τ_p = 30 fs << electron recombination time of 150 fs.

$\Delta n = 0$ at W = 4.5 TW/cm^2 (k=4) or W = 0.7 TW/cm^2 (k=3)

$\rho^e \approx 2\times10^{19}$ cm^3 (k=4) or 3.2×10^{18} cm^3 (k=3)

Recompression of downchirped fs pulses in bulk fused silica (numerical simulation)

Downchirped Gaussian pulse:

$$A\big|_{z=0} = A_0 \exp\left[-(\ln 2)\left(\left(\frac{t - t_0}{\tau} \right)^2 + \frac{r^2}{2a^2} \right) - \frac{i\chi(t - t_0)^2}{2} \right]$$

traveling through a piece of fused silica with normal dispersion. Combined nonlinear (generalized) Schrödinger equation in dimensionless variables:

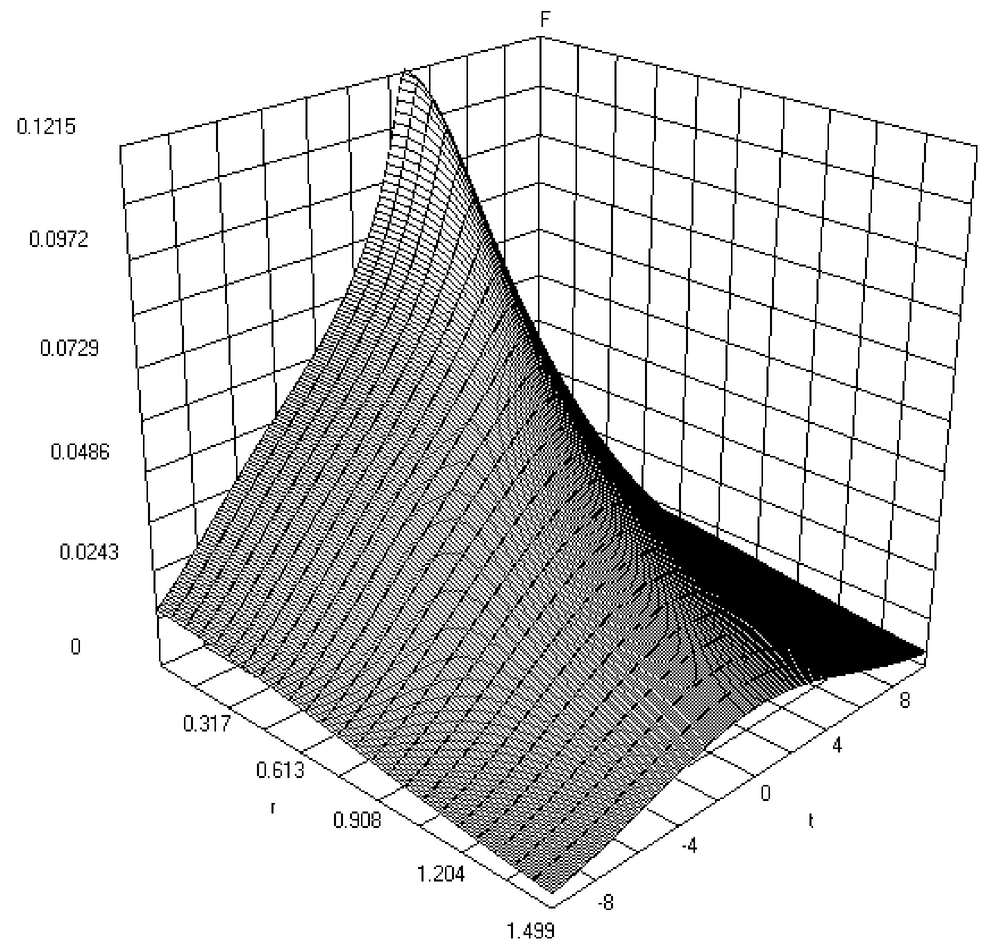
$$\frac{\partial A}{\partial z} + iD_r \Delta_r A + iD \frac{\partial^2 A}{\partial t^2} + i(\alpha |A|^2 - \beta\rho)A + \gamma \frac{\partial}{\partial t}((\alpha |A|^2 - \beta\rho)A) = 0$$

$$0 < z \le L_z, \quad 0 < t < L_t, \quad 0 < r < R$$

$$\frac{\partial \rho}{\partial t} + \frac{\rho}{\tau_{rel}} = \delta(1 - \rho)|A|^{2n}, n = 3$$

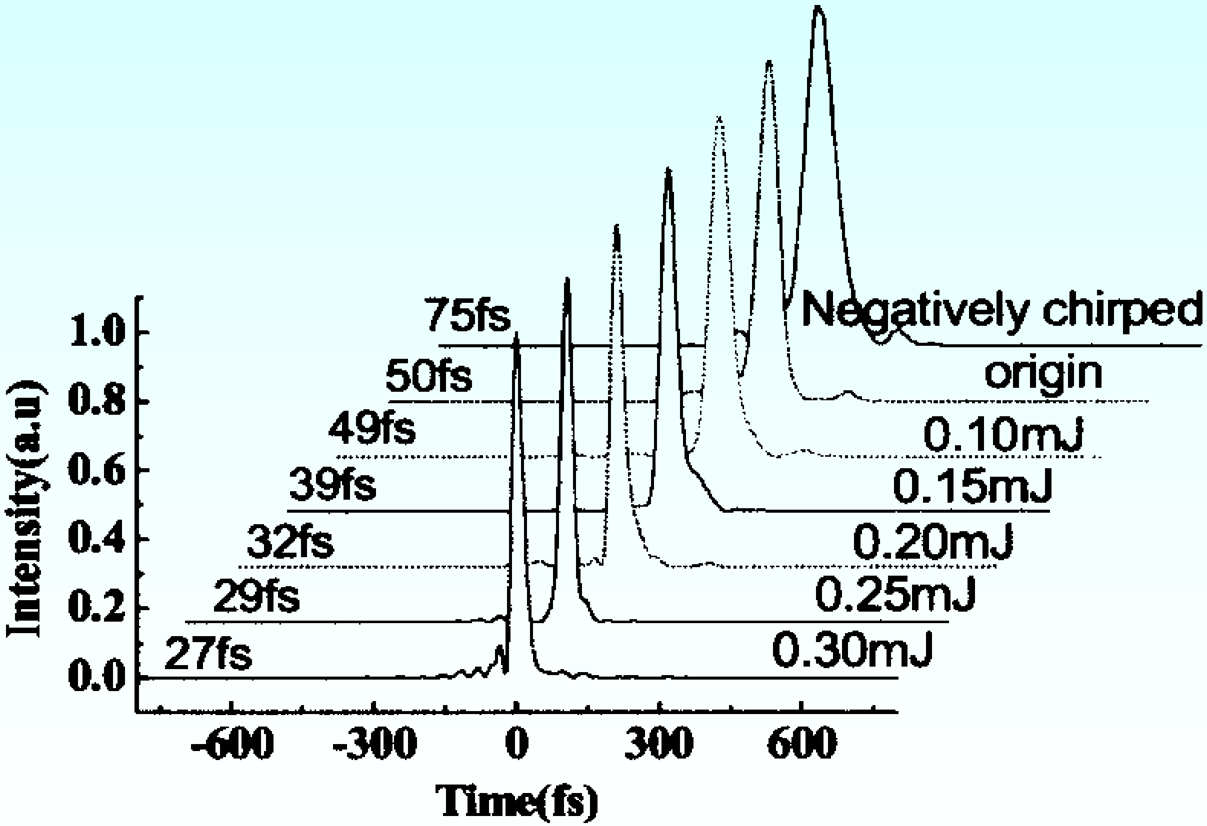
Where

$D_r = L^{-1}_{diffr}$, $D = L^{-1}_{disp}$, $\alpha = L^{-1}_{sf}$, $\gamma = 2(\omega_0 \tau_{pulse})^{-1}$, $\delta = \sigma^{(3)} N I^3$, $\beta = k_0 N_a / 2\rho_{cr}$, $W = 1.6\ TW/cm^2$


F
0.1215
0.0972
0.0729
0.0486
0.0243
0
0.317
0.613
r
0.908
1.204
1.499
-8
-4
0
t
4
8

Nonlinear compression of negatively chirped fs pulses in BK7 (experiment)

Jun Liu et al. Opt.Express, v.14, 979 (2006)



BK-7

λ = 800 nm

1.7 TW/cm^2

Conclusions

- Optimistic experimental and theoretical results obtained show that realization of compressor-free hybrid fs system is expected to be feasible.
- Preparation work is now in progress to demonstrate 50 TW peak power in the hybrid fs system which is being built at P.N.Lebedev Institute.