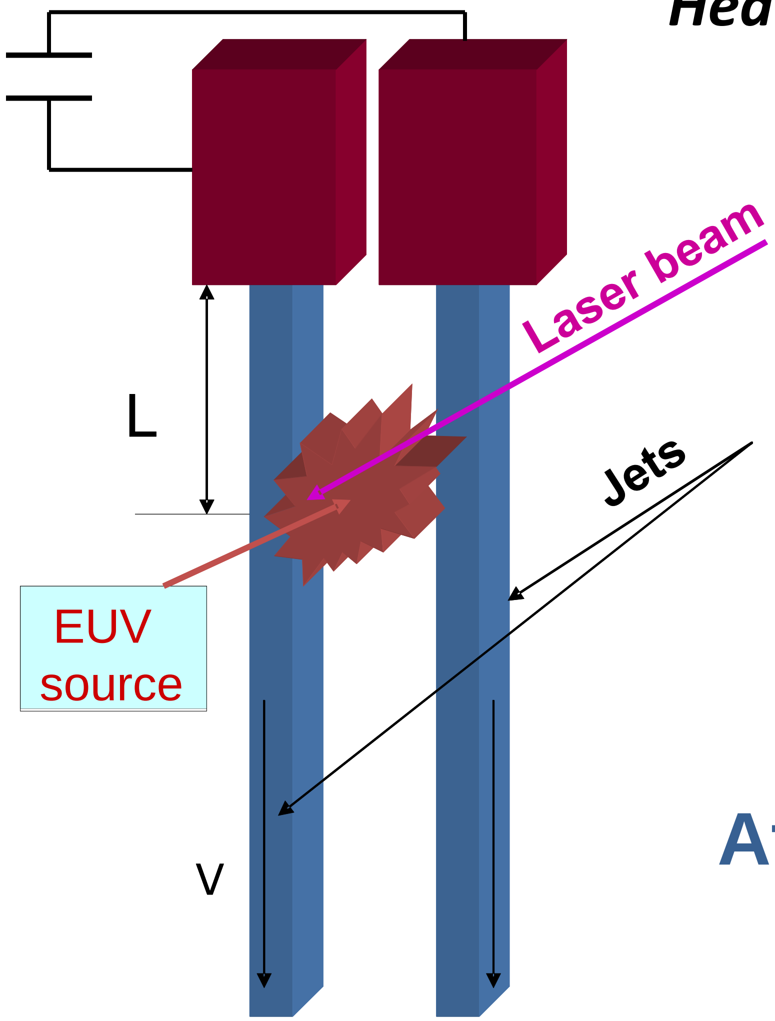
High power DPP source based on liquid tin jet electrodes

V. Krivtsun, O. Yakushev
A. Vinohodov, V. Borisov
V.Ivanov and K.Koshelev

Agenda

- Principles of liquid jet electrodes
- History of the idea
- Experimental set-up
- Demonstration of operation
- Summary & conclusions

Jet electrodes system



Heat load limit (moving electrodes)

$$P_0 \approx \frac{2}{\eta} * V^{1/2} * D^{3/2} * C * \Delta T$$

At V =300 cm/s, C=2,6 J/cm³K; ΔT ≈ 1000 K; D ≈ 1 cm,

HLL estimated as : $P_0 \approx 86/\eta$ kW

$$P_{MAX} = 5 \times V^{0,5} kW$$

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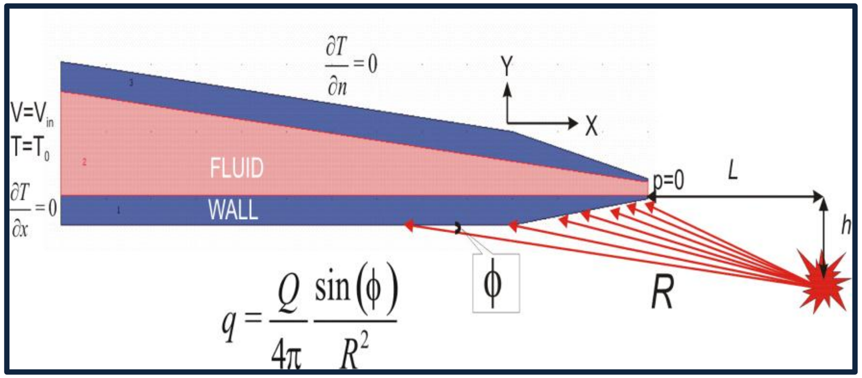
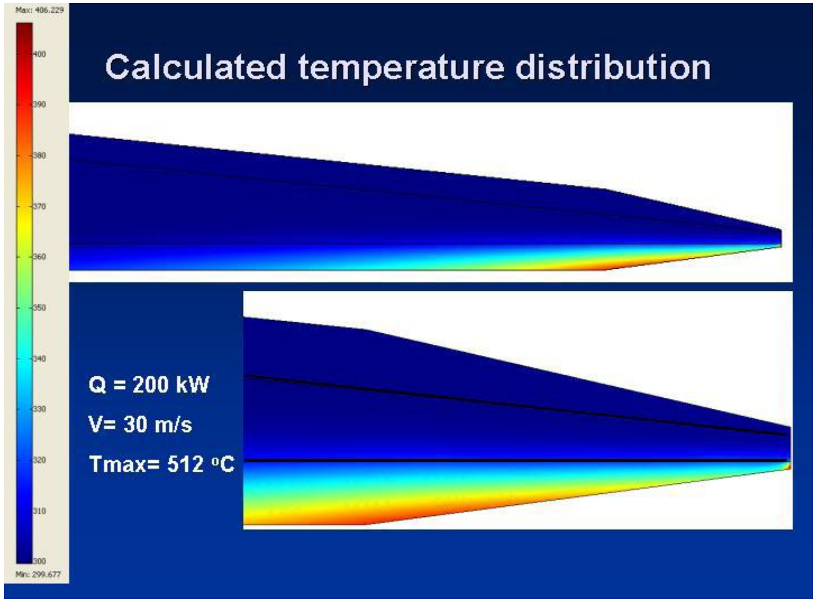
At v = 25 m/s (2500 cm/s)
Pmax = 250 kW

Heat load limit for metal nozzles





Detailed modeling of heat transfer based on solution of Navier-Stokes and heat advection-conduction equations in fluid and heat conduction equation in the walls for L = 1 cm, h = 2 mm T_0 = 300 °C

Self-cooling of metal nozzles by tin flux allows to dissipate 250 kW of electrical energy in a discharge

Debris mitigation features

Affected types of debris

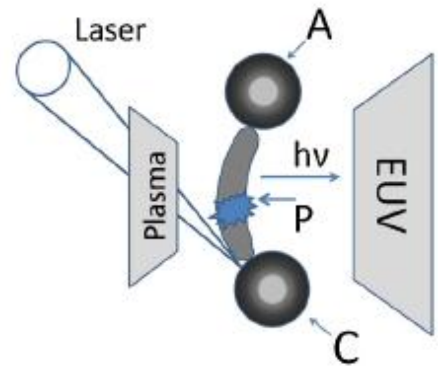
Large droplets
go with jets flow

Small fast droplets
formation changes

Plasma flow
redirection is possible

Tin vapors
open surface decreases

Fast ions
? interesting question



Principle of plasma flow redirection using jet electrodes

dense plasma these directions are free of plasma flow

Witness sample demonstrated plasma flow redirection

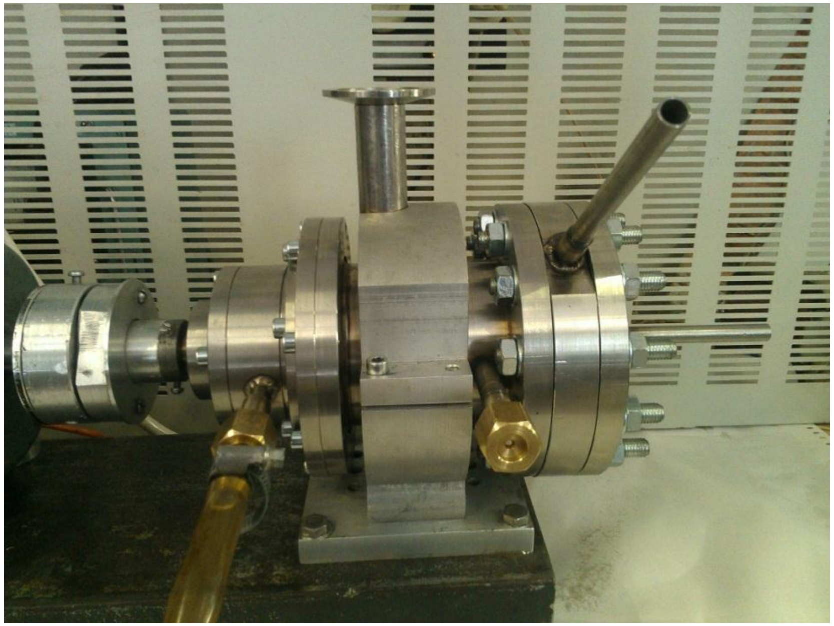
Liquid tin jets – continuous operation

	2005-2010 MoreMoore	2011	2012
	Jet 1	Jet 2 (demo)	Jet3 (demo)
material	Sn+Ga (30 C)	Sn (300 C)	Sn (300 C) achieved
CE, %	1.3	Up to 2	2.5 achieved
Stored energy, J	2.5 (cruise) 5 (burst)	2.5 - 5 (burst)	5 (cruise) achieved
Rep.rate, kHz	1 – 4 (cruise)	Short bursts	8 (cruise) in preparation
Power load kW	10 (cruise) 20 (burst)		32 (cruise) in preparation
EUV in 2 pi, W	130 (cruise) 260 (burst)		800 (cruise) To be demonstrate

View of experimental setup

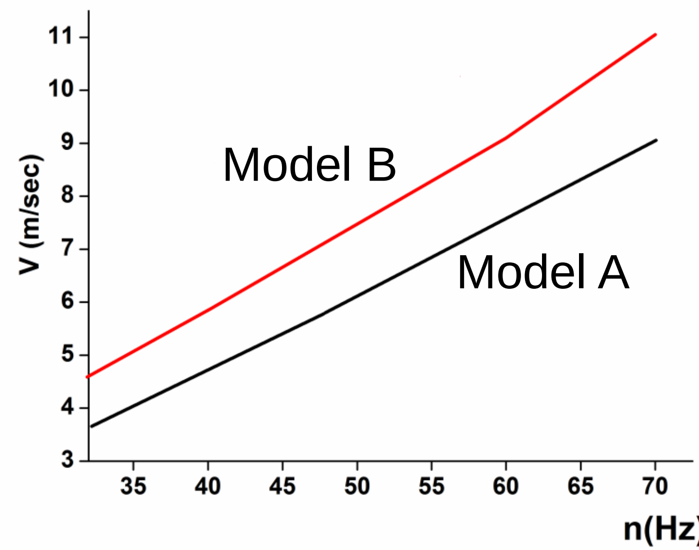
Jet III (demo)
Fuel – liquid tin
Temperature – 300^0 C
Stored energy - 4 J
Rep.rate – 8 kHz
Dissipated power 32 kW
CE = 2– 2.5 %

Centrifugal tin pump



Pump model A –tin jet velocity - 6 m/s demonstrated at 50 Hz

Pump - model B – tin jet Velocity 12 m/s

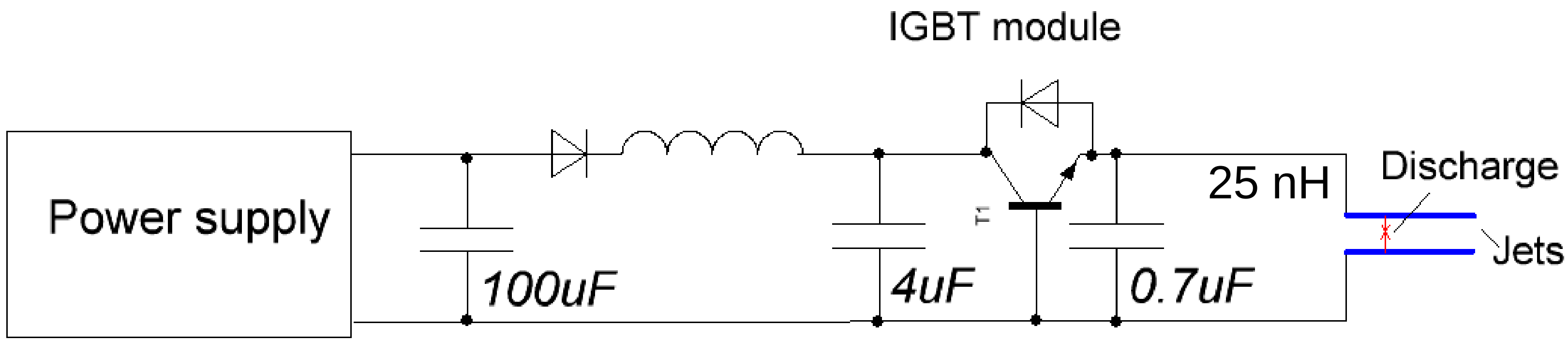


Design features of centrifugal tin pump

Magnetic coupling drive
Vacuum isolation
Operation temperature up to 400°C
Turbine rate of rotation up to 70 Hz

Dependence of jets velocity on turbine frequency for centrifugal tin pump

Electrical power circuit



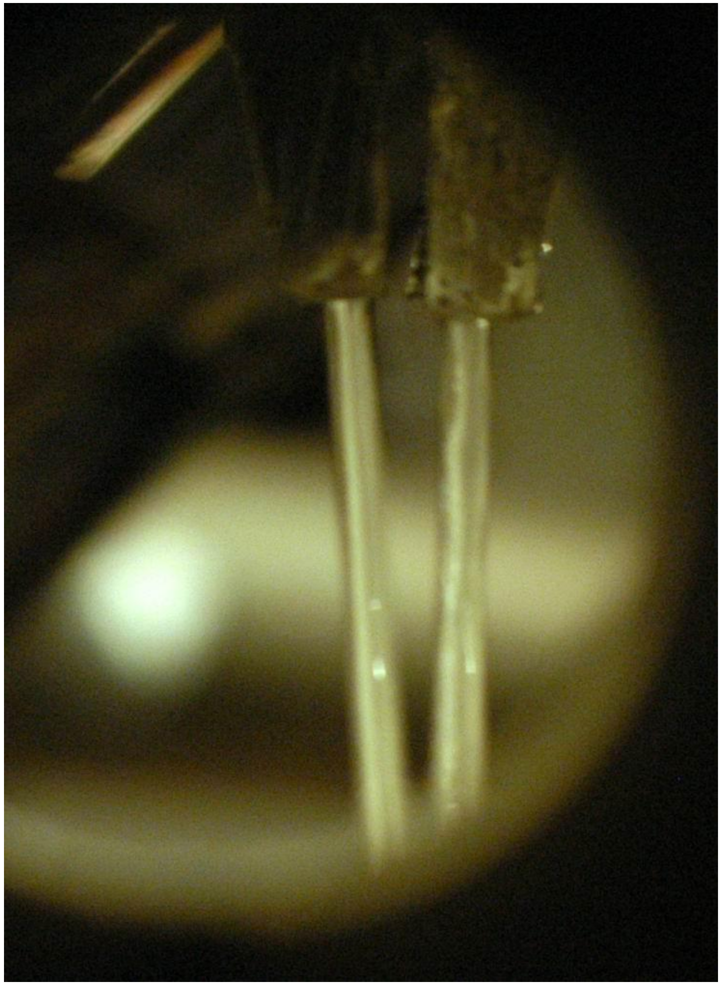
Electrical circuit parameters

Storage capacitor	0.7uF
Discharge voltage	~4 kV
Rise time of voltage	4.5 us
Input power up to	40 kW

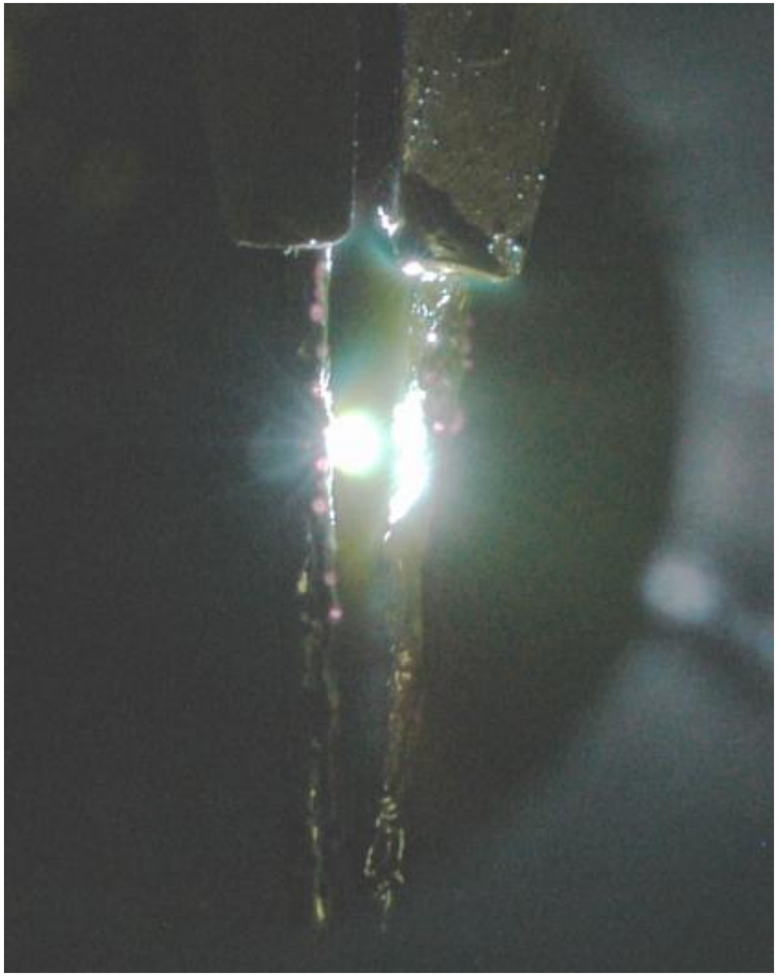
Ignition laser parameters

Wavelength	1.06 um
Pulse energy up to	50 mJ
Pulse duration	80 ns
Max. repetition rate	8 kHz

Photo of tin jets

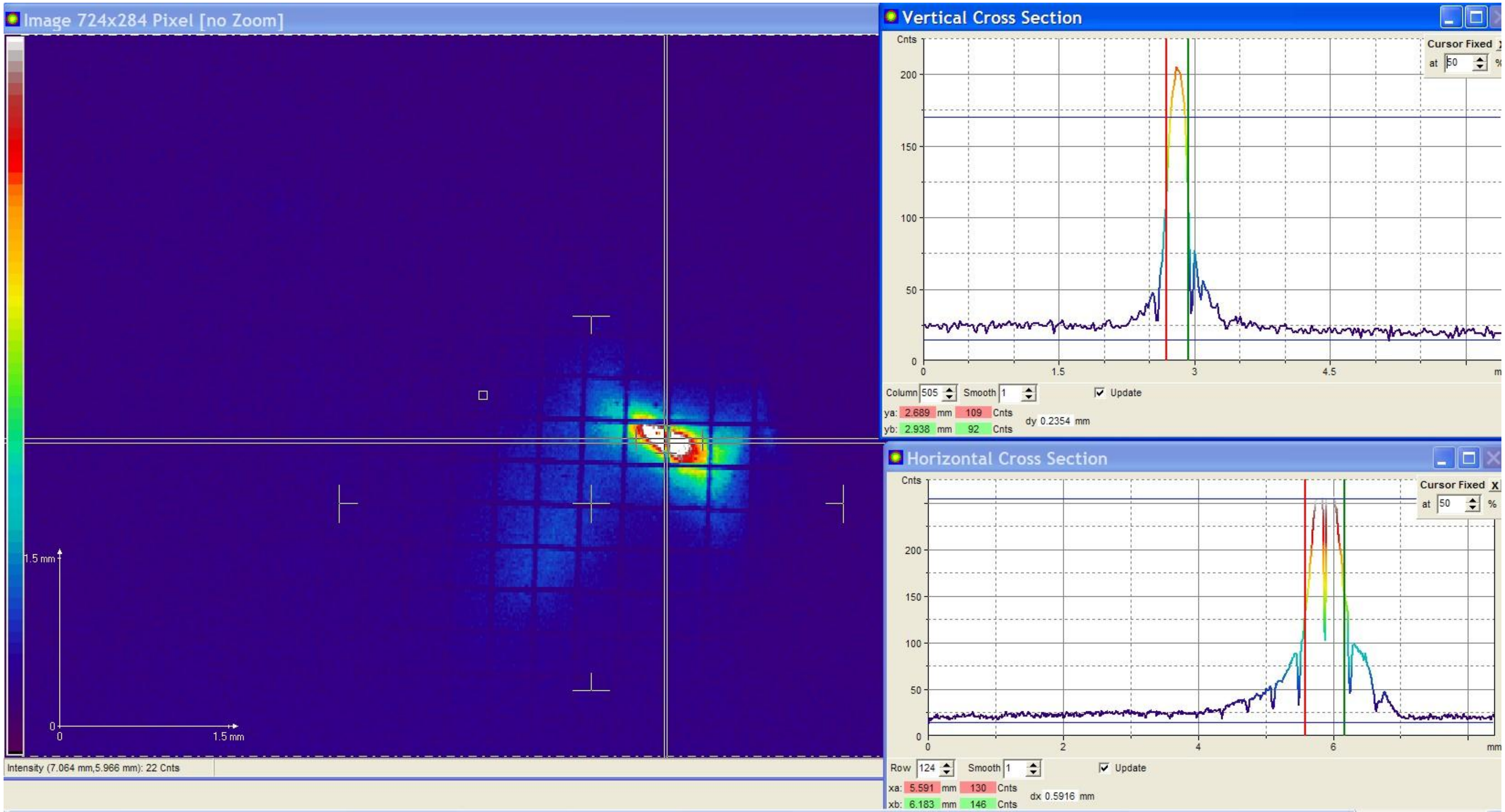


Without discharge



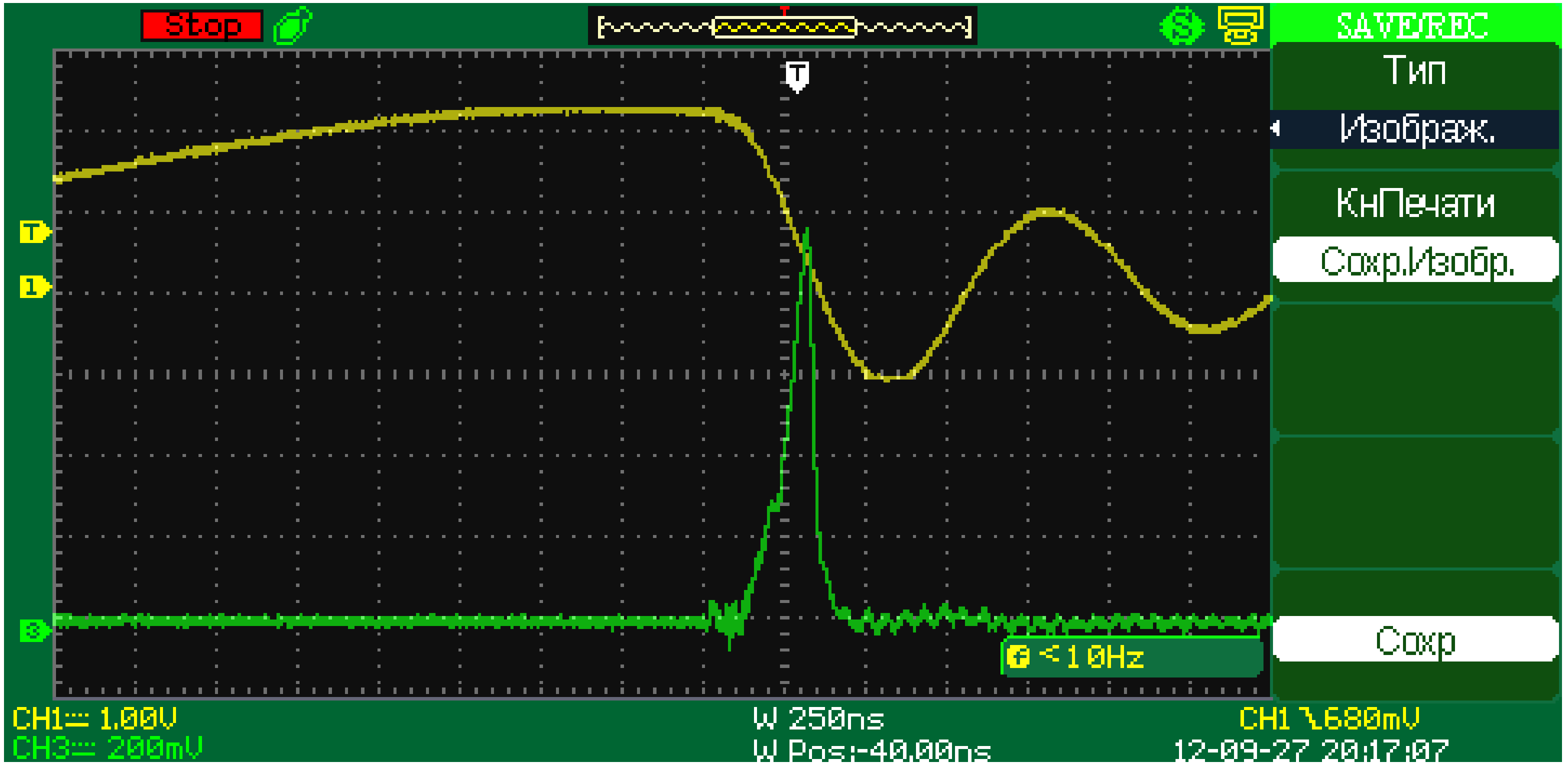
With discharge

EUV image of the pinch



Sizes of pinch (FWHM): 0.23mm x 0.59 mm

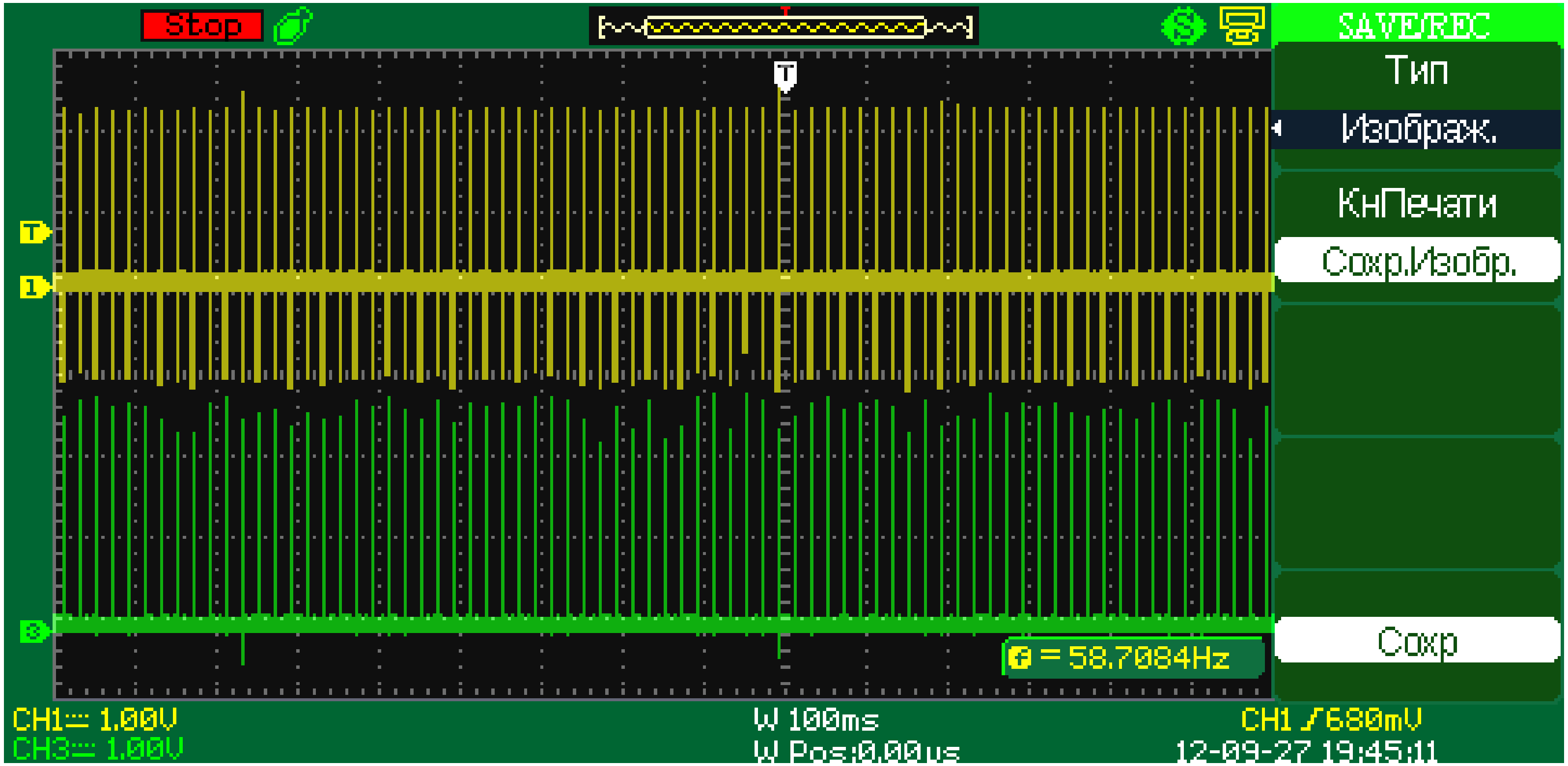
Oscillogram of single discharge



Yellow – voltage on discharge capacitor
Green – fast EUV signal (SXUV-5HS+ZrSi filter)

Measured CE = 2.3% (in 2π sr., 2% band)

Continuous operation



Yellow – voltage on discharge capacitor

Green – EUV signal (SXUV-5HS+Zr/Si filter)

Conclusions

1) A new approach for DPP EUV sources based on the usage of two liquid Sn jets as discharge electrodes has been developed.
2) Compact centrifugal tin pump has been developed
3) Experiments conversion “in band” efficiency (CE) more 2% in 2π sr was shown.
4) Stable EUV signal at continuous operation has been demonstrated.

Organizations contributed to the presentation

Thank You for Your Attention