ECLIM 2016 Moscow

Self-organisation of interelectrodes nanodisperse ensembles and hard X-rays yield related in vacuum discharge with virtual cathode

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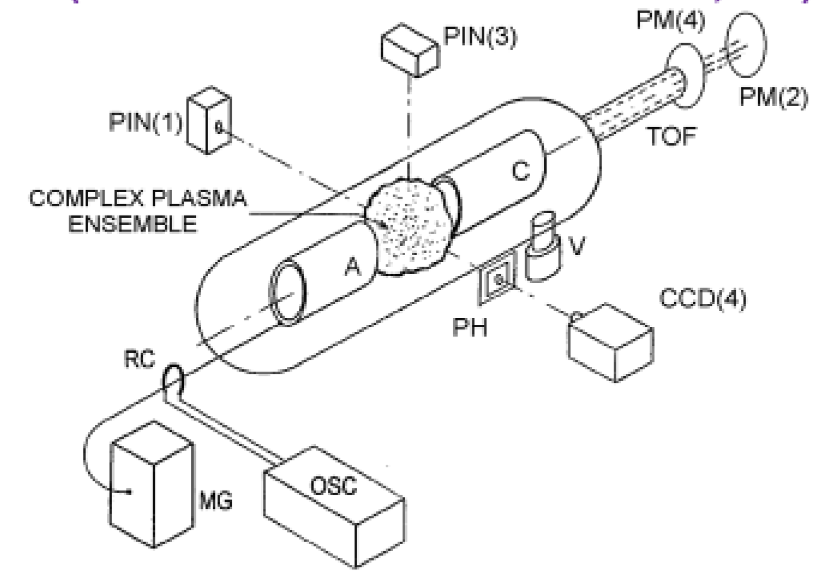
Generation of DD neutrons and hard x-rays at miniature nanosecond vacuum discharge (NVD) with virtual cathode has been demonstrated earlier [1]. The nanodisperse "target" (nucleated clusters, nano – and micro particles of different size from erosion of Pd anode irradiated by autoelectron beams) is forming automatically at chosen discharge conditions after high voltage applied during the pre-breakdown stage. Current-carrying stage is accompanied by emission of hard x-rays of different intensity from interelectrode complex plasma ensembles [1]. Preliminary experiments have recognized also the partial trapping of x-rays by interelectrodes ensembles of nanoparticles which is growing with the ensemble density. Also, the effect of x-rays trapping becomes more pronounced under self-organisation of interelectrode ensembles [2]. Perhaps, the high power density interelectrode ensembles of clusters at NVD are possible candidates for x-rays lasing media.

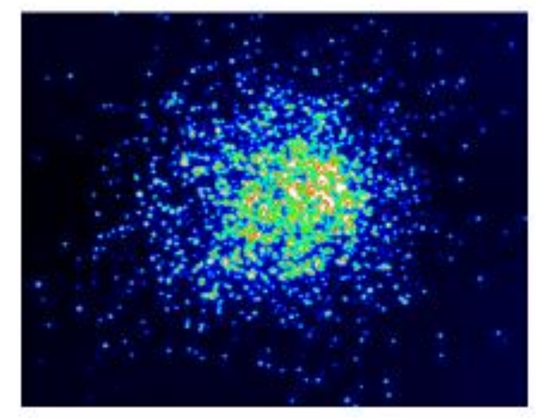
Scheme of experiment with miniature nanosecond vacuum discharge with virtual cathode. Hard x-rays and DD neutrons generation
(M.Skowronek and Yu.K.Kurilenkov 2003,2006)



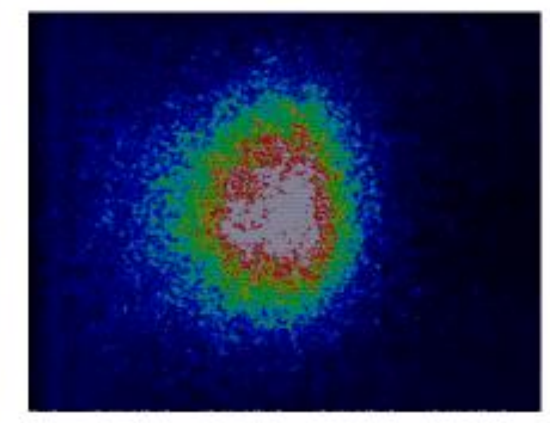
- Parameters of discharge: ≈ 1 J of total energy, U=70 kV, t=50 ns I_{max} = 1kA, TOF = 30 -90 cm P_{min} ≈ 10^{-7} mbar.

From hard x-rays release to partial diffusion of x-rays in more dense ensemble of clusters

a) typical «transparent» interelectrodes ensemble

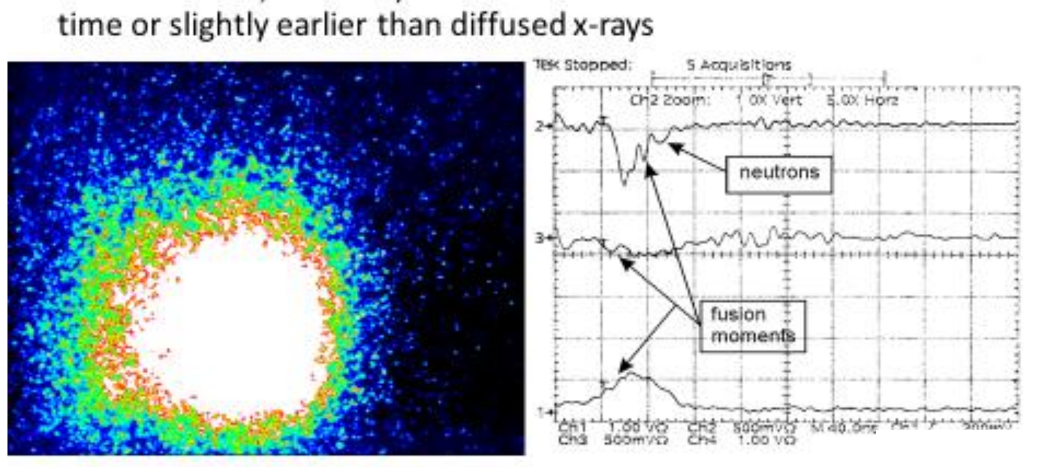


b) partial «trapping»(diffusion) of x-rays and total one for fast ions

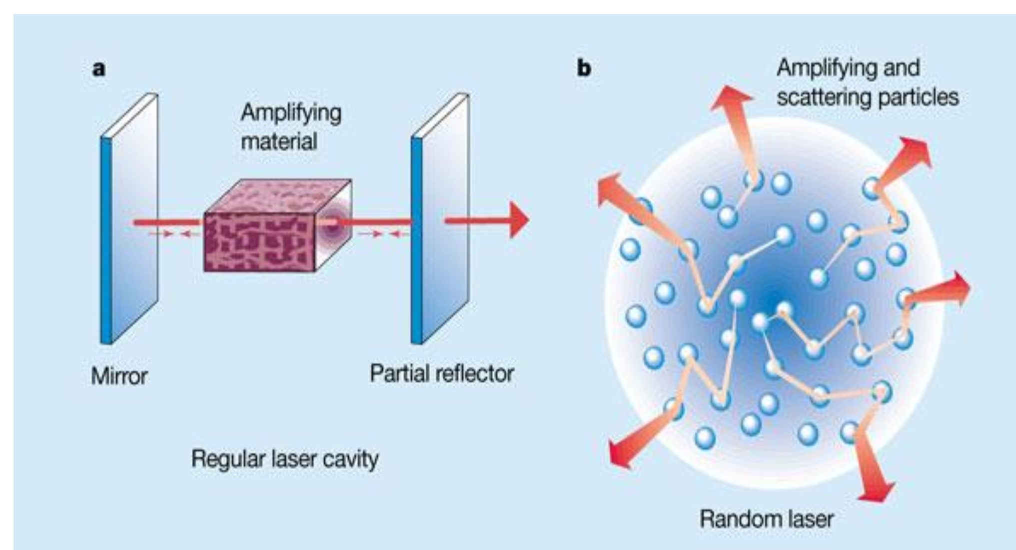


dense interelectrode ensemble with total *trapping of fast ions and partially trapped (diffused) hard x-rays* (inside of cluster ensemble)

- Diffusion (delay) of lower energy hard x- rays (ch.1,3). Release of harder x-ray. Enhanced neutron yield from the « ball » (sensitivity of ch.2 is 500 mV, 0426D1). Neutrons leave the « ball » at the same time or slightly earlier than diffused x-rays

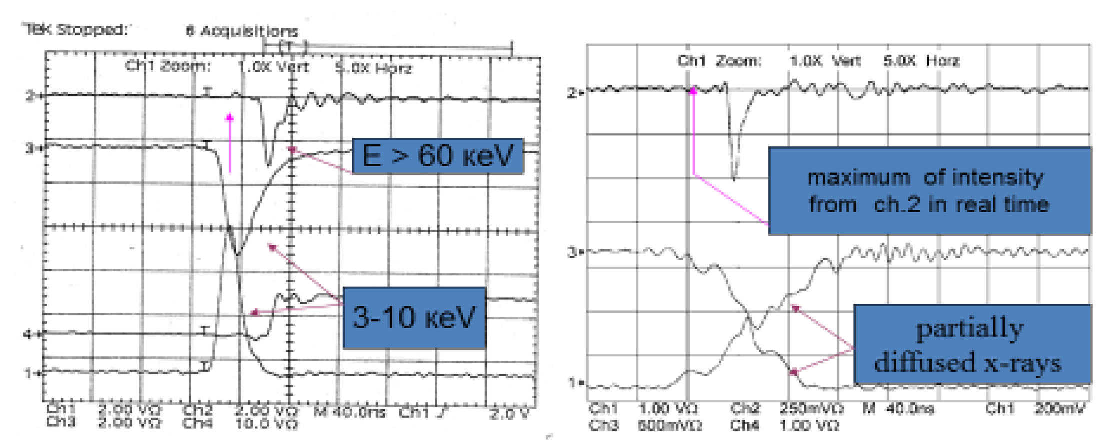


"Random-laser" emission



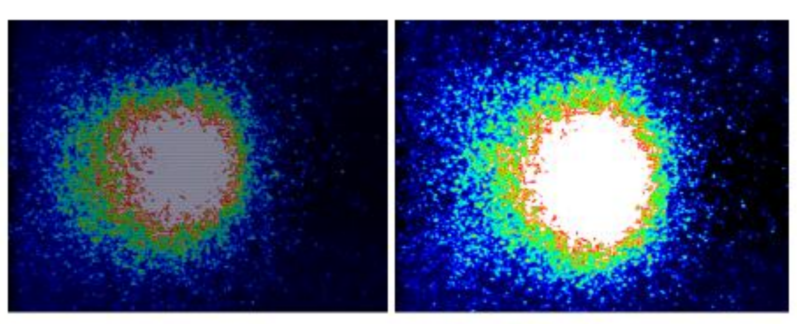
V.Letokhov 1968 JETPh D.Wiersma, Nature,406, 132 (2000)

Oscillogrammes of intensities of hard x-rays released :
(a) from dilute («transparent») ensemble and
(б) more dense interelectrode ensembles of clusters



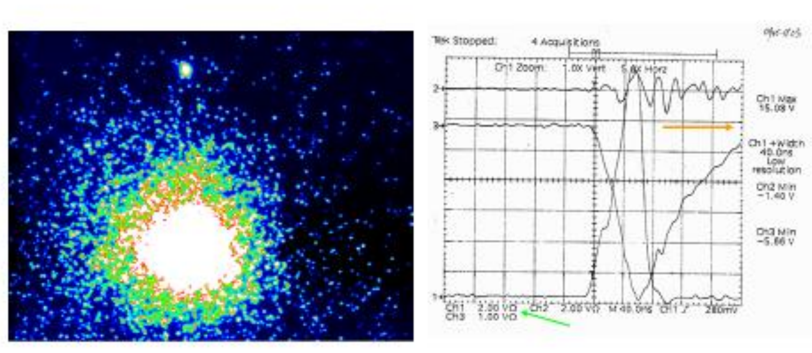
Examples of ensembles with diffused hard x-rays:
x-rays intensities from ch.1 less than triggering voltage (=100 mV) needed to get oscillogrammes (no oscillogrammes for these shots)

0509d1 no x-rays yield at channels 1 0426d5



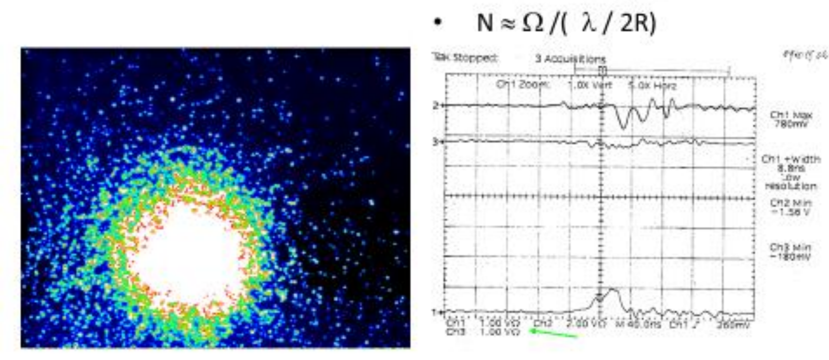
Disordered ensemble with x-rays release

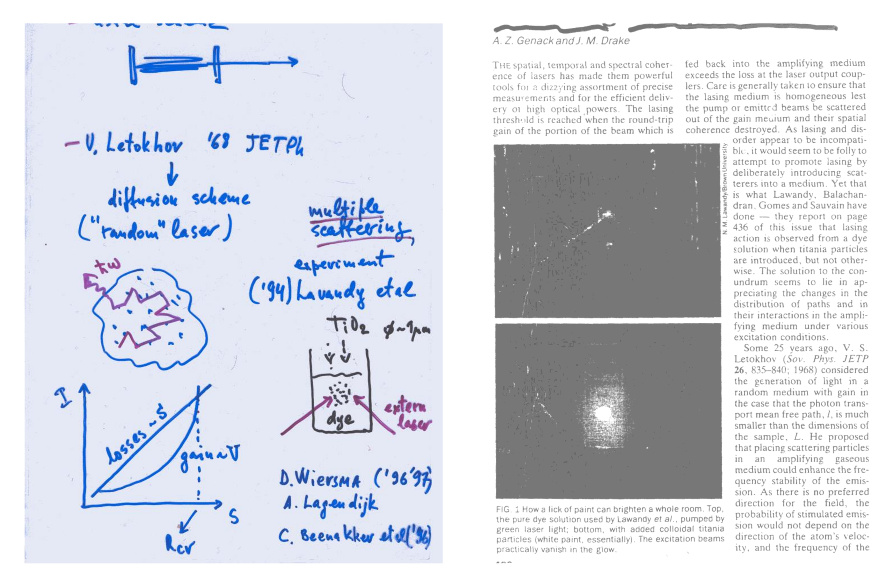
- High x-rays release



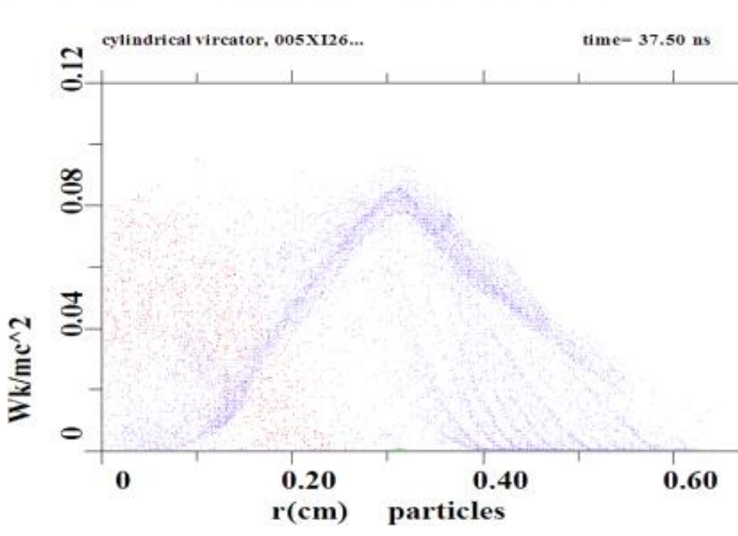
Cluster self -organised ensemble below « random » x-ray lasing threshold with trapped x-rays ~ 5 -10 keV (chs 1,3).

- multimode system
- N ≈ Ω /(λ / 2R)

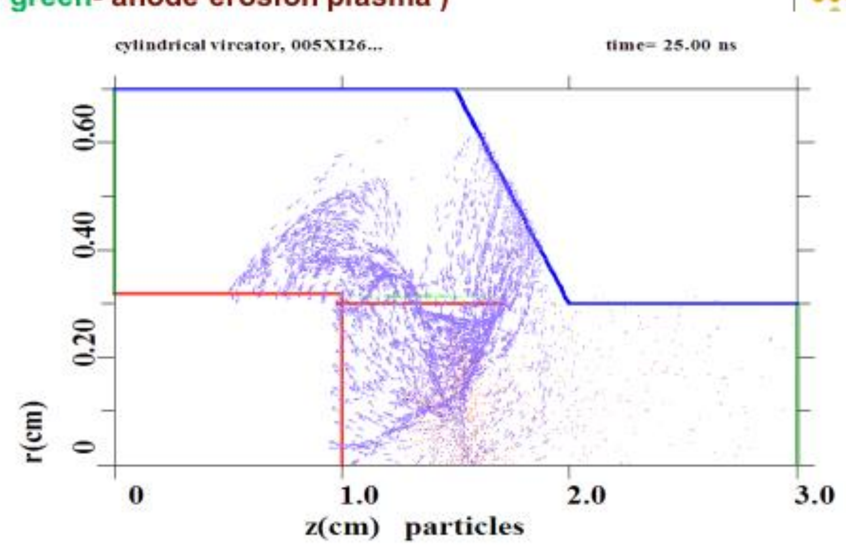




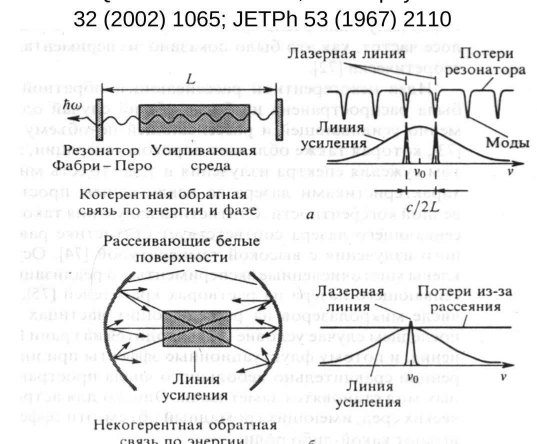
Energies of deuterons (red) and electrons (blue) as function of their positions by radius



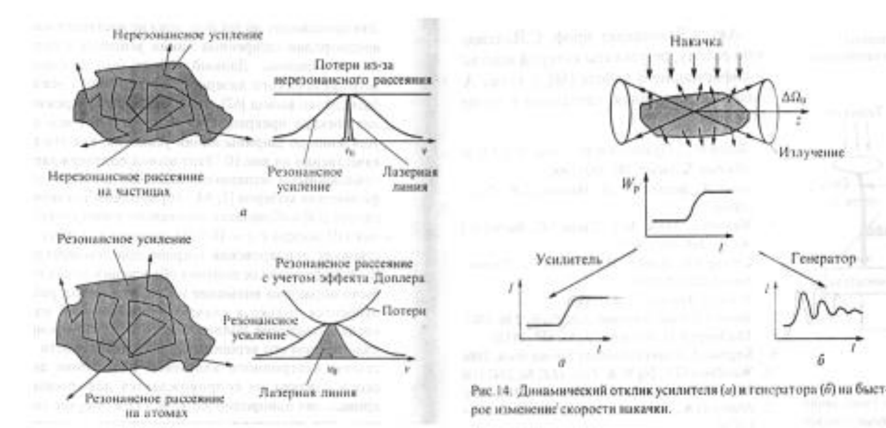
Example of particles dynamics by KARAT code (**blue – beam electrons, red – ions accelerated by VC, green- anode erosion plasma**)



Stohastic resonators: coherent and non-coherent feedback (by energy)
V.Letokhov.Quantum Electronics, « Astrophysical Lasers » 32 (2002) 1065; JETPh 53 (1967) 2110



(a) Lasers with non-resonant (non-coherent) feedback. (b) Reaction on rate of pumping: ampliphyer and generator (from V.Letokhov 2002)



Size and structure of Pd clusters determined by XRD (X-ray diffraction) and HREM (high resolution electron microscopy), by M.Suleiman, C.Borchers et al. Z.Phys.Chem 223 (2009) 169-181

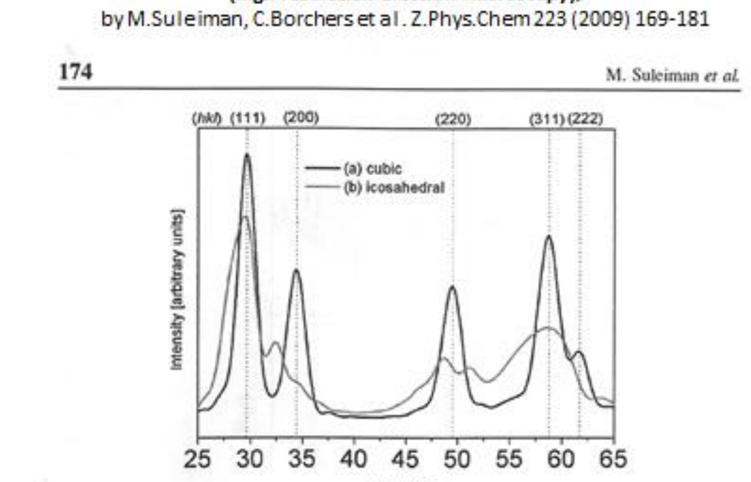


Fig. 1. Diffraction patterns of a model Pd cluster consisting of 2057 atoms: (a) shows the diffraction pattern of a cubic cluster (3.7 nm), (b) represents an icosahedral cluster (3.7 nm). The dotted vertical lines are the position of the Bragg reflections for bulk Pd with cubic lattice structure after [15].

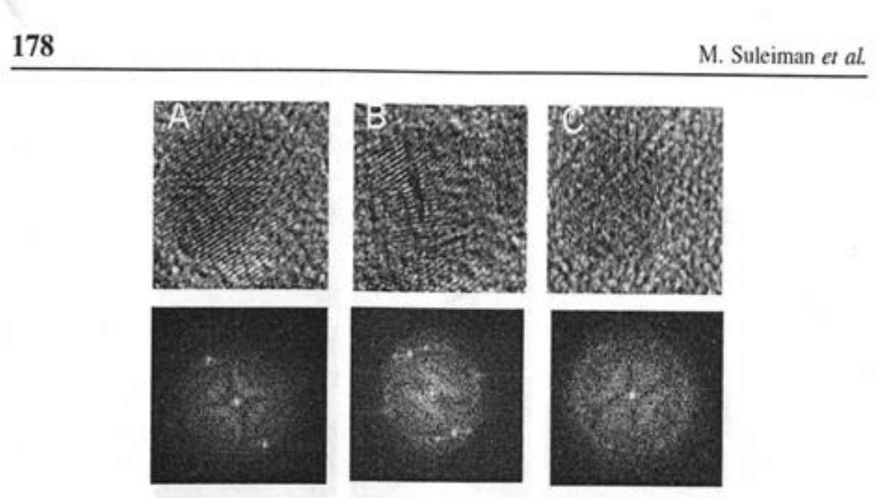


Fig. 5. HRTEM images and diffraction images of the 5.6 nm cluster: 90% of the clusters have cubic structure (A). The rest are multi-twinned (B) or icosahedral (C).

Structure of Palladium Clusters ... 179

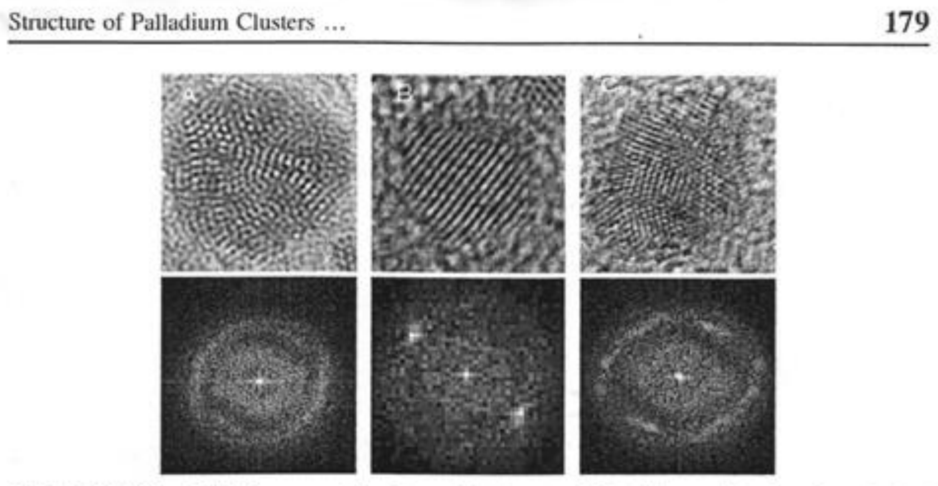


Fig. 7. HRTEM and FFT images of the 3.6 nm Pd clusters: 95% of the particles have icosahedral structure (A). The rest is cubic (B) or multi-twinned (C).

prevailing of surface properties at decreasing of cluster radii and increasing of their number

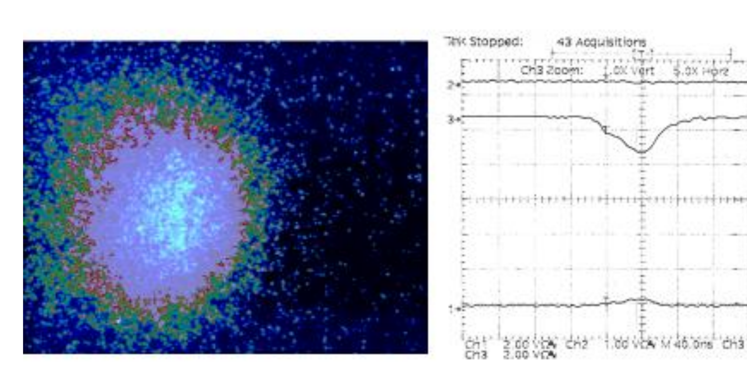
Rewrite $I_{sc} = 1/N_0 Q_S$ as $I_{sc} = V_{1clus} / V_{clusters} S_{1clus} = 1/V_{clusters} (S_{1clus}/V_{1clus})$

S_{1clus} and V_{1clus} -mean surface and volume of single cluster

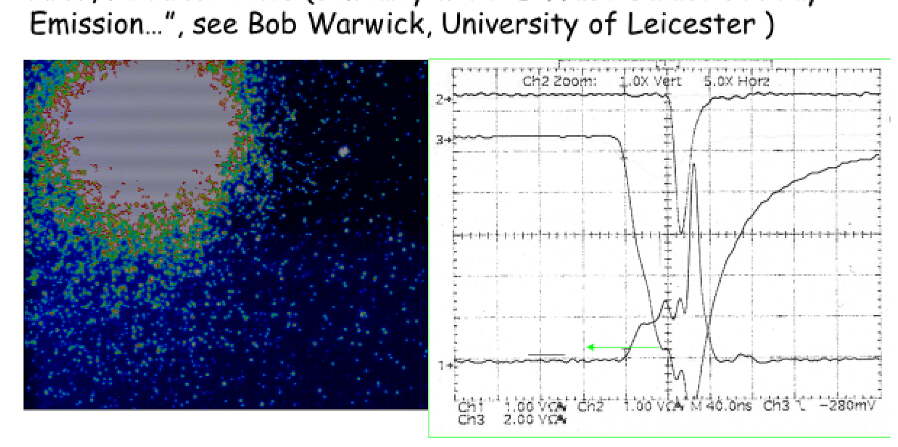
At cluster radius $r_{clus} \to 0$ we have $S_{1clus}/V_{1clus} \to$? and $I_{sc} \to 0$ formally

- Since metallic nanoclusters are **nanocrystalls**, the specific role of exact Bragg reflection and scattering in volume as well as by cold shells as effective "ring resonators" need separate analysis.

Example of interelectrode ensemble with diffused x-rays (below x-ray « random » lasing threshold $R < R_{CR}$)

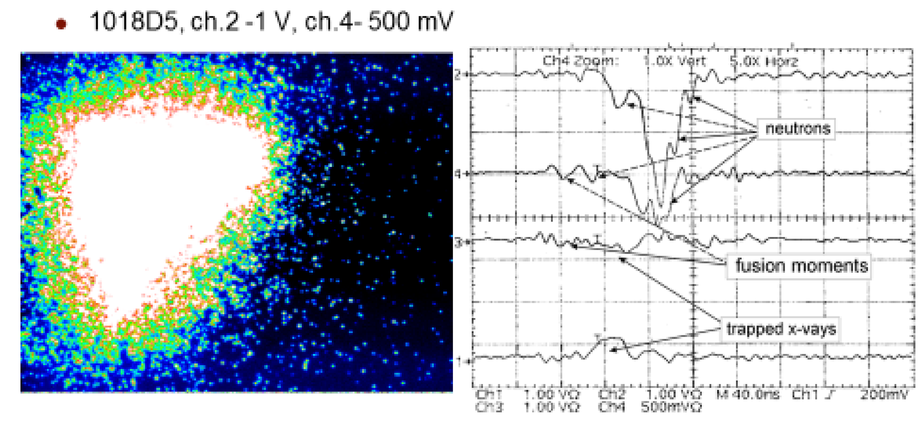


Ensemble above «random» lasing threshold (?) at $R > R_{CR}$.
Anisotropic hard X-rays burst with spikes at channels 1 and 3. This short is done with Fe anode, and looks probable that emission registered by Chs 1,3 represents mainly the energy range 6 – 7 keV , including fluorescent Fe K-alpha, and some Fe XXV, Fe XXVI lines (similarly with "Diffuse Galactic X-ray Emission…", see Bob Warwick, University of Leicester)



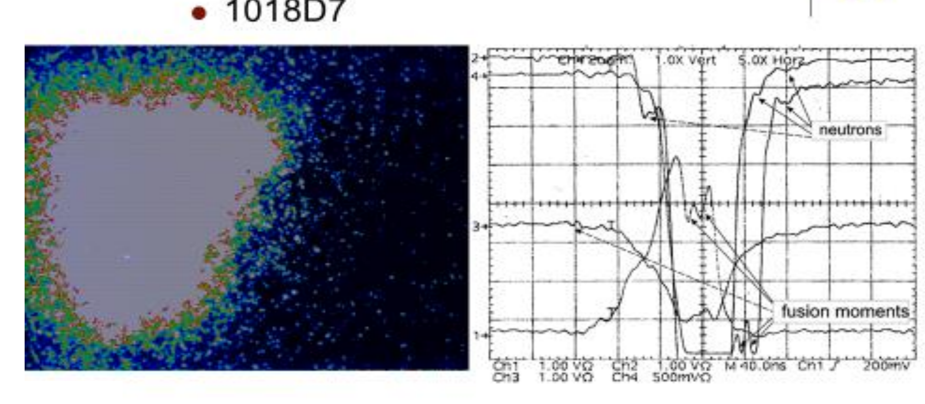
Another shape of dense ensemble with multiple fusion (« microreactor ») and essential x-rays trapping
High pulsating neutron yield and *very low level of x-rays yield* (chs 1,3)
(it provides the registering of just neutrons mainly at PM4 also)

- 1018D5, ch.2 -1 V, ch.4- 500 mV

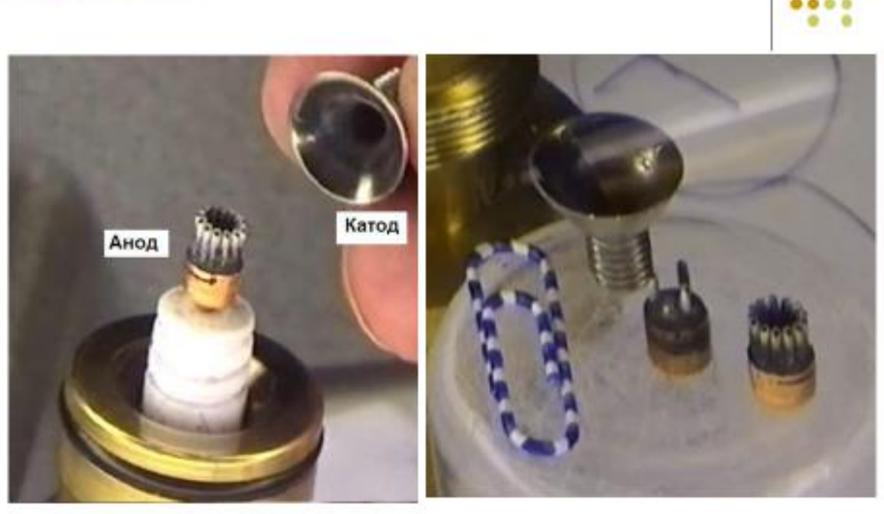


Next shot. Strong hard x-rays release (chs 1-4)

- 1018D7

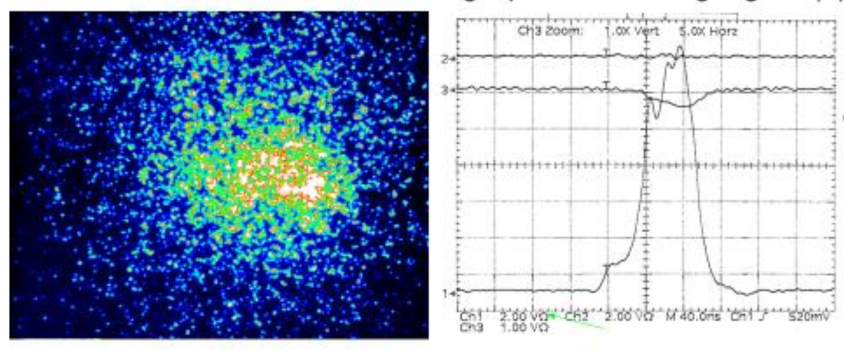


Electrodes



Broken symmetry of ensemble, accompanied by strongly anisotropic x-rays burst (channel 1)

- single pass ASE lasing regime (?)



Partial and essential x-ray trapping by ensembles as well as random laser-like behavior of potentially amplifying media of interelectrode complex plasma are presented above. This scheme of stochastic (random) laser with non-resonant feedback by energy have been suggested much earlier [3]. Note the increased interest to random lasers at visible spectra during last decades [4]. In the case of NVD this scheme assumes the diffusion and partial "random walk" of even x-rays photons inside of x-rays interelectrode "ball" due to multiple scattering and reflecting in disordered media (Since the metallic nanoclusters are nanocrystalls of different size [5], the cold clusters shells of ensemble represent the distributed Bragg reflector structures for x-rays [2]). When the volume gain if available overcomes the surface losses, hard x-ray burst may take place. The properties of ensembles with observed strong hard x-ray bursts which could be interpreted as ASE (superradiance) regimes or random lasing with non-coherent feedback as well as specific mechanisms of pumping and feedback by energy [3] are the subject of further study.

This work was supported partially by RFBR Grant No. 15-08-08720a and Grant No. 14-50-00124 of the Russian Science Foundation.

1. Yu.K. Kurilenkov, M. Skowronek and J.Dufty. *Journal of Physics A: Math. & General* 39 (2006) 4375; Yu.K. Kurilenkov et al. *Contrib. Plasma Phys.* 51, No. 5, 427 – 443 (2011).
2. Yu.K. Kurilenkov, V.P. Tarakanov, S.Yu. Gus'kov, I.S. Samoylov, V.E. Ostashev. *J. Phys.: Conference Series* 653 (2015) 012026.
3. V. S. Letokhov. *Sov. Phys. JETPh* 26 no 4(1968) 835; *Quantum Electronics* 32 (2002) 1065.
4. D.S.Wiersma. *Nature* 4 (2008) 350.
5. Suleiman M, Borchers C, Guerdane M et al *Z. Phys.Chem.* 223 (2009)169-181