TOMSK
POLYTECHNIC
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Lecture 8

Part 1. Electronic Speckle Pattern Interferometry

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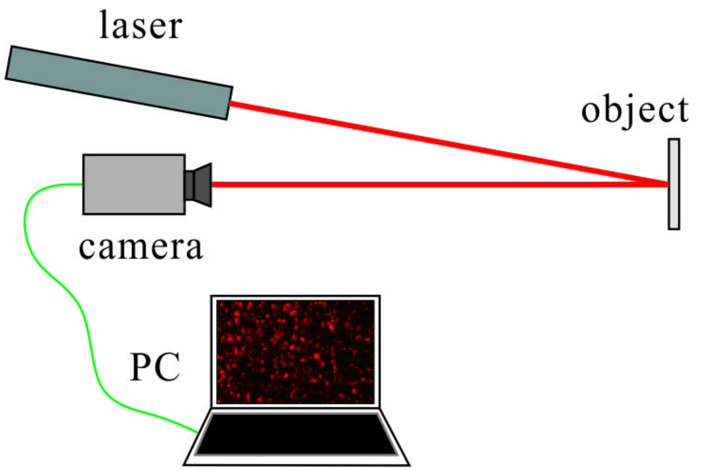
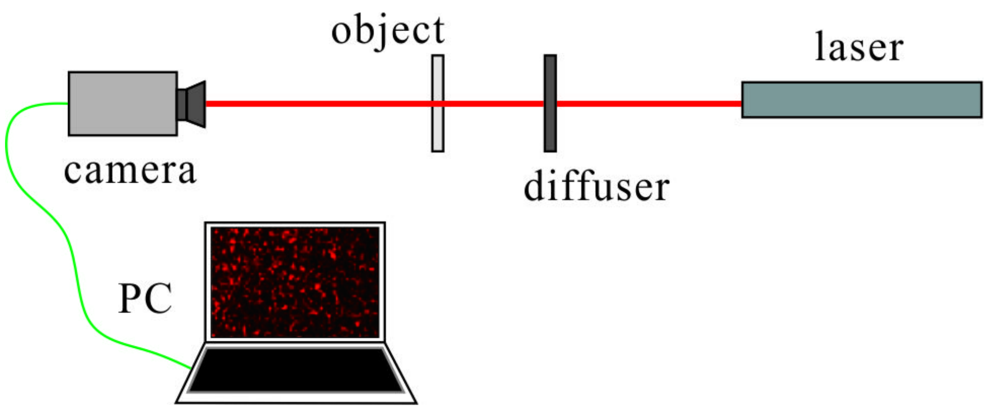
2017

Method Description

Laser speckles produced by reflected or transmitted light, which is free to mix in the space, can produce the interference space with varying brightness. If we take a photograph of this area in some plane, we obtain the image with speckle, called speckle image. Due to the fact, that the scattered coherent light forms it, in a sense, a change in the speckle image corresponds to the change of the object properties.



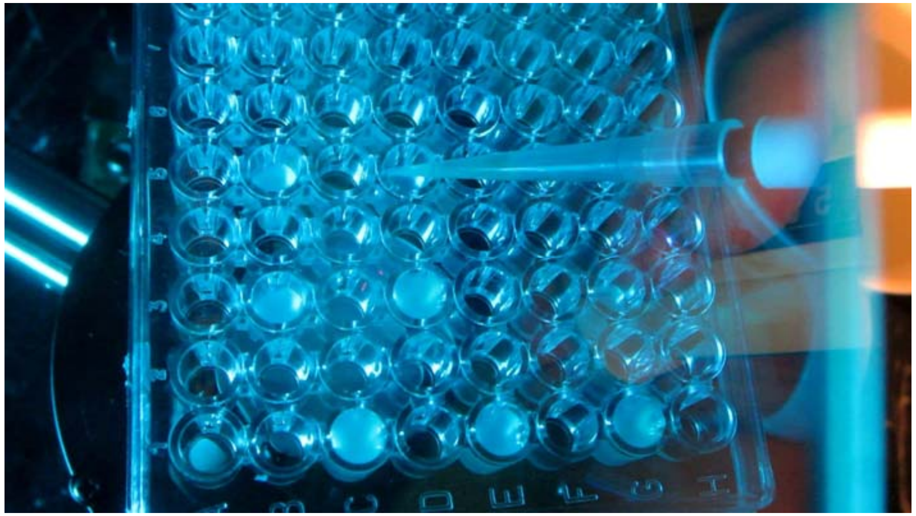
For non-transparent objects reflecting light is used usually.

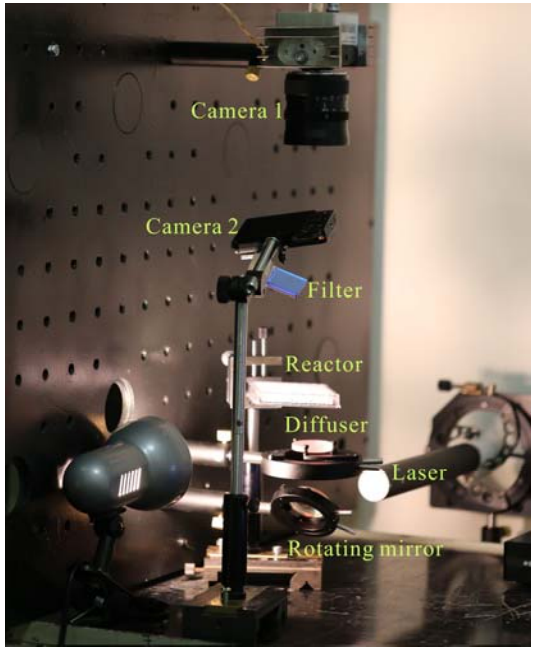


For transparent objects - through-passing light.

Liquid transparency changing dynamics estimation by means of digital speckle correlation

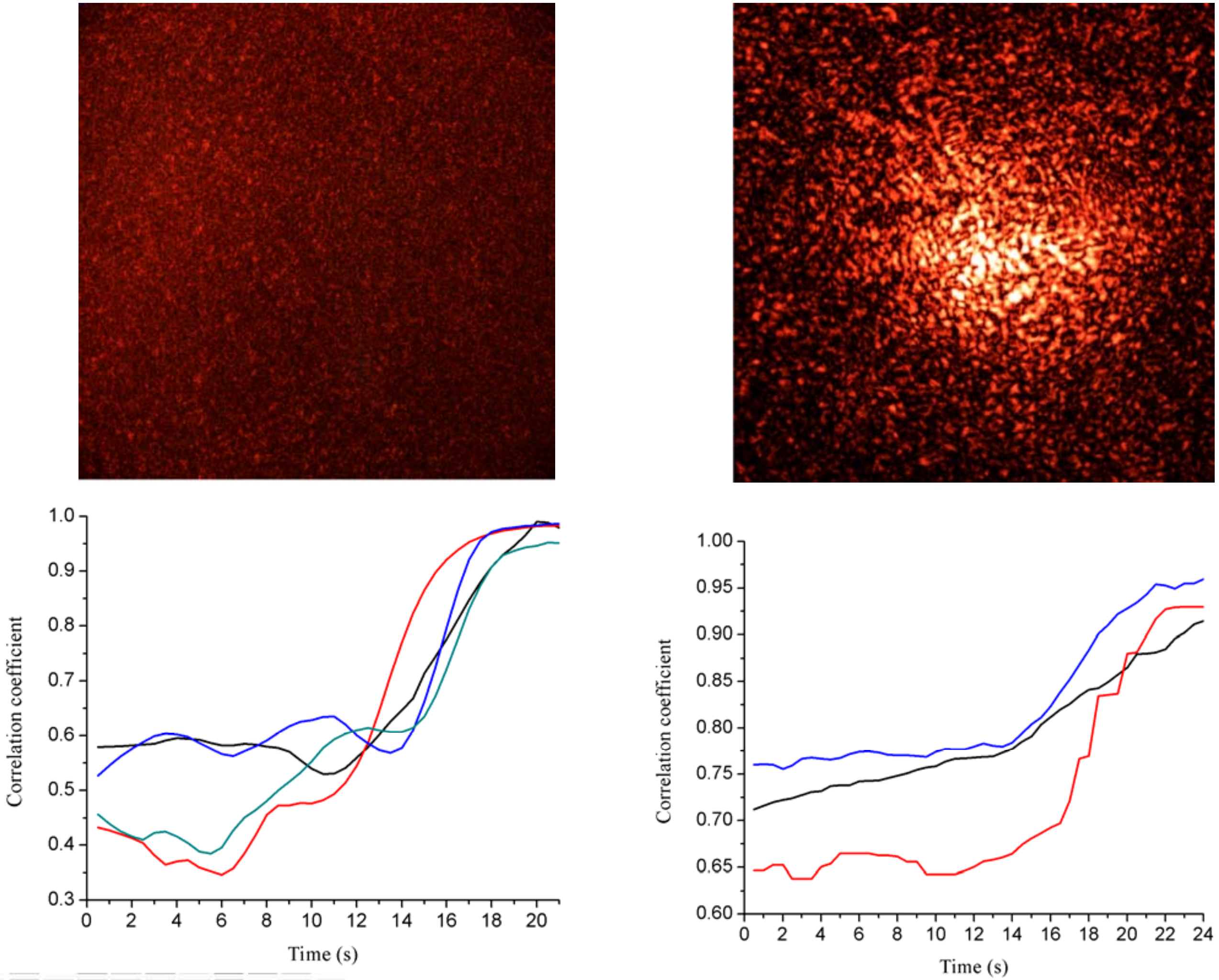
Due to the changes of speckles, images can show the changes of the object under observation. This feature provides the possibility for measurement and investigation of biological liquid samples using speckle-image correlation analysis. The sample can be a body fluid, particularly blood. Time of blood coagulation is an important parameter to characterize the blood diseases. Too strong or too weak clotting capacity can indicate about such diseases. Thus, developing a fast and easy method for the clotting time measuring is very important and necessary task.



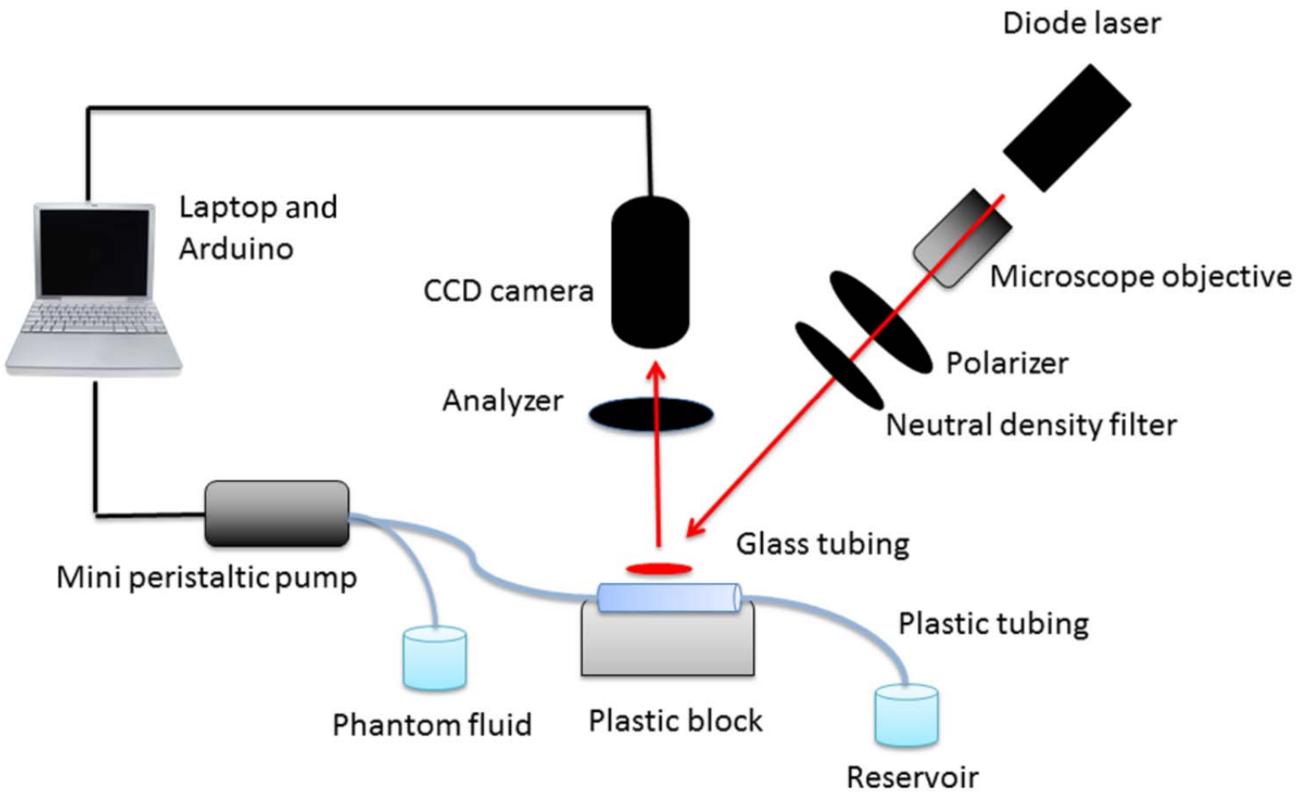


Speckle Imaging

Speckle images (a) with the diffuser and (b) without the diffuser during the clotting process and corresponding graphs of correlation coefficients.



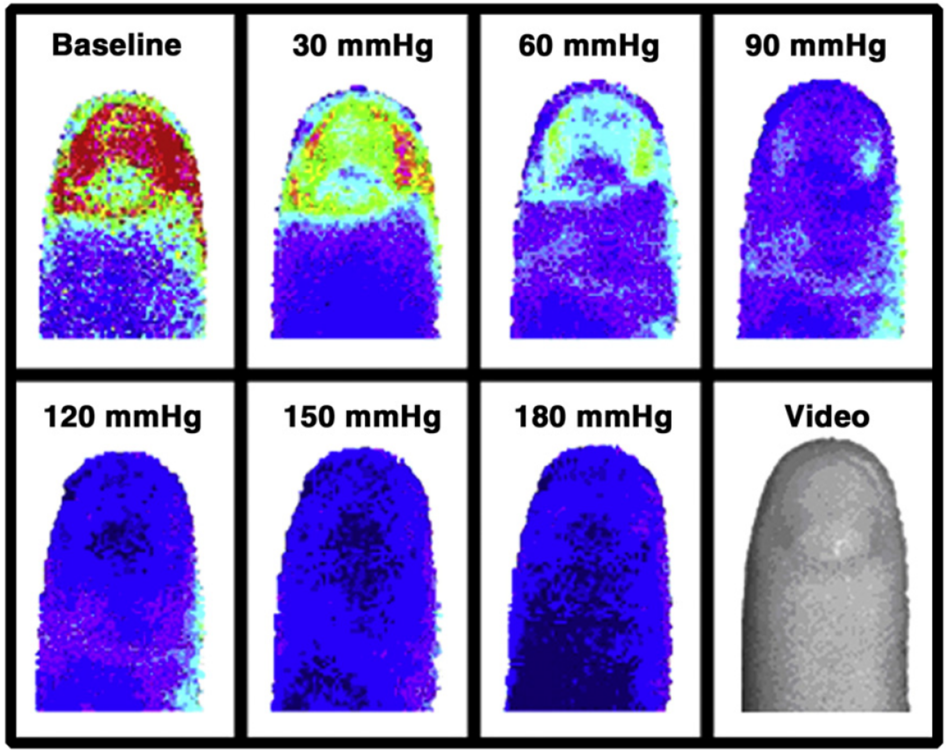
Measurement of advective flux



The scheme of a LSCI (Laser speckle contrast imaging) and flow systems

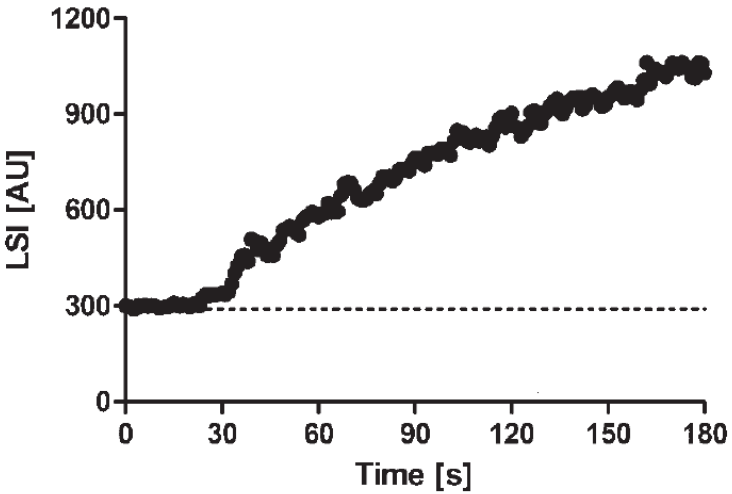
Kosar Khaksari and Sean J. Kirkpatrick, Laser speckle contrast imaging is sensitive to advective flux// Journal of Biomedical Optics., 2016, Vol. 21(7) pp. 076001.1 – 8.

Assessing microvascular perfusion



*Blue indicates low perfusion and red indicates high perfusion

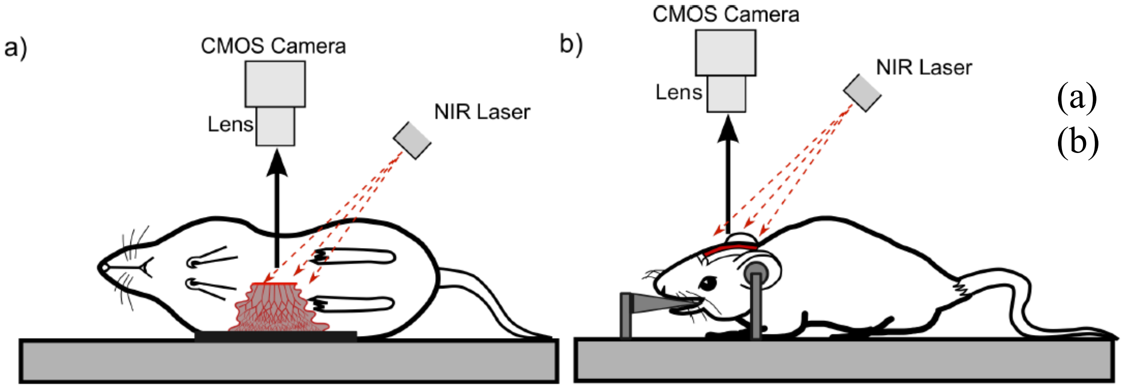
The images show the representative laser speckle imaging perfusion maps for 0 (baseline), to 180 mm Hg occlusion. And Typical laser speckle imaging (LSI) perfusion trace during heating of the skin2.



In this paper, authors have shown that LSI responds linearly to changes in red blood cell velocity in the nail fold of healthy volunteers during gradual occlusion. Therefore LSI is a valid modality for measuring microcirculatory perfusion both at rest and during different provocation tests.

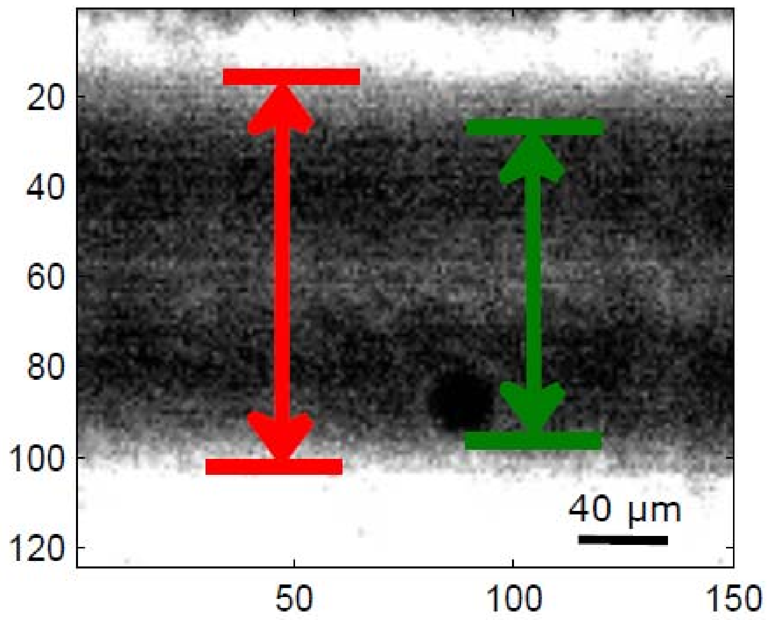
Bezemer R., Klijn E., et al.. Validation of near-infrared laser speckle imaging for assessing microvascular (re)perfusion// Microvascular Research 2010, Vol. 79, pp. 139 – 143.

Estimation of vessel diameter and blood flow dynamics from laser speckle images



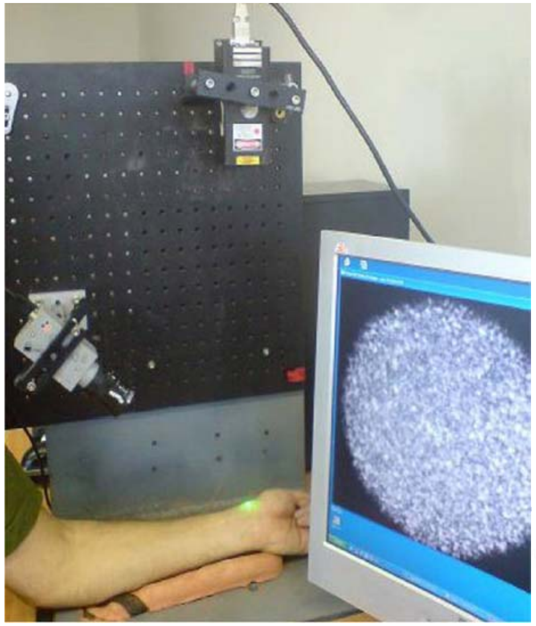
(a) Imaging of mesenterium arteries
(b) laser speckle imaging of vascular network in mouse cortex

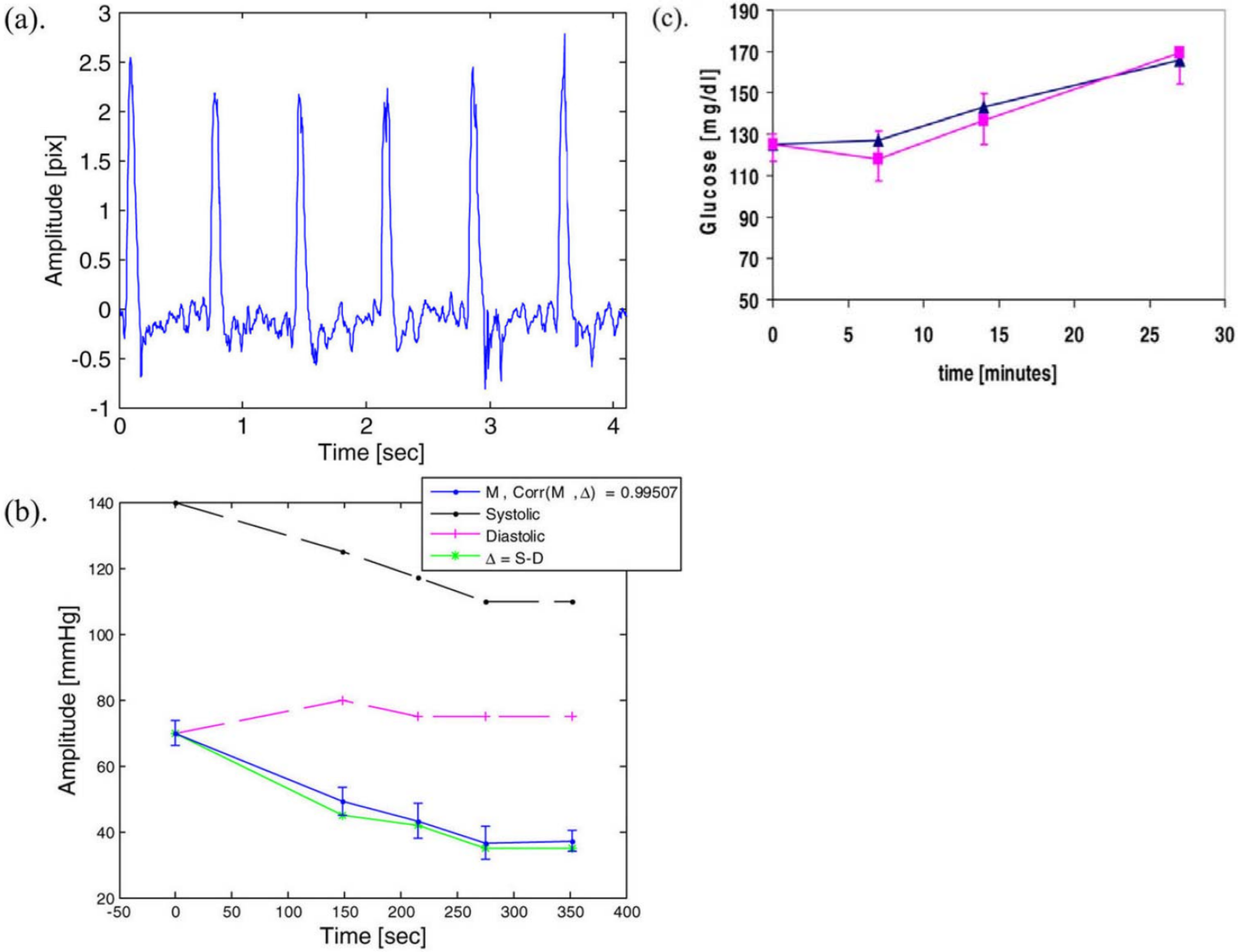
The right panel shown microphotography of a vessel. Red color indicates the outer diameter and green color marks the inner diameter. And the grayscale of image can show the flow speed.



Dmitry D. Postnov, Valery V. Tuchin, Olga Sosnovtseva, Estimation of vessel diameter and blood flow dynamics from laser speckle images//Biomedical optics express 3016 Vol. 7, No. 7, pp. 1-10.

Remote Estimation of Blood Pressure

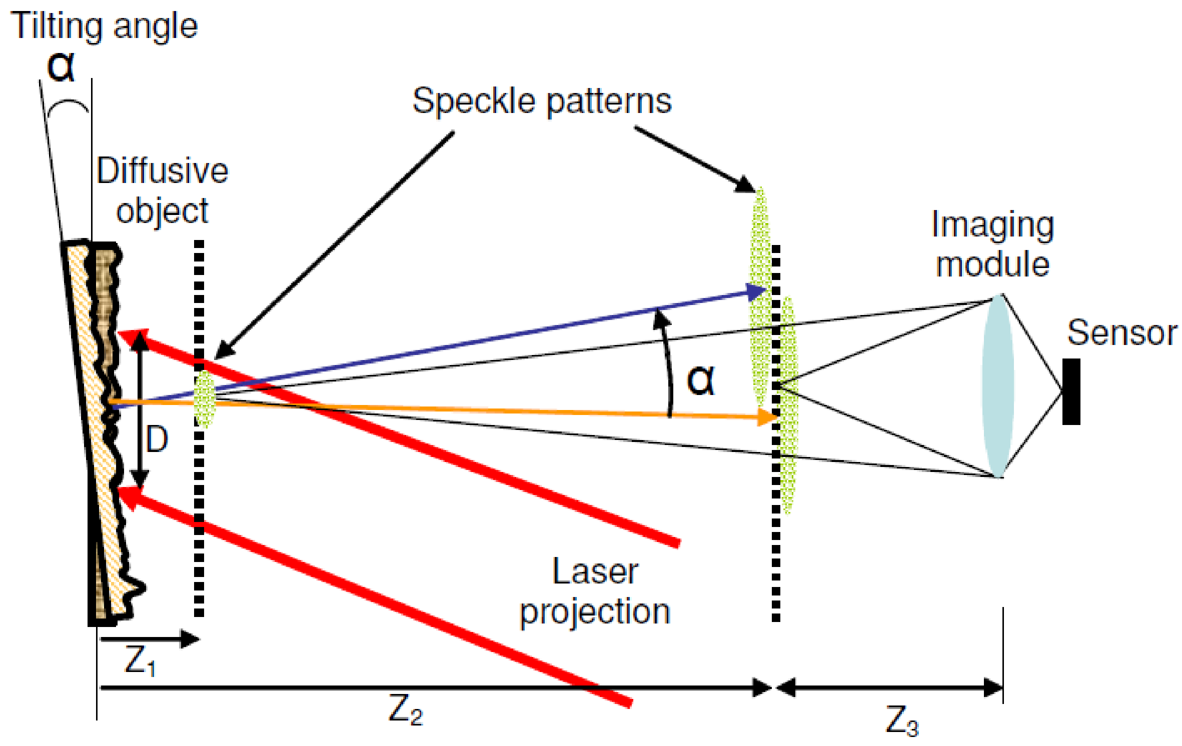




Individual heart beat measurements (a), graph of blood pulse pressures (b), and blood glucose concentration (c)

Zalevsky Z., Beiderman Y., Micó V., Garcia J. A novel technique for remotely monitoring key biological parameters // SPIE Newsroom. – 2011. – DOI. 10.1117/2.1201106.003742.

Principle of Vibration Measurements



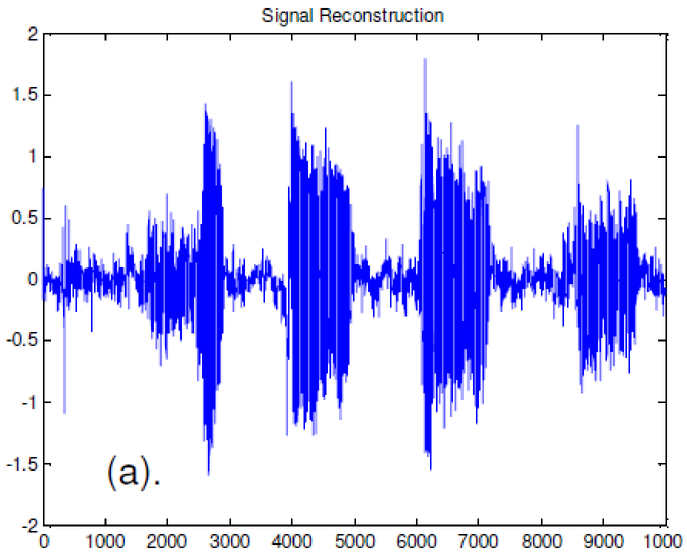
Magnification factor is

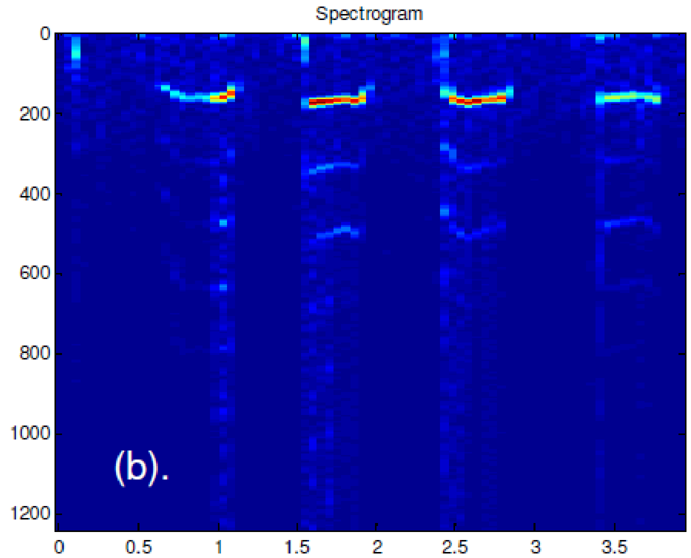
$$M = \frac{Z_3 - F}{F} \approx \frac{Z_3}{F}$$

The conversion of angle to the displacement of the pattern on the camera is as follows:

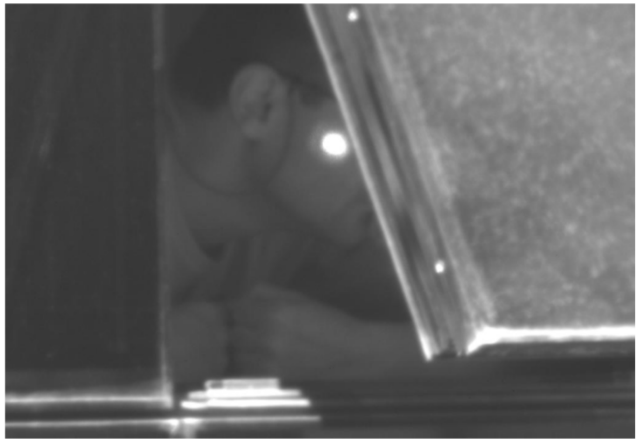
$$d = \alpha \frac{Z_2 F}{Z_3}$$

Remote Extraction of Multiple Speech Sources





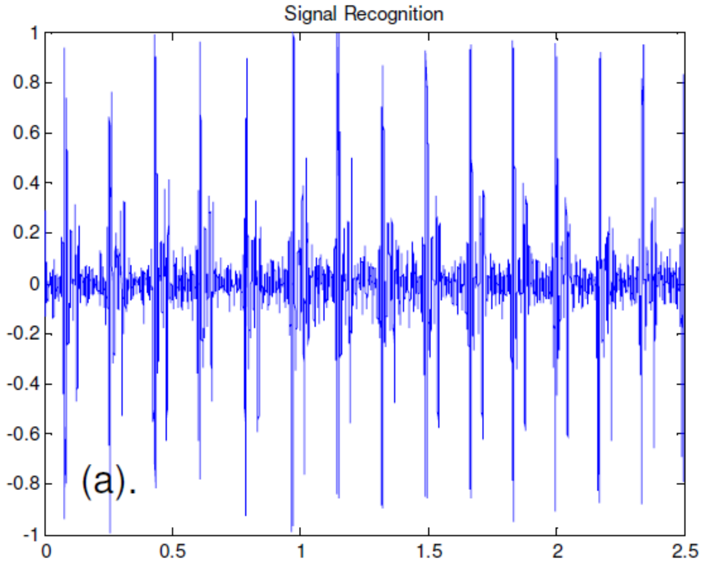
Zalevsky Z., Beiderman Y., Margalit I., Gingold S., Teicher M., Mico V., Garcia J. Simultaneous remote extraction of multiple speech sources and heart beats from secondary speckles pattern // Optics express. – 2009. – Vol. 17. – No. 24. – P. 21566-21580.

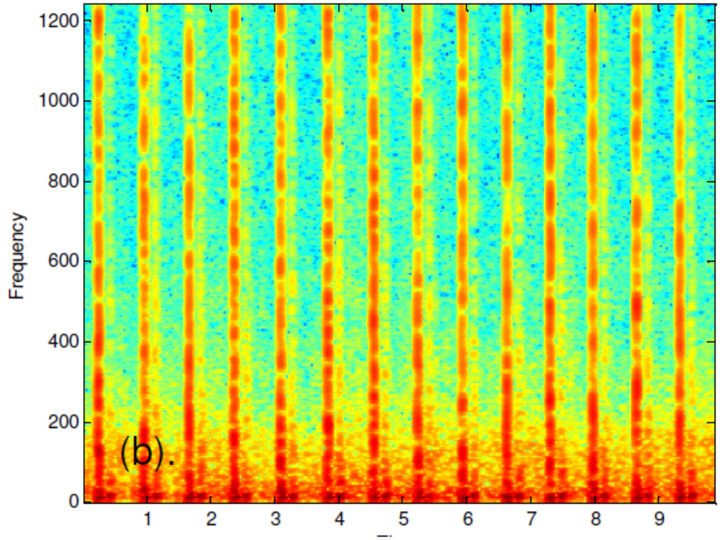


(c).

The temporal voicesignal (a), the spectrogram (b) and scenario (c)

Remote Extraction of Heart Beats



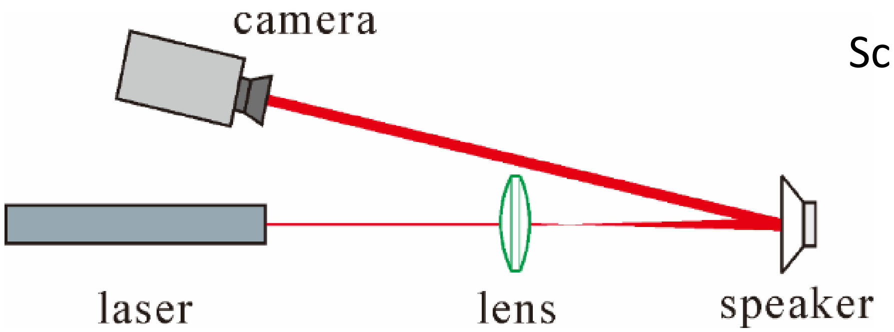


Zalevsky Z., Beiderman Y., Margalit I., Gingold S., Teicher M., Mico V., Garcia J. Simultaneous remote extraction of multiple speech sources and heart beats from secondary speckles pattern // Optics express. – 2009. – Vol. 17. – No. 24. – P. 21566-21580.

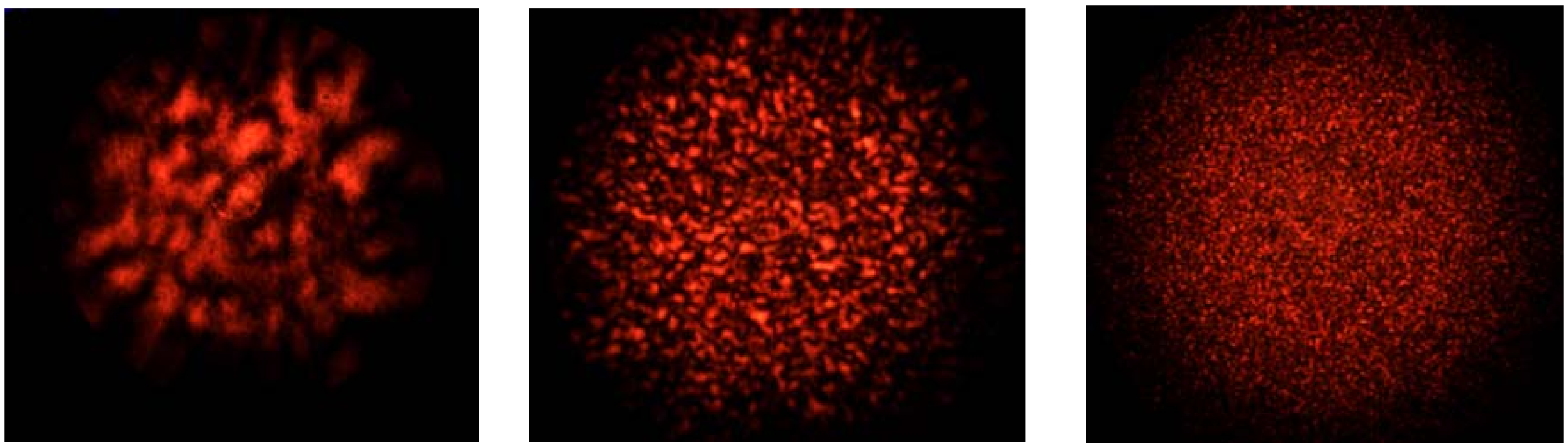
(c).

Experimental results for heart beats detection of remote subject. The temporal signal (a), the spectrogram (b), and scenario (c)

The Influence of the Radiation Source Parameters on the Accuracy of Digital Speckle Correlation Method



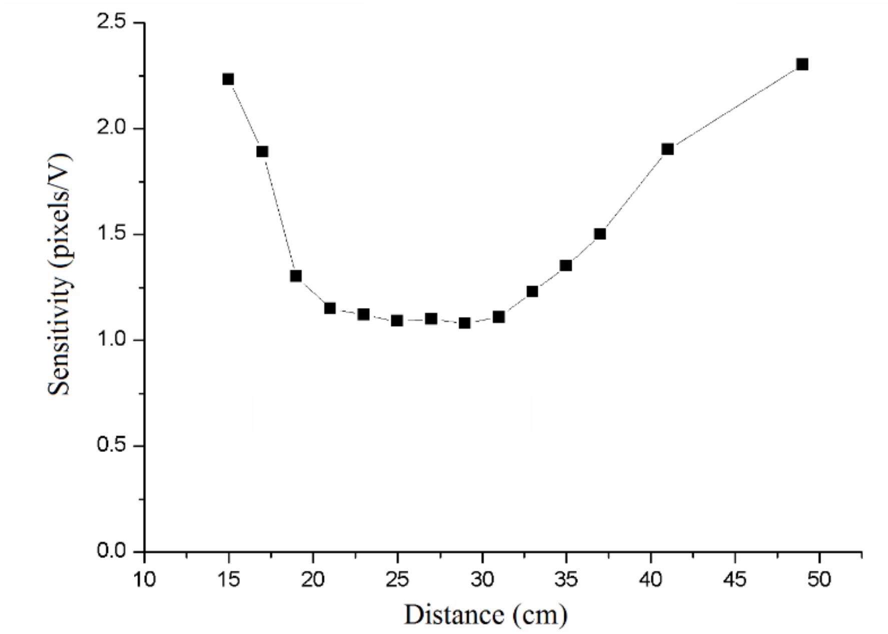
Schematic illustration of the experiment



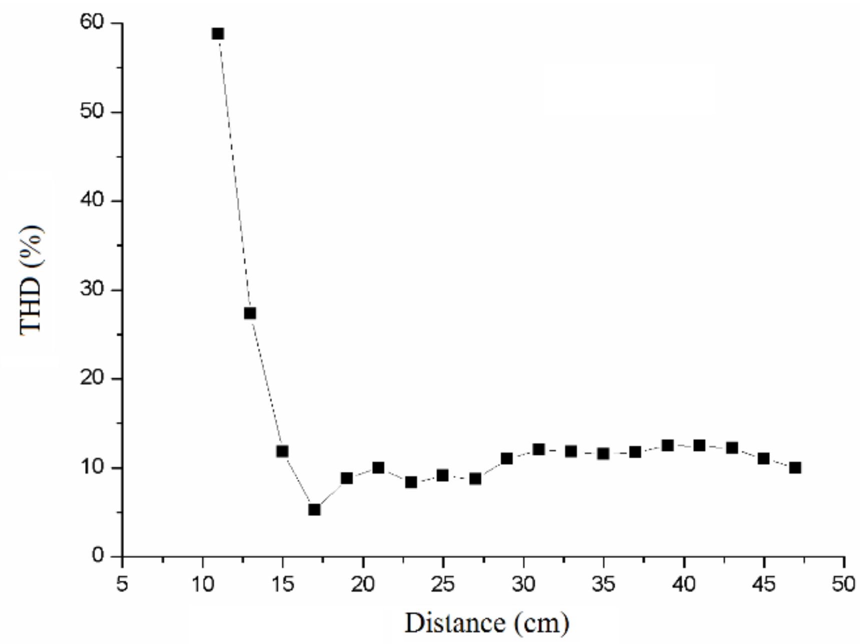
a) b) c)

The speckle patterns with different diameter laser spot on the diffuser speaker: a) 11 mm, b) 17 mm, c) 47 mm. The distance between the surfaces of the object and the camera is 50 cm. The camera's exposure time is 1.995 ms.

The Influence of the Radiation Source Parameters on the Accuracy of Digital Speckle Correlation Method

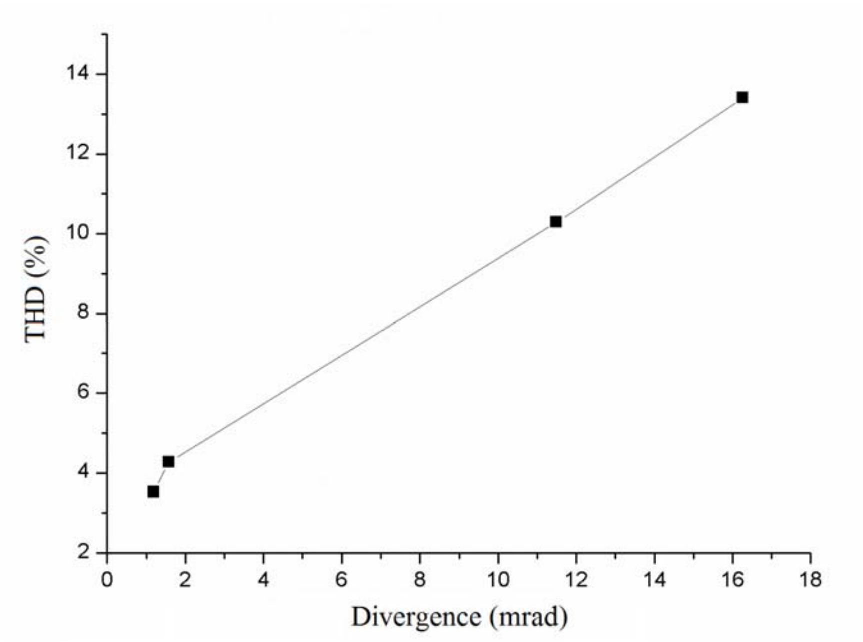


The dependence of sensitivity fluctuation amplitude of the decoded signal of the distance between the focusing lens and the speaker cone. The signal frequency is 50 Hz. The frequency of camera registration is 500 Hz, the camera`s exposure time is 1.995 ms.

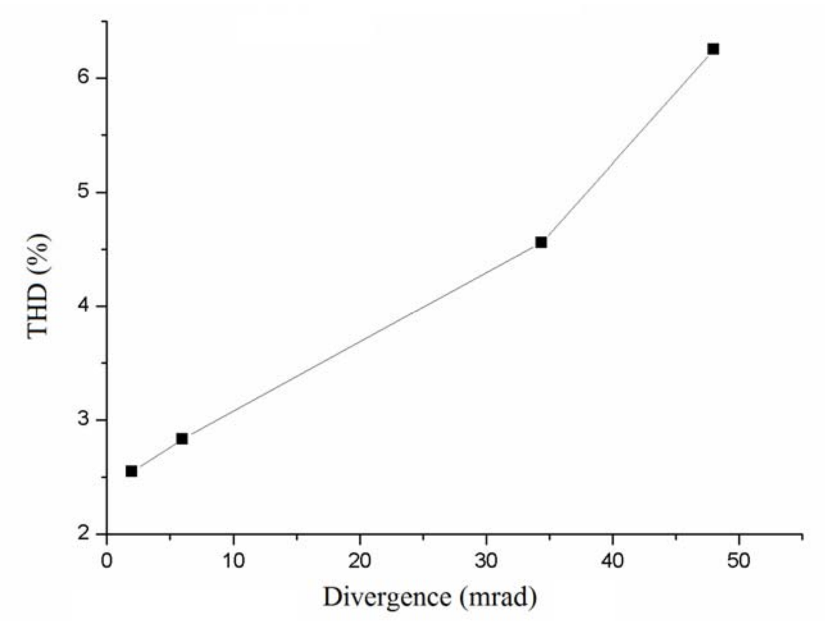


Dependence of the THD decoded signal average value on the distance between the focusing lens and the loudspeaker. The frequency of the sinusoidal signal is 50 Hz. The frequency of camera recording is 500 Hz, the camera`s exposure time is 1.995 ms.

The Influence of the Radiation Source Parameters on the Accuracy of Digital Speckle Correlation Method



The dependence of the decoded signal average value on the THD values of the beam divergence using the He-Ne laser. The amplitude of the signal voltage is 2 V. The signal frequency is 50 Hz. The frequency of camera registration is 500 Hz, The camera's exposure time is 1.995 ms.



The dependence of the decoded signal average value on the THD value of the beam divergence using the green semiconductor laser. The amplitude of the signal voltage is 2 V. The signal frequency is 50 Hz. The camera registration frequency is 500 Hz. The camera's exposure time is 1.995 ms.

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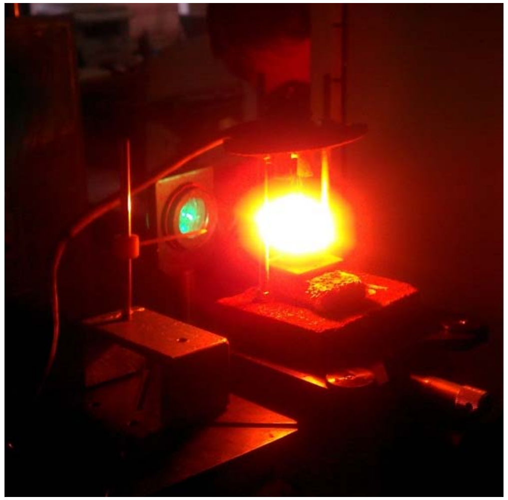
Lecture 8

Part 2. Monitoring of Hidden Objects

2017

Laser monitors for diagnostics of processes

Arc and laser welding

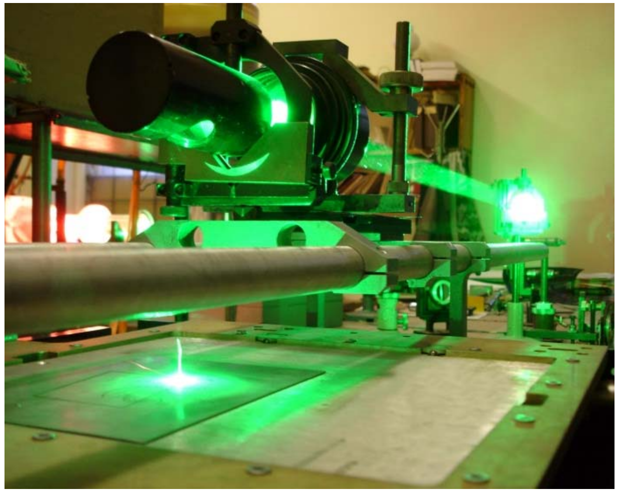


Self-propagating high-temperature synthesis

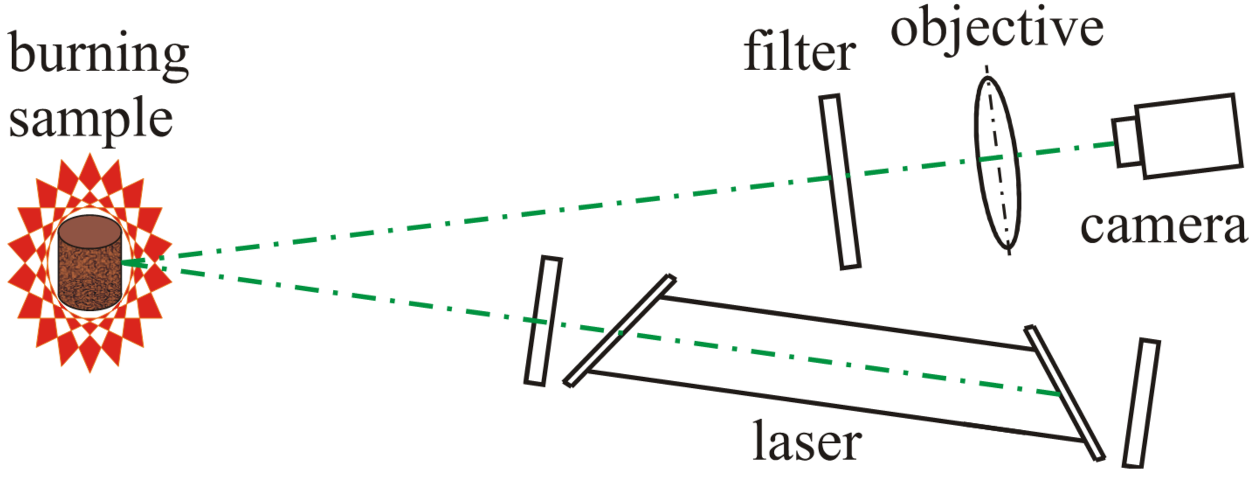
Also:

plasma processes;
coatings deposition;
extreme conditions of matters;
surface modification;
effect of energy flows on bio-objects (coagulation, ablation)

Microprocessing of materials

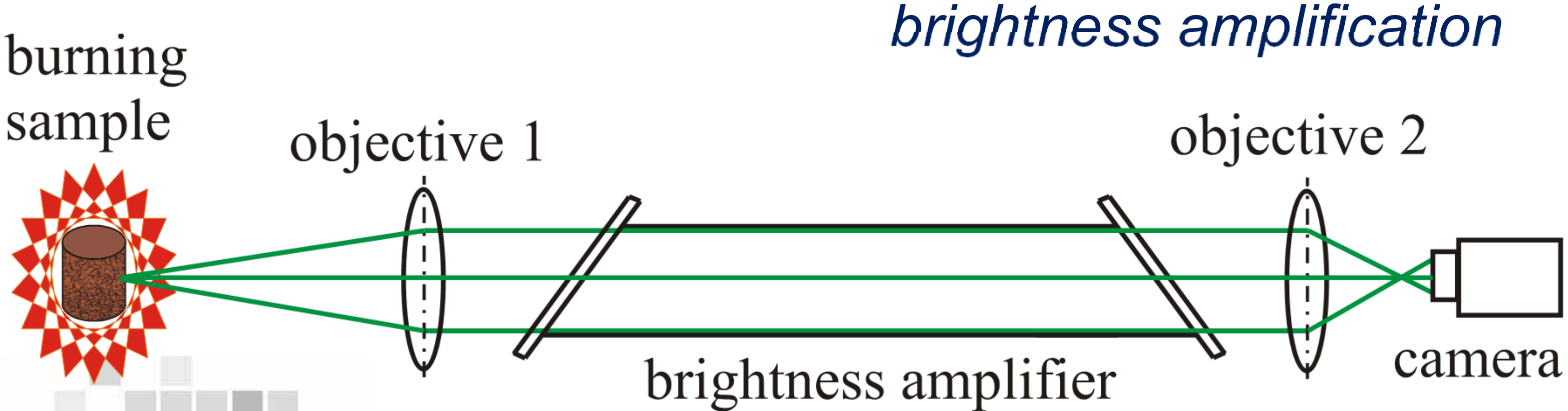


Monitoring of object shielded by strong background light

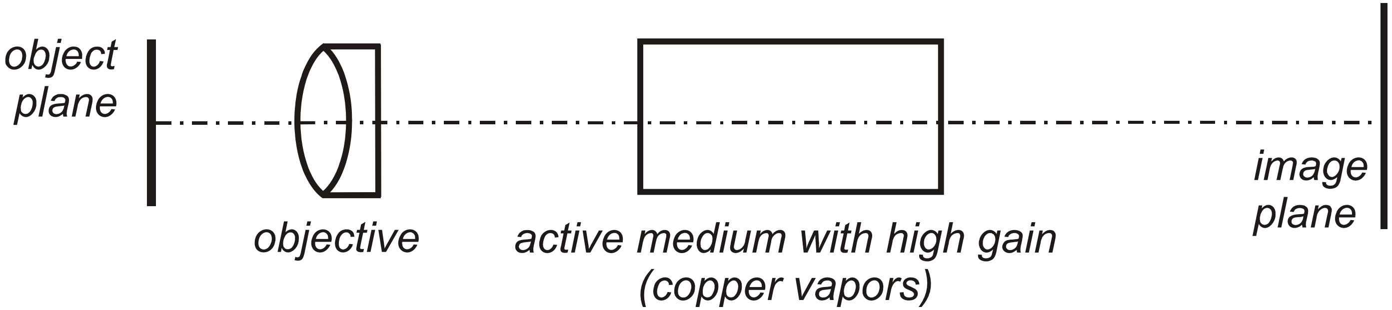


External laser illumination

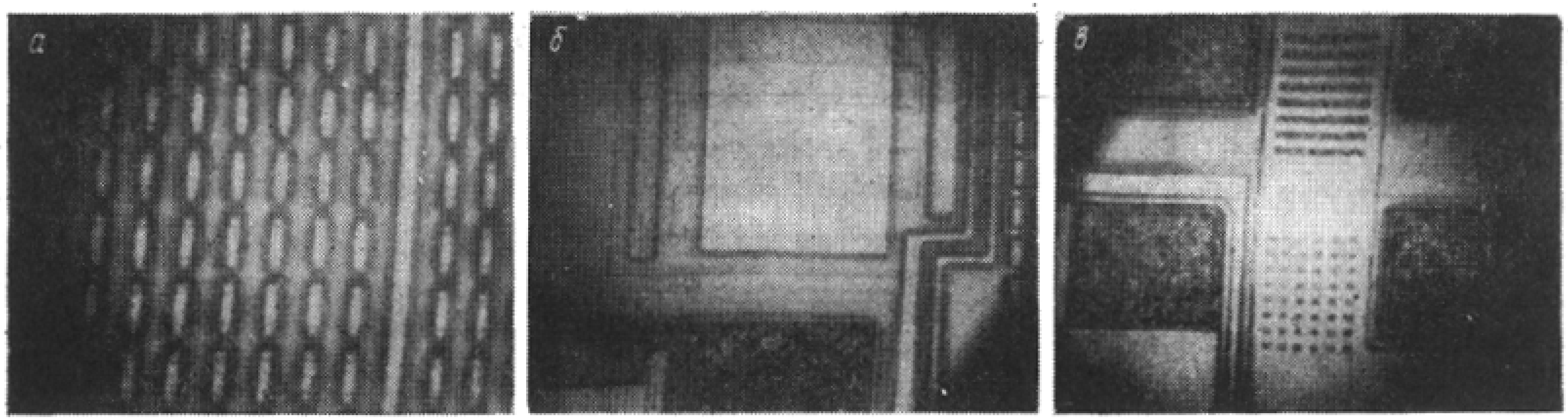
Active optical system with brightness amplification



Laser projection microscope



The scheme of a laser projection microscope[1]

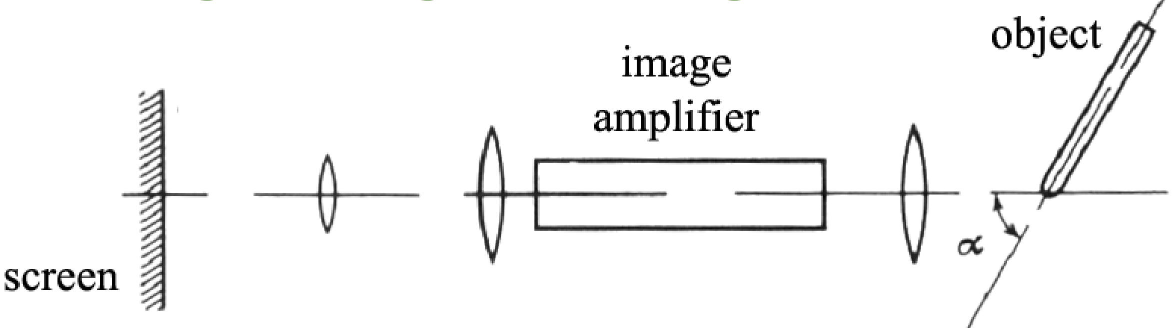


Images of fragments of integrated circuit from the system screen[2]

[1] *Zemskov K.I., Isaev A.A., Kazaryan M.A., Petrash G.G. Laser projection microscope // Soviet J. Quantum Electron., 1974, N 1, pp.14-15.*

[2] *Astadjov D.N., Vuchkov N.K., Zemskov K.I., Isaev A.A., Kazaryan M.A., Petrash G.G., Sabotinov N.V. Active optical systems with a copper bromide vapor amplifier // Soviet J. Quantum Electron., 1988, Vol.15, N 4, pp. 716-719.*

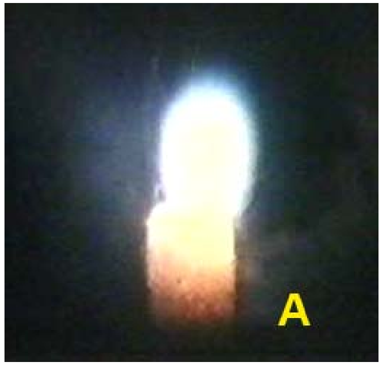
Monitoring of objects through strong background light



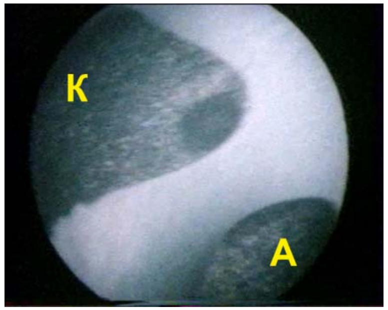
Electric arch with graphite electrodes [3]

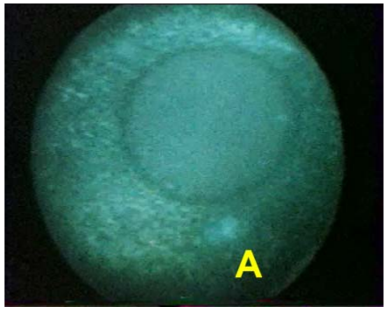
The active medium – copper vapors

Registration of images was carried out photographically



Carbon arch in own light (on the left – a side view, on the right – from the anode)

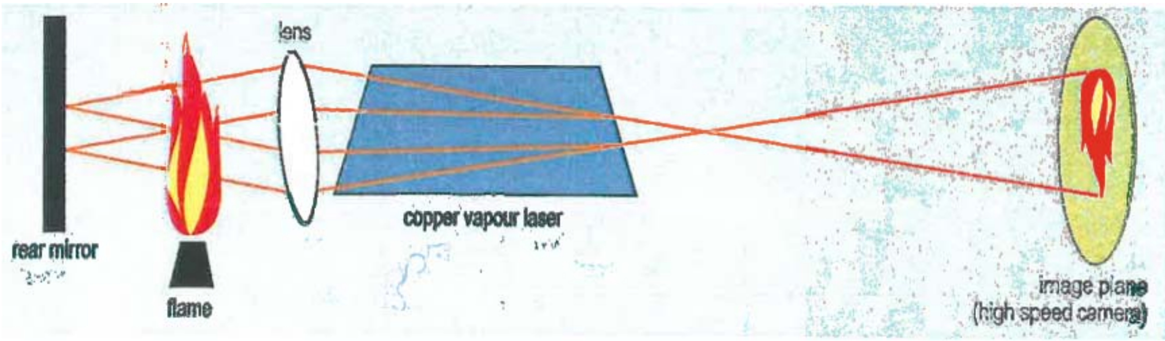


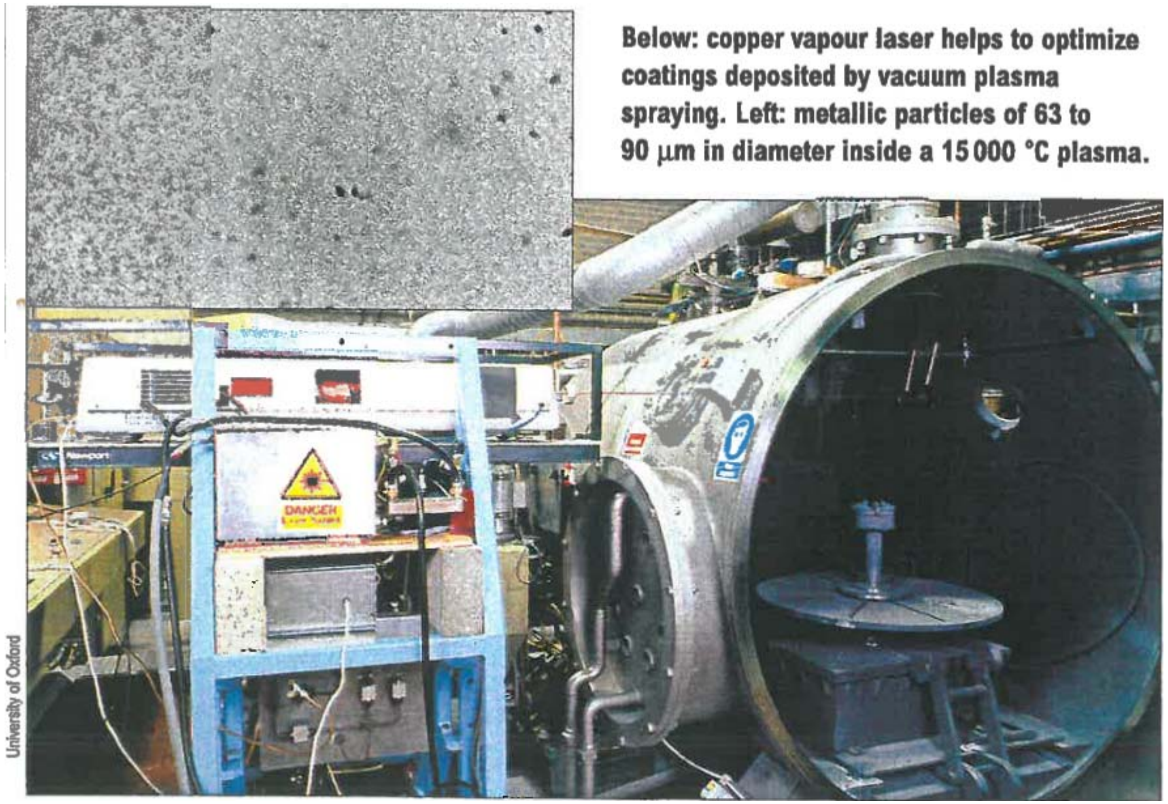


Images of electrodes of the carbon arch, received by means of the laser monitor

[3] *Batenin V.M., Klimovskii I.I., Selezneva L.A. Research of surfaces of electrodes of a carbon arc during its burning // Doklady Akademii Nauk, 1988, Vol. 303, N 4, pp. 857-860.*

High speed imaging of particles within intensely radiating plasmas [4]



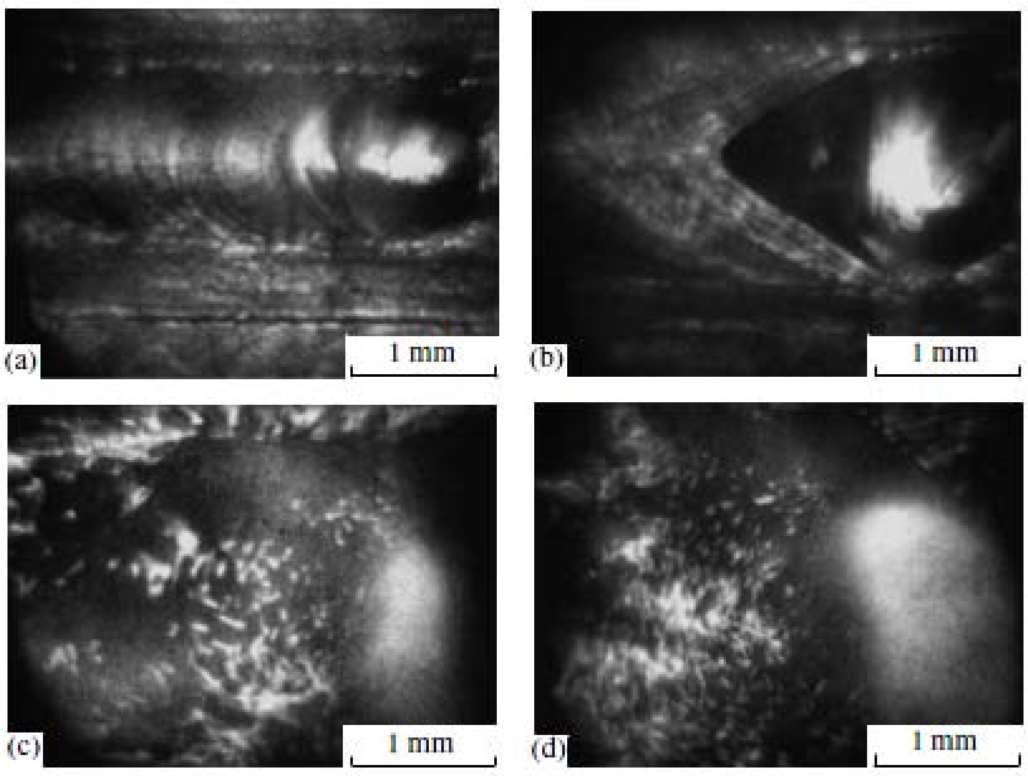


Below: copper vapour laser helps to optimize coatings deposited by vacuum plasma spraying. Left: metallic particles of 63 to 90 µm in diameter inside a 15 000 °C plasma.

[4] *Buchkremer F.B.J., Andrews A.J., Coutts D.W. and Webb C.E. A new method for high speed imaging of particles within intensely radiating plasmas // Technical Digest of Papers Presented at The Thirteenth UK National Quantum Electronics Conference, University of Wales, Cardiff, 8-11 September 1997, p.116.*

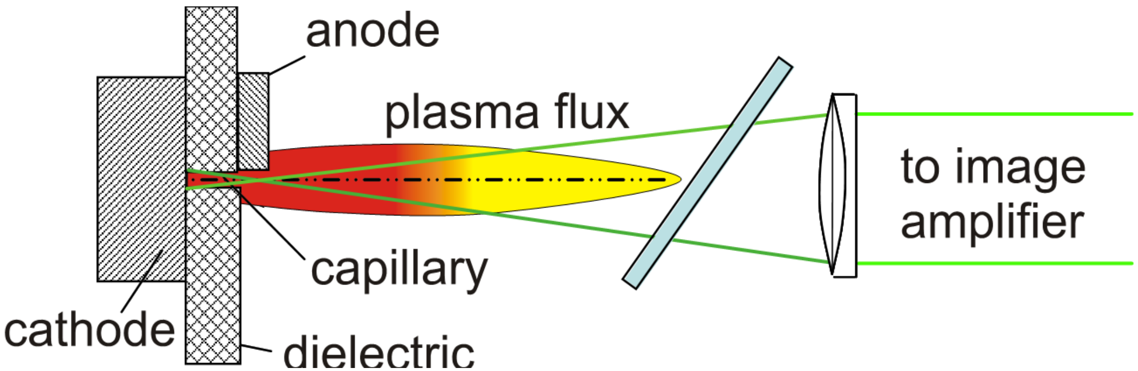
Laser welding monitoring using CVL [5]

(National research nuclear university “MEPhI”)



[5] *Yermachenko V.M., Kuznetsov A.P., Petrovskiy V.N., Prokopova N.M., Streltsov A.P., Uspenskiy S.A. Specific features of the welding of metals by radiation of high-power fiber laser // Laser physics. – No 8. – Vol. 21. – 2011 . – P. 1530-1537.*

Observation of erosion capillary discharge [6]

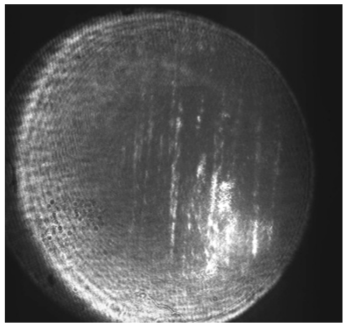


Parameters of plasma

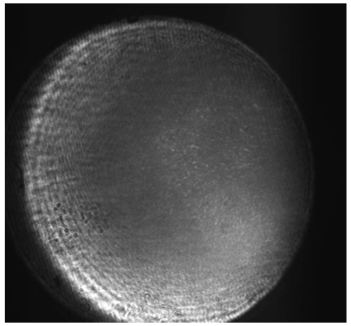
$T^{max} \approx 8600^0$ K (0.74 eV)

$n_e^{max} \approx 6.3 \cdot 10^{16}$ cm^{-3}

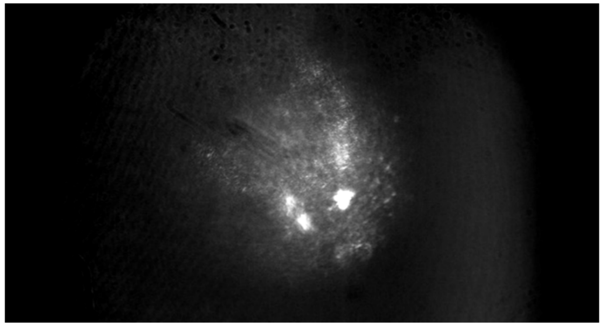
Plasma flux dimensions: 12–15cm length and 2.5–3 cm diameter.



Before discharge



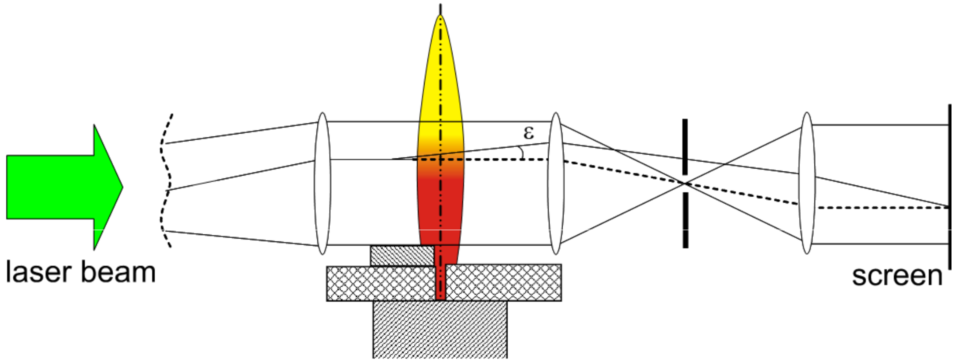
After discharge



At 2nd ms of a discharge

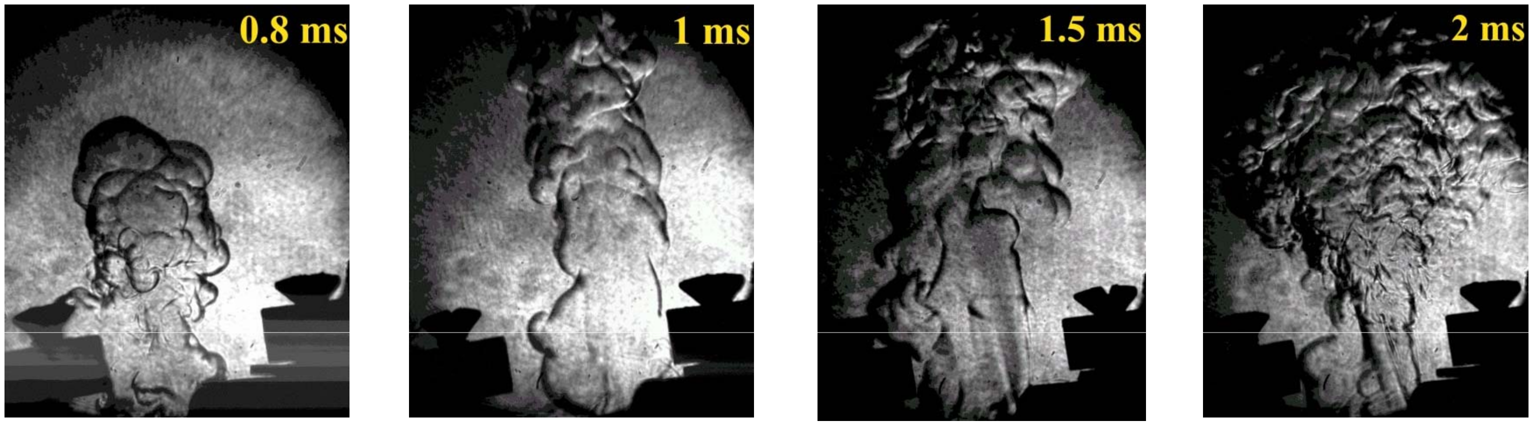
[6] *Kuznetsov A.P., Gubskii K.L., Savjolov A.S., Sarantsev S.A., Terekhin A.N., Buzhinskij R.O. Visualization of plasma-induced processes by a projection system with a Cu-laser-based brightness amplifier // Plasma Physics Reports, 2010. V. 36. No 5. pp. 428–437.*

Observation of erosion capillary discharge by shadow method [6]



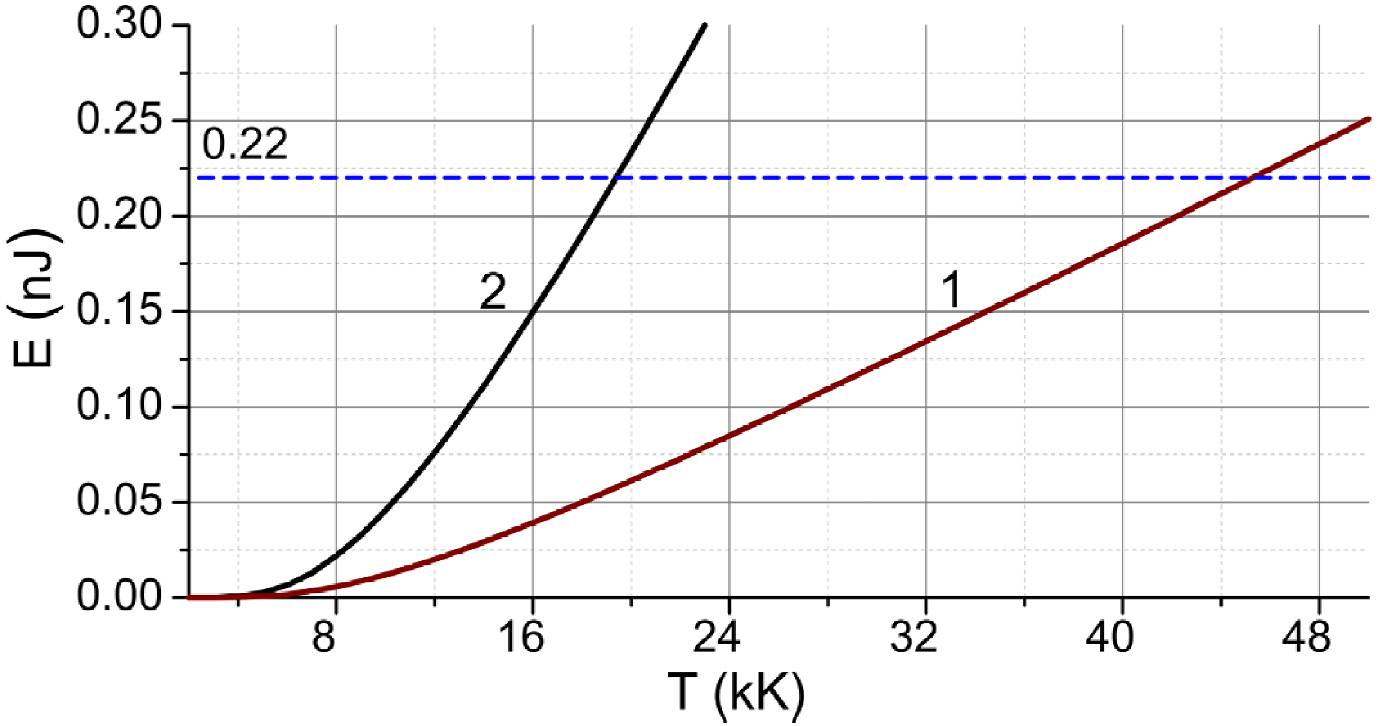
Laser beam is produced by copper vapor laser.

Shadow method was offered by August Toepler in 1867 year



[6] *Kuznetsov A.P., Gubskii K.L., Savjolov A.S., Sarantsev S.A., Terekhin A.N., Buzhinskij R.O. Visualization of plasma-induced processes by a projection system with a Cu-laser-based brightness amplifier // Plasma Physics Reports, 2010. V. 36. No 5. pp. 428–437.*

Limitations of laser monitor



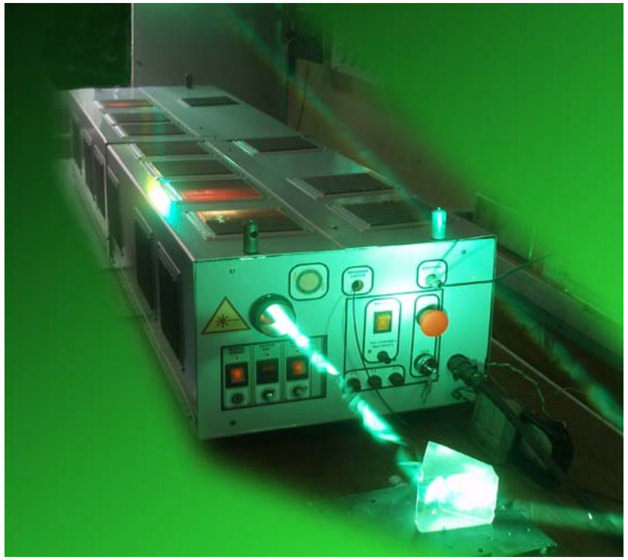
The dependence of the radiation energy of the lighting source on the temperature: 1 – the depth of the plasma layer is 5 mm, 2 – the depth of the plasma layer is 80 mm (a direct line is the self-noise of the brightness amplifier)

[7] Evtushenko G.S., Trigub M.V., Gubarev F.A., Evtushenko T.G., Torgaev S.N., Shiyanov D.V. Laser monitor for non-destructive testing of materials and processes shielded by intensive background lighting // Rev. Sci. Instrum., 2014, Vol. 85, 033111-1–033111-5.

Metal vapor laser brightness amplifiers

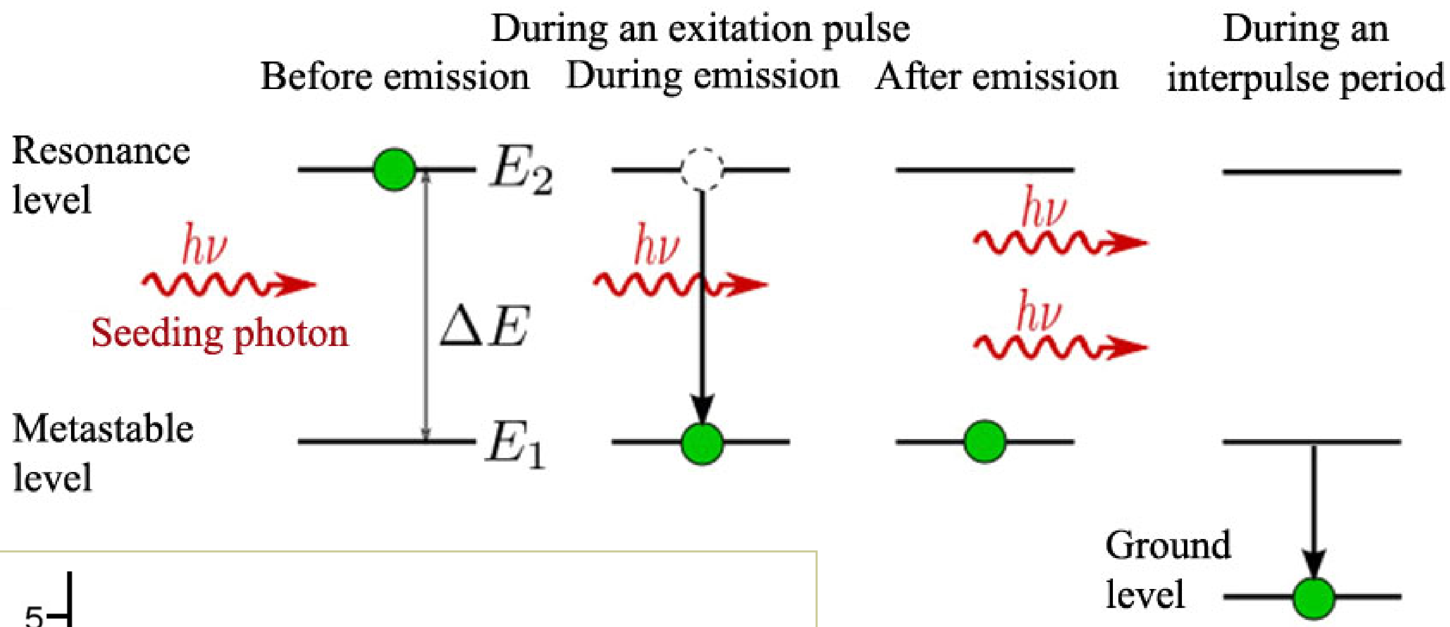
«Heart» of a laser monitor is a metal vapor laser brightness amplifier

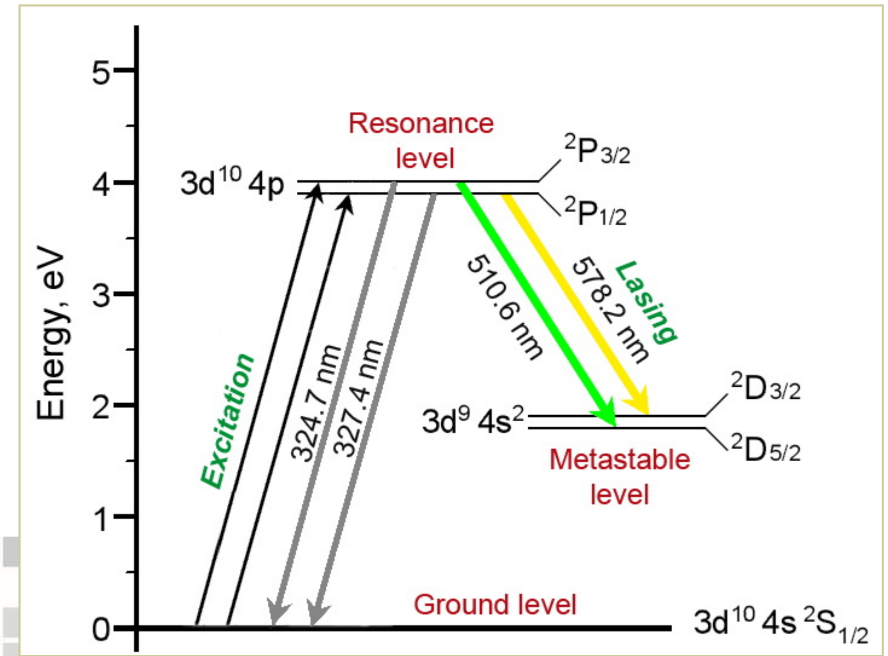
Metal vapor laser «Kulon-10Cu», “Istok” Enterprise, Fryazino town.



le vapor laser and one of the laser tube construction, Institute of Atmospheric optics SB RAS, Tomsk

Light amplification in metal vapor lasers and brightness amplifiers



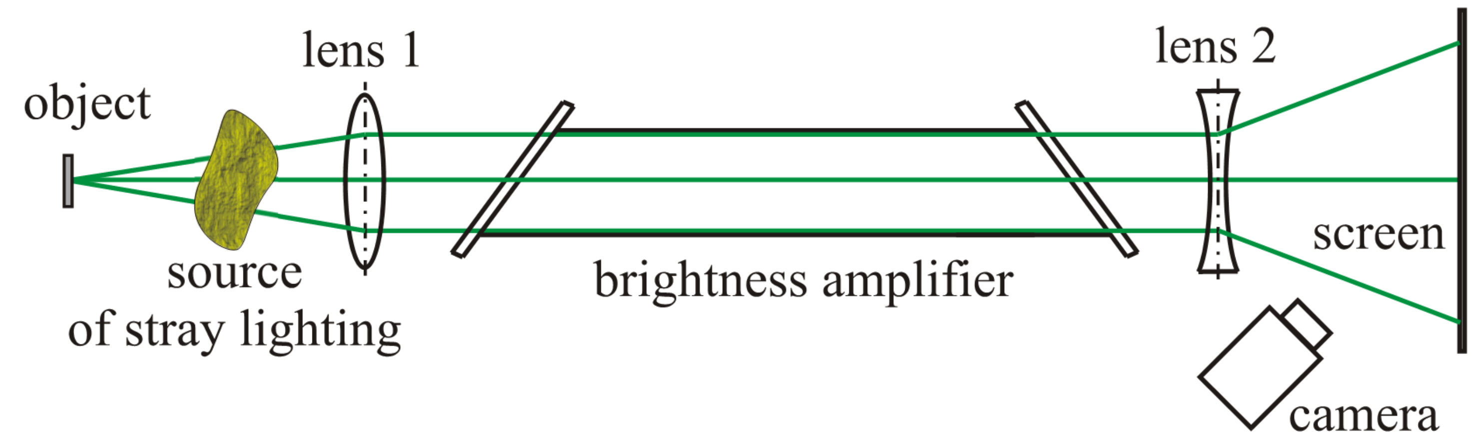


$$E_2 - E_1 = \Delta E = h\nu$$

λ_1= 510,6 nm
λ_2= 578,2 nm

Copper atom energy levels diagram

LASER MONITOR



Recording of images from screen

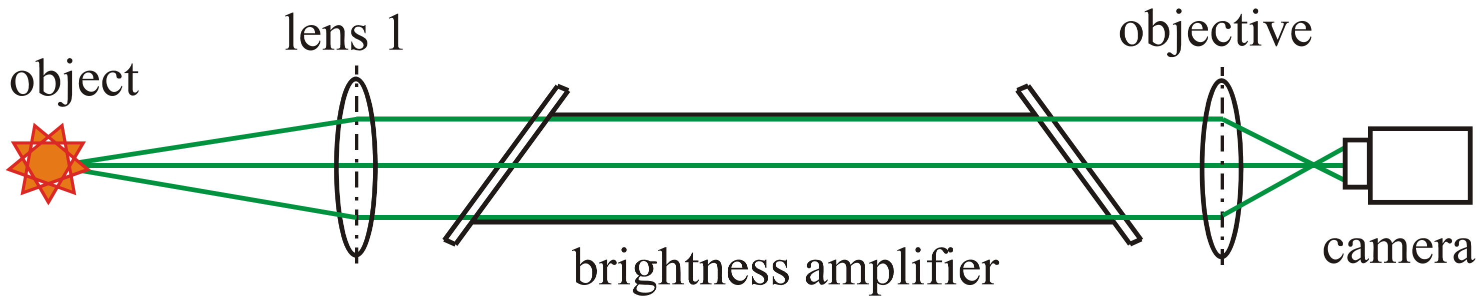
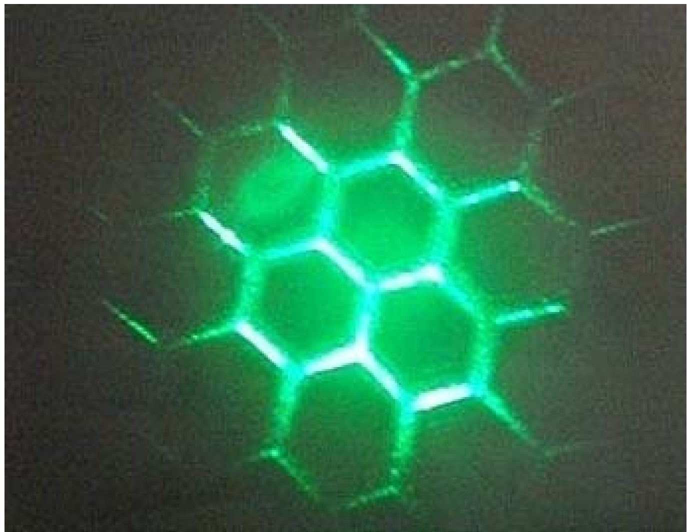


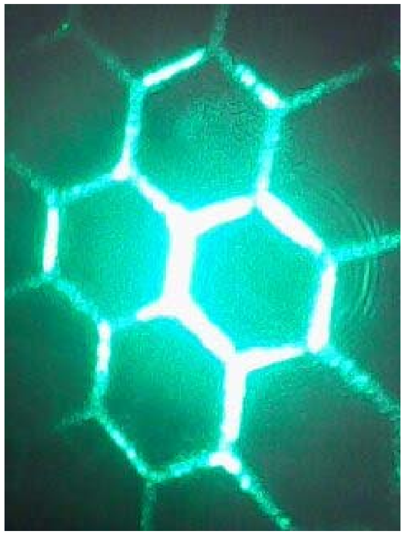
Image is projected directly on the camera CCD matrix

Looking through candle

Grid size
0.75 mm

Visualization in Green and Yellow

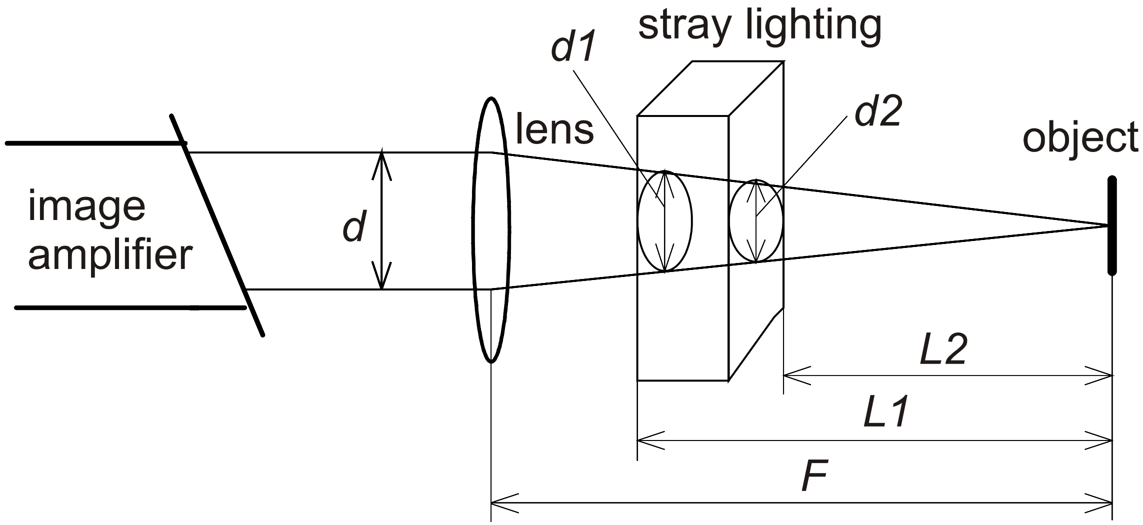




green filter

yellow filter

External stray lighting (estimations)



CuBr image amplifier:

λ_1= 510.6 nm,

λ_2 = 578.2 nm

GDT Ø 1.5 cm,

L = 40 cm

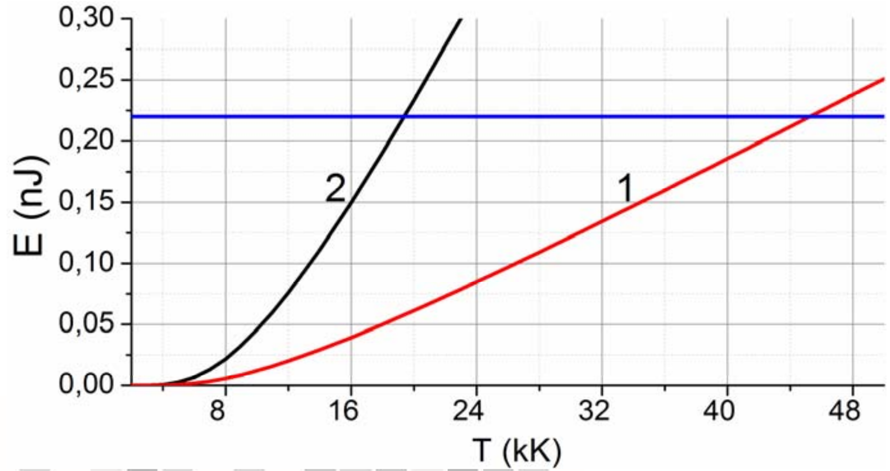
L1=6 cm, L2=5 cm

f = 28.2 kHz,

E_{spont} = 2.8 μJ

P_{spont} = 80 mW

Stray lighting



Noise of amplifier (spontaneous emission)

$$P_{\text{noise}} = h\nu_0 \Delta\nu \frac{\tau}{T}\left(\frac{d^2}{l\lambda}\right)^2 = 1.3\ \mu\text{W}$$

$$E_{\text{pulse}} = 3.4\cdot 10^{-11}\,\text{J}$$

$$E(T) = \frac{8\cdot\pi\cdot h\cdot\nu^3}{c^3}\cdot\frac{1}{e^{\frac{h\cdot\nu}{k\cdot T}}-1}\cdot\Delta\nu\cdot V$$

One of perspective applications of laser monitors based on CuBr lasers is visualization of processes at self-propagating high-temperature synthesis (SHS)

$FeTiO_3+SiO_2+Si+Al+C$

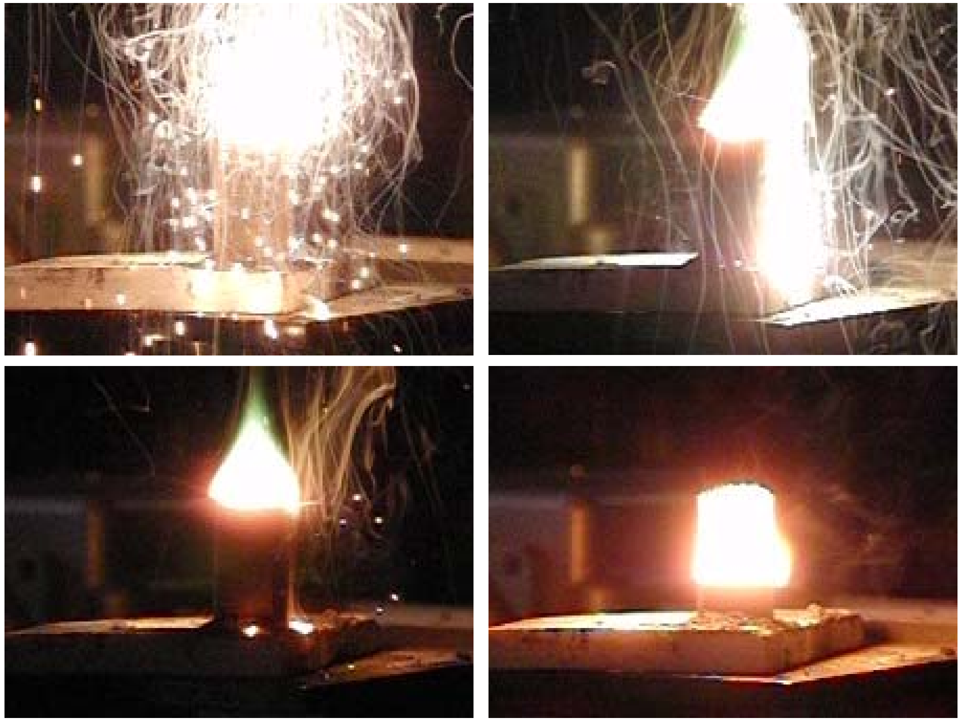
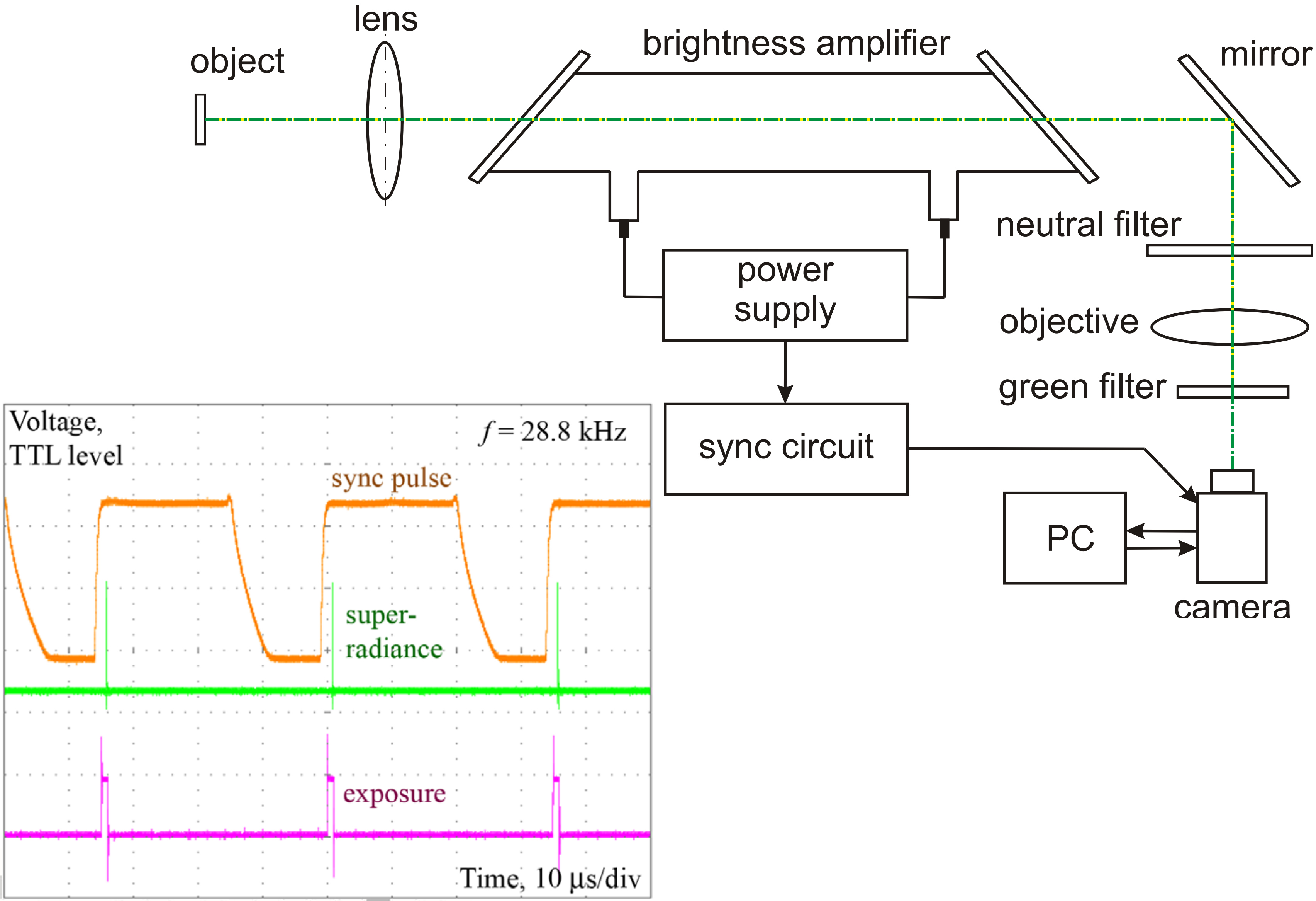


Image acquisition in each pulse of superradiance



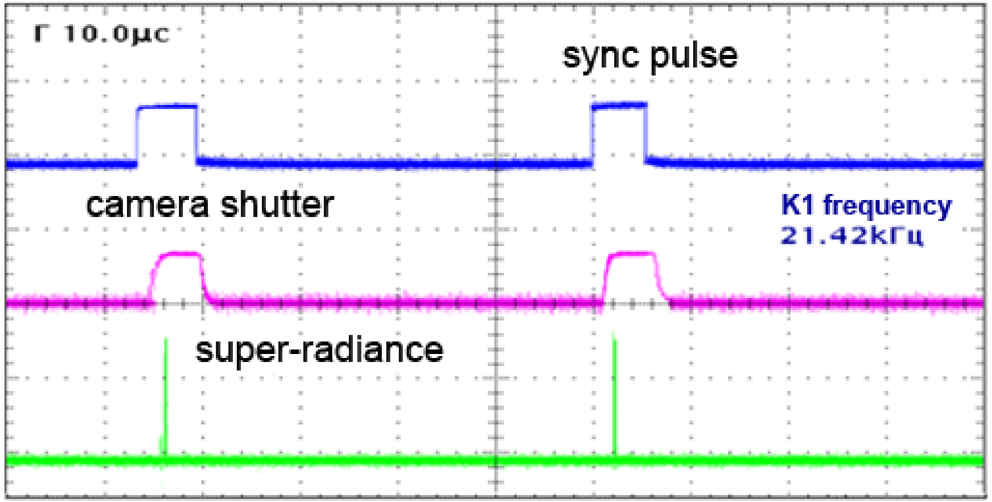
Changing speed of imaging

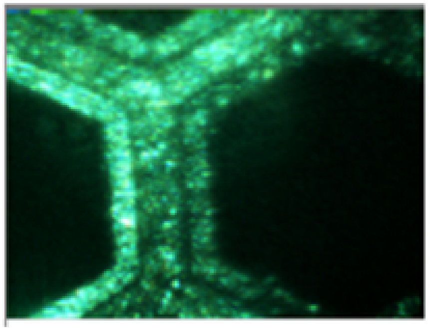
GDT Ø 5 cm,

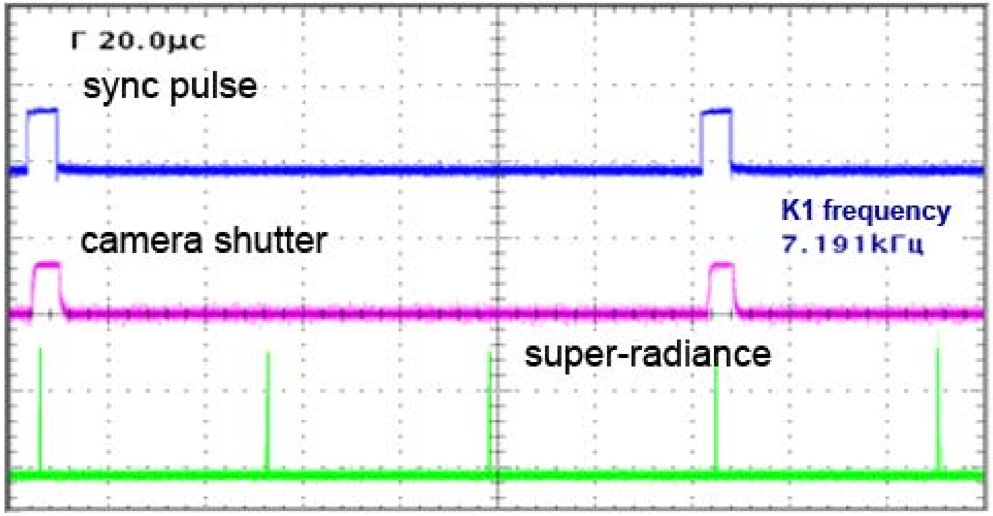
L = 90 cm

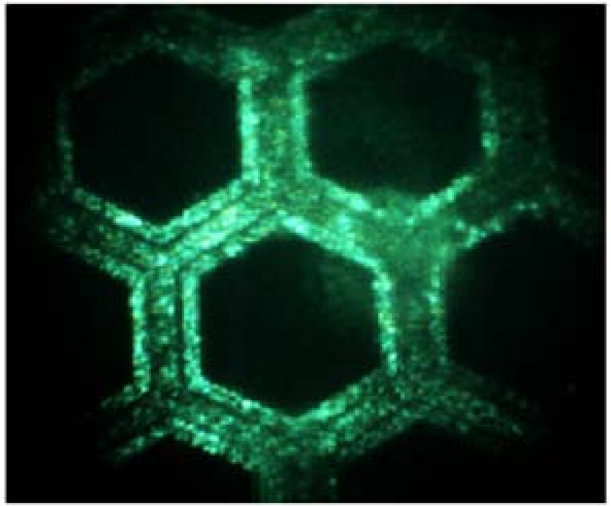
f = 21.4 kHz,

exposition is 2 μs

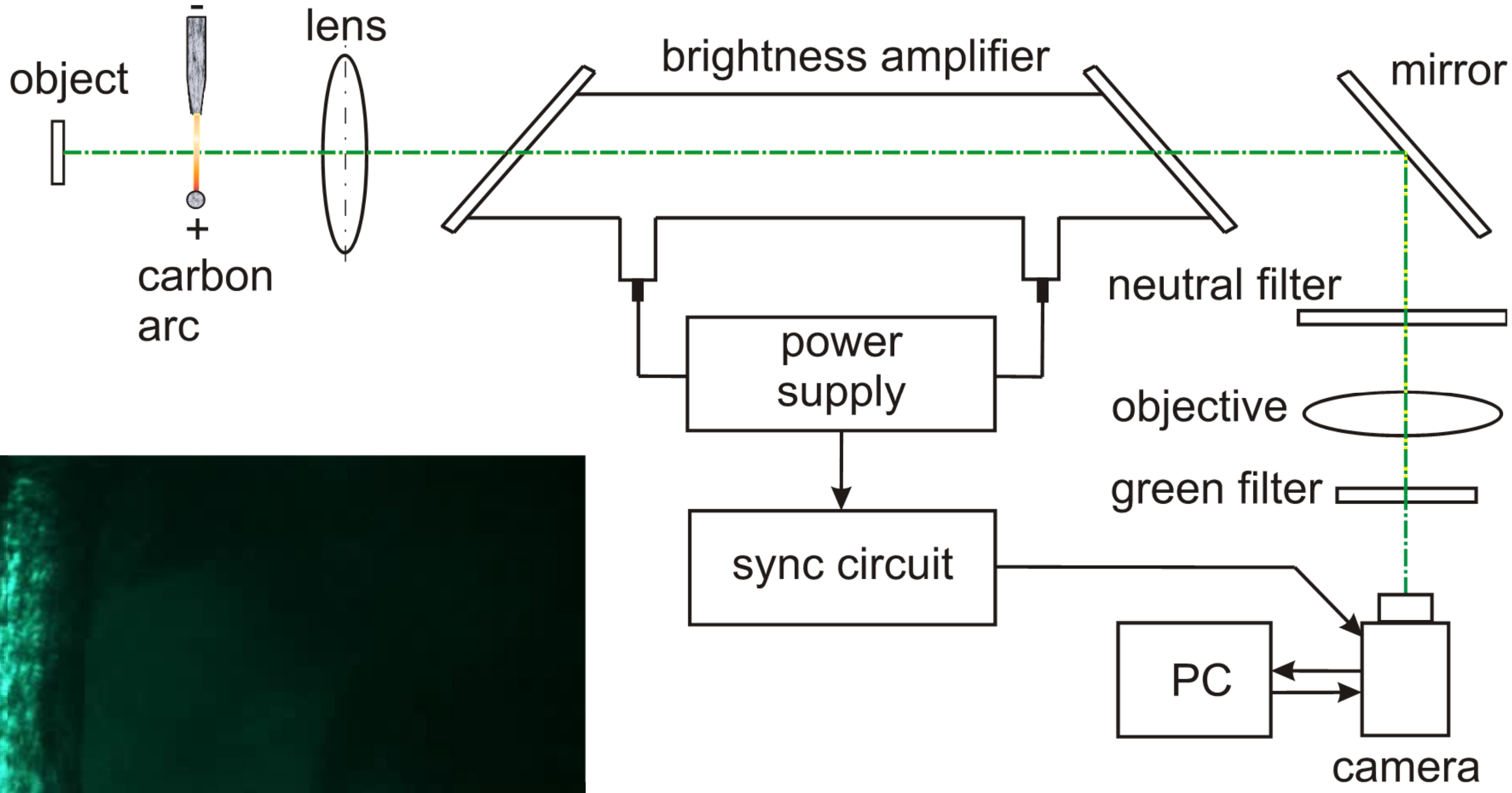


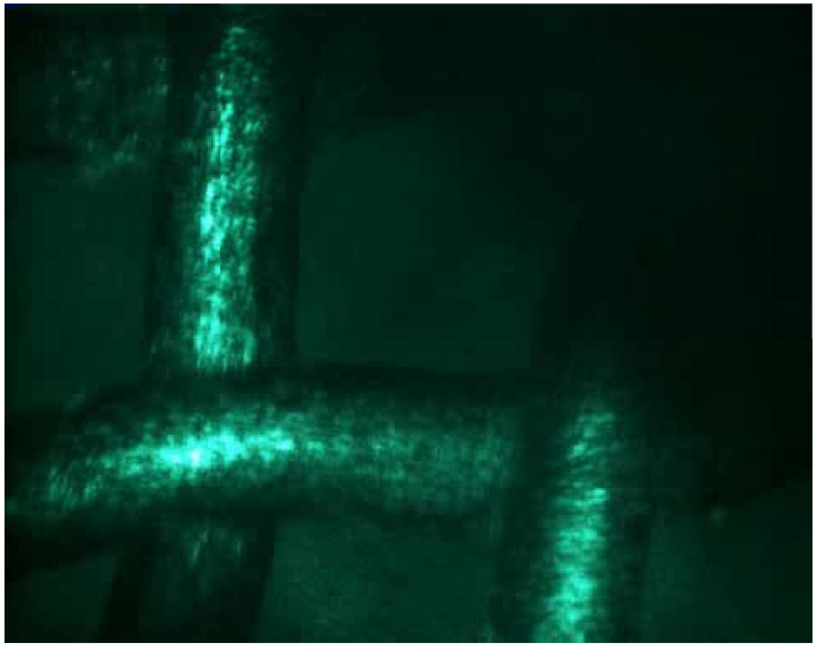


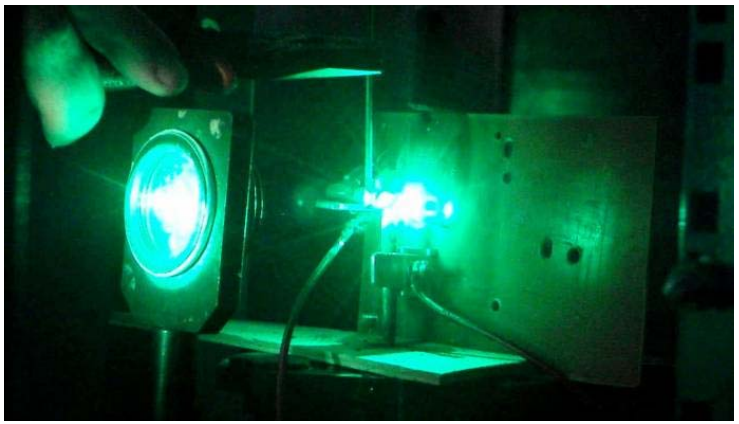




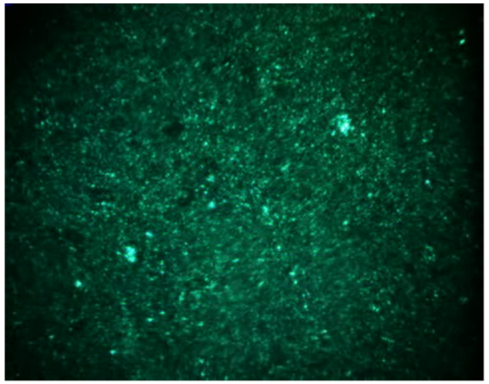
Monitoring of object through d.c. arc



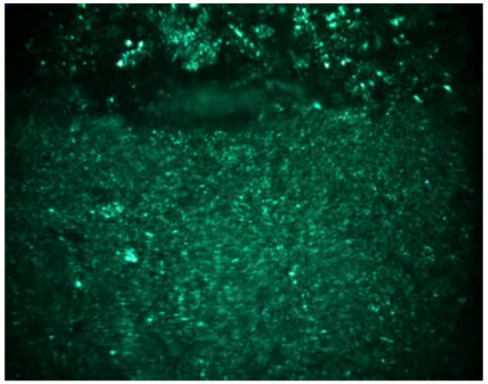




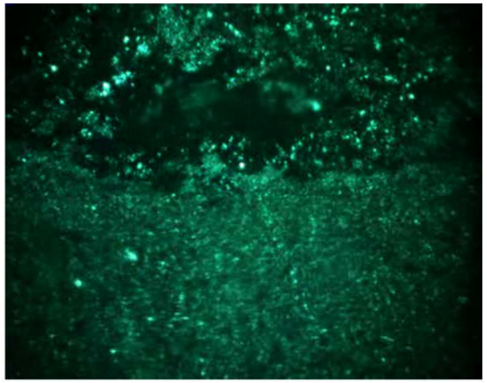
Visualization of SHS using laser monitor



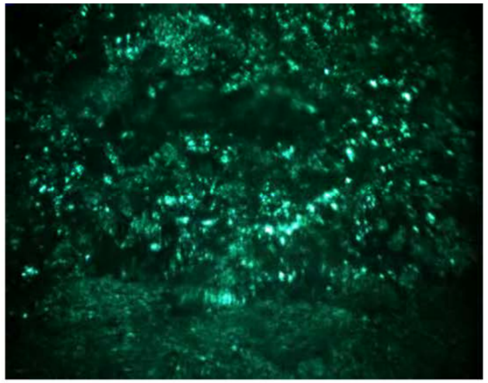
0 ms



120 ms



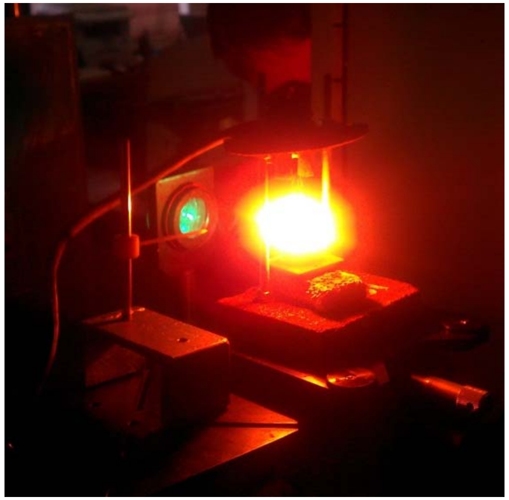
200 ms

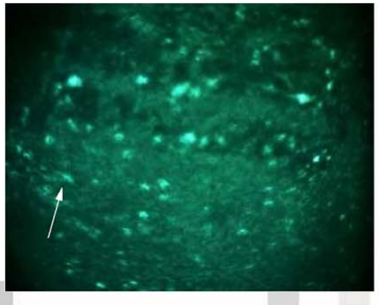


300 ms

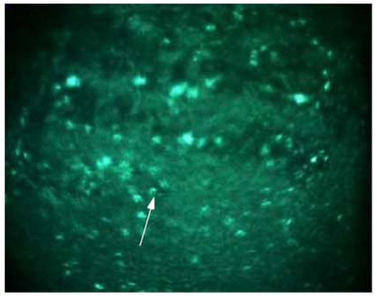
$FeTiO_3$+SiO_2+Si+Al+C

Vision area – Ø5 мм
Imaging speed – 2400 frms/sec
Camera – Fastec HiSpec 1
Exposition – 2 µs

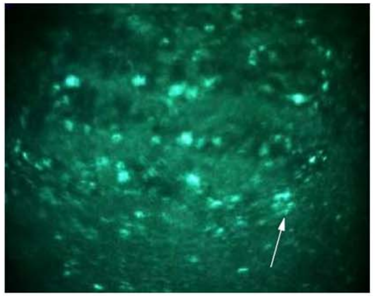




0 ms



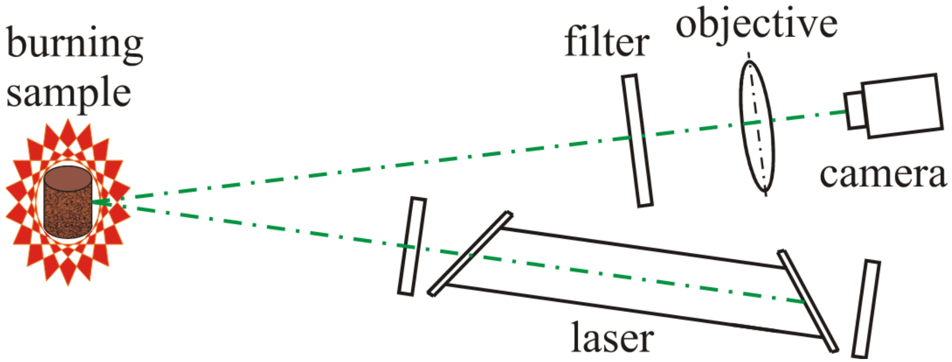
3 ms

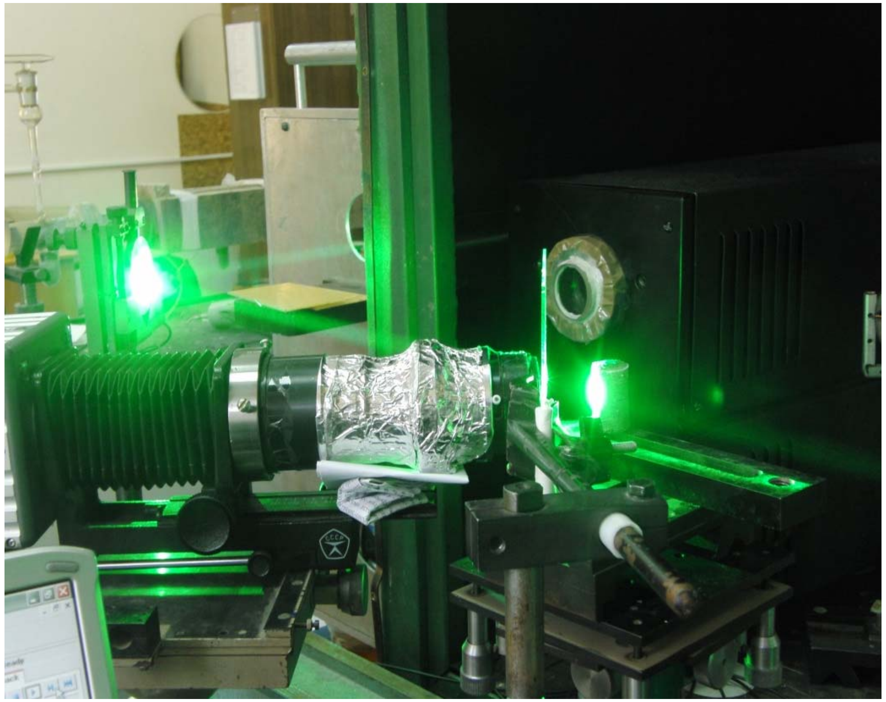


5 ms

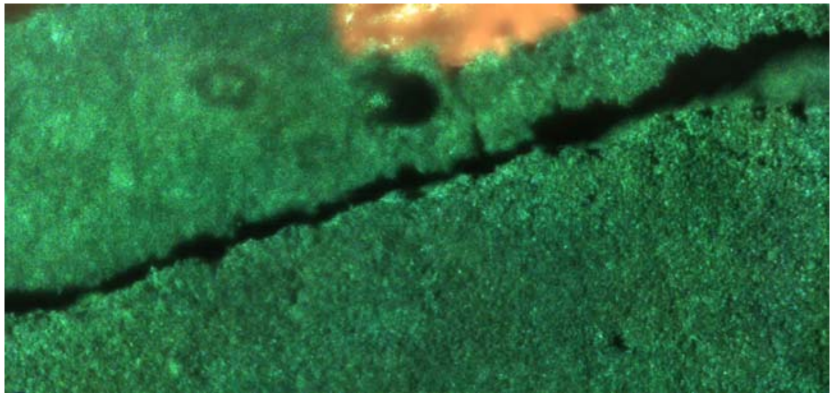
80%Ni + 20%Al

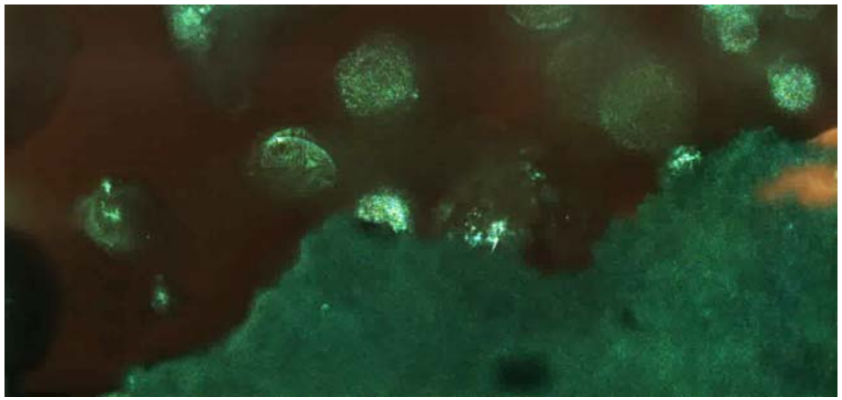
SHS process observing using laser illumination





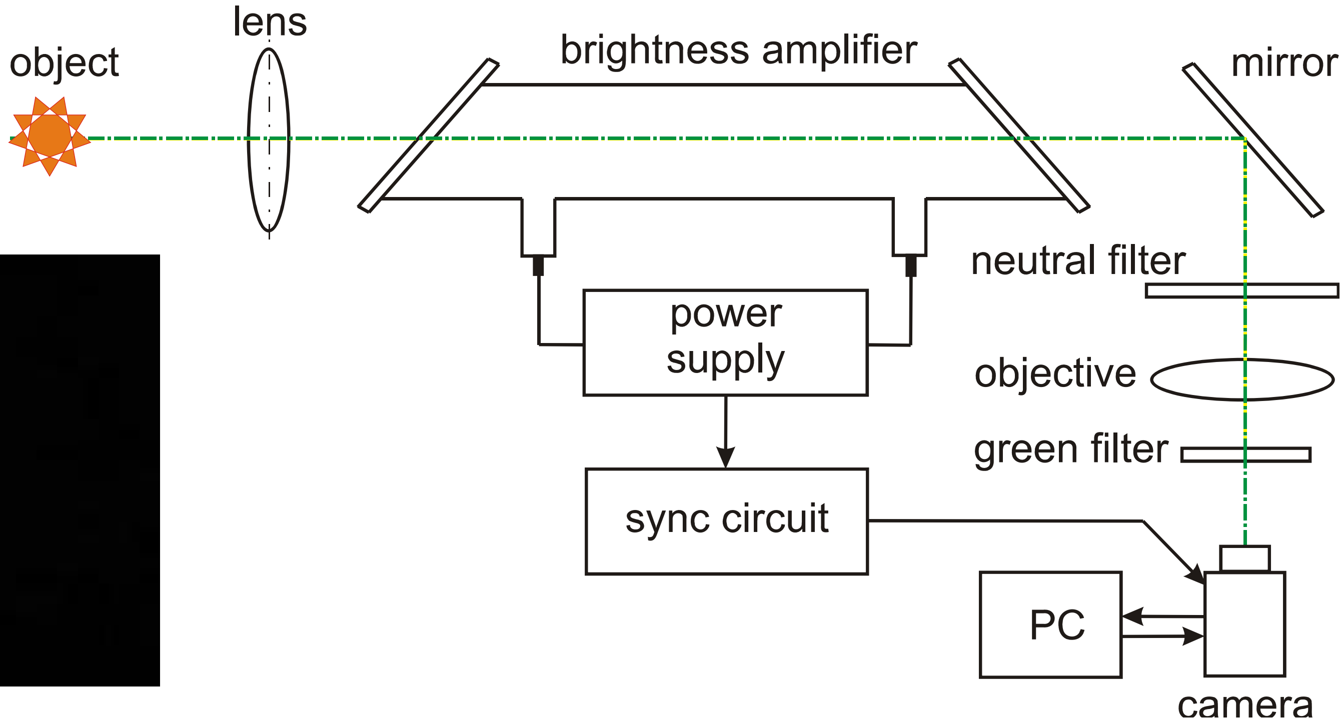
Vision area – 5 mm
Imaging speed – 1400 frms/sec.
Camera – MotionPro X3
Lasing power – 2.5 W
Image is formed by a single lasing pulse

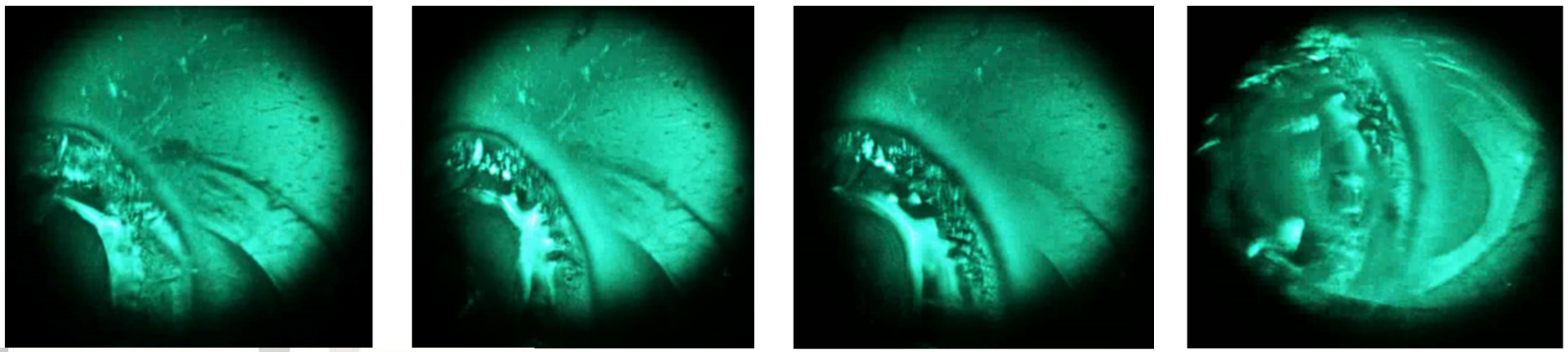




Ni + 25%Al+ 0.2%$CaCO_3$

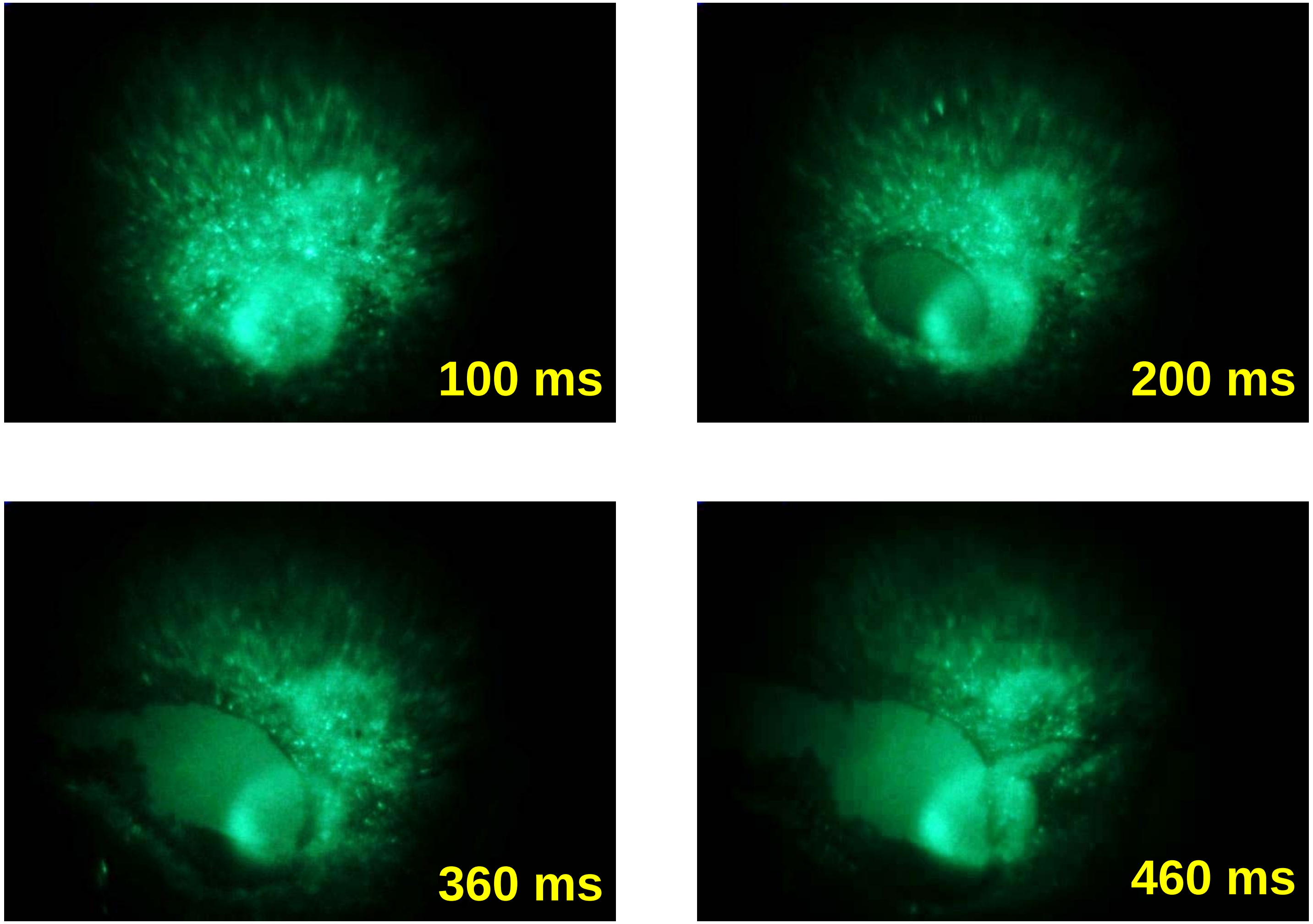
Monitoring of CO2 laser interaction with glass surface





Laser monitor in biology

Visualization of the apple skin cutting with electrocoagulator “ЭХВЧ - 400 СХ”



Camera FastCam HiSpec 1
1800 frms/s

Exposition 2 μs
PRF of radiation 28.8 kHz

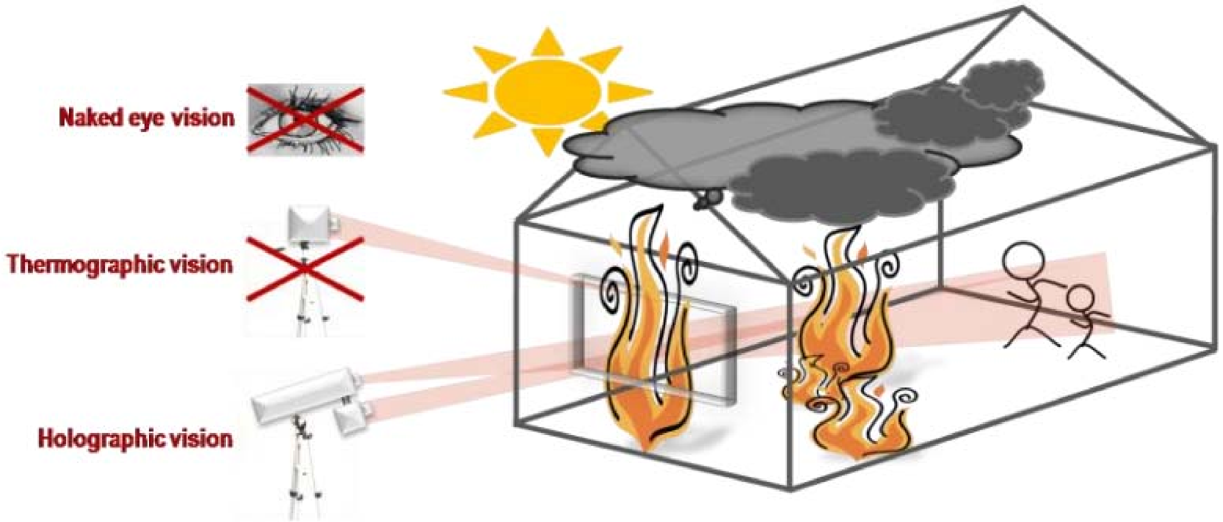
Conclusion

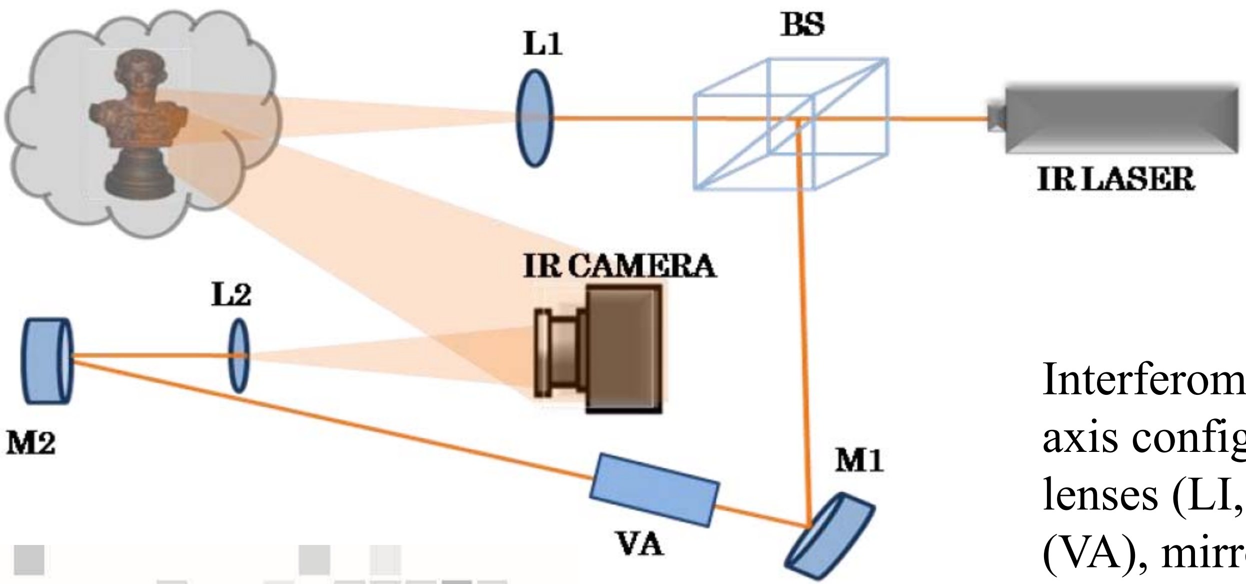
- *Thus,* laser monitors based on brightness amplifiers on copper or copper bromide vapors allows visualizing high-speed processes, shielded from the observer by intensive background lighting.
- Using laser monitors we see through the flame the processes and objects which can’t be seen by naked eye.
- A grand break-through in high-speed video sensors allowed laser monitors to move up to the advanced technical level.
- The temperature range of objects to be observed is wide. The brightest object controlled experimentally was plasma with particle energy temperature up to 15 000 K!
- According to the theoretical estimation, using copper vapor (copper bromide vapor) laser monitors it’s possible to observe plasma or objects through plasma with brightness temperature up to 45 000 K!

Laser monitors prospects:

- Enhancement of image quality and extend the functionality.
- Search for new applications.

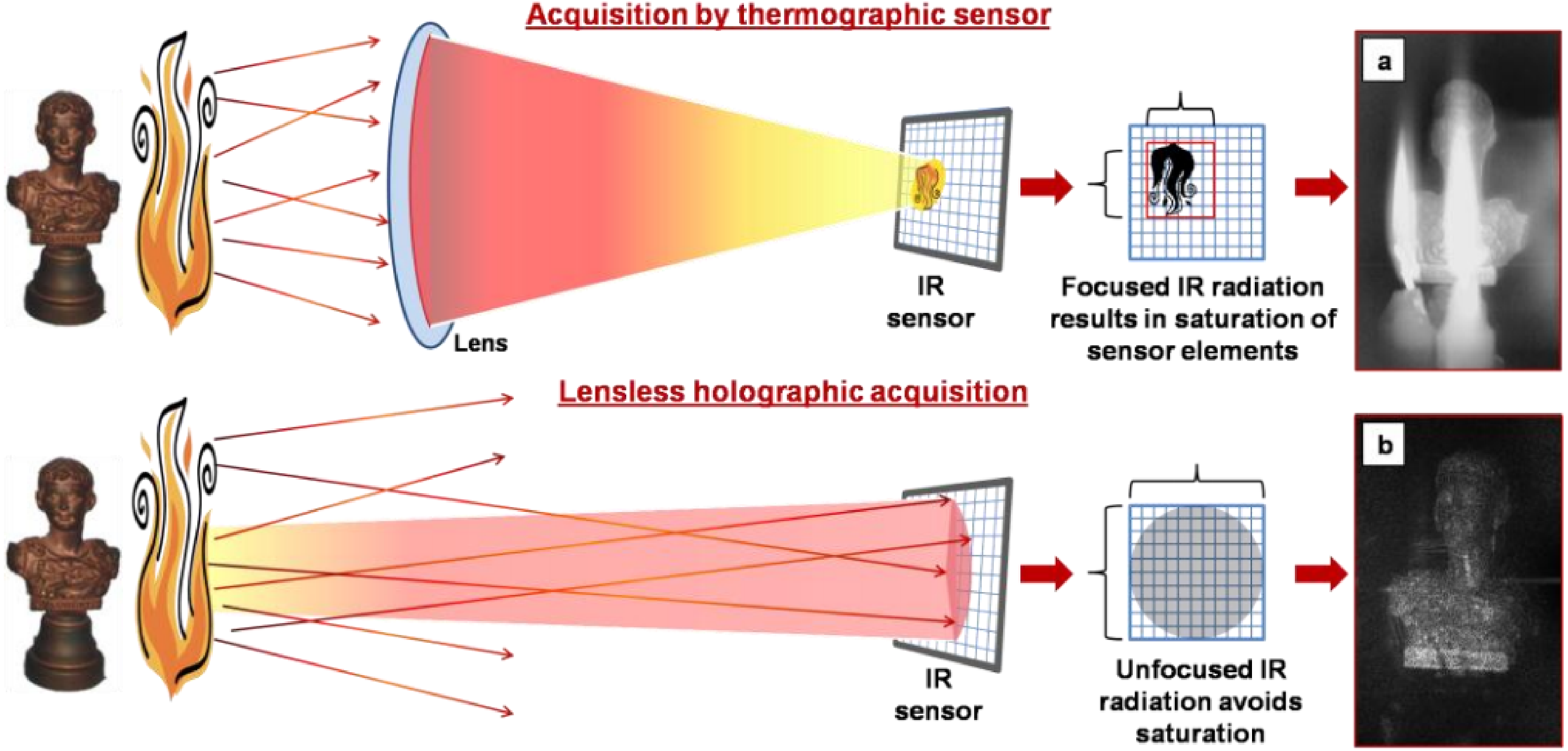
Digital holography technique for humans imaging





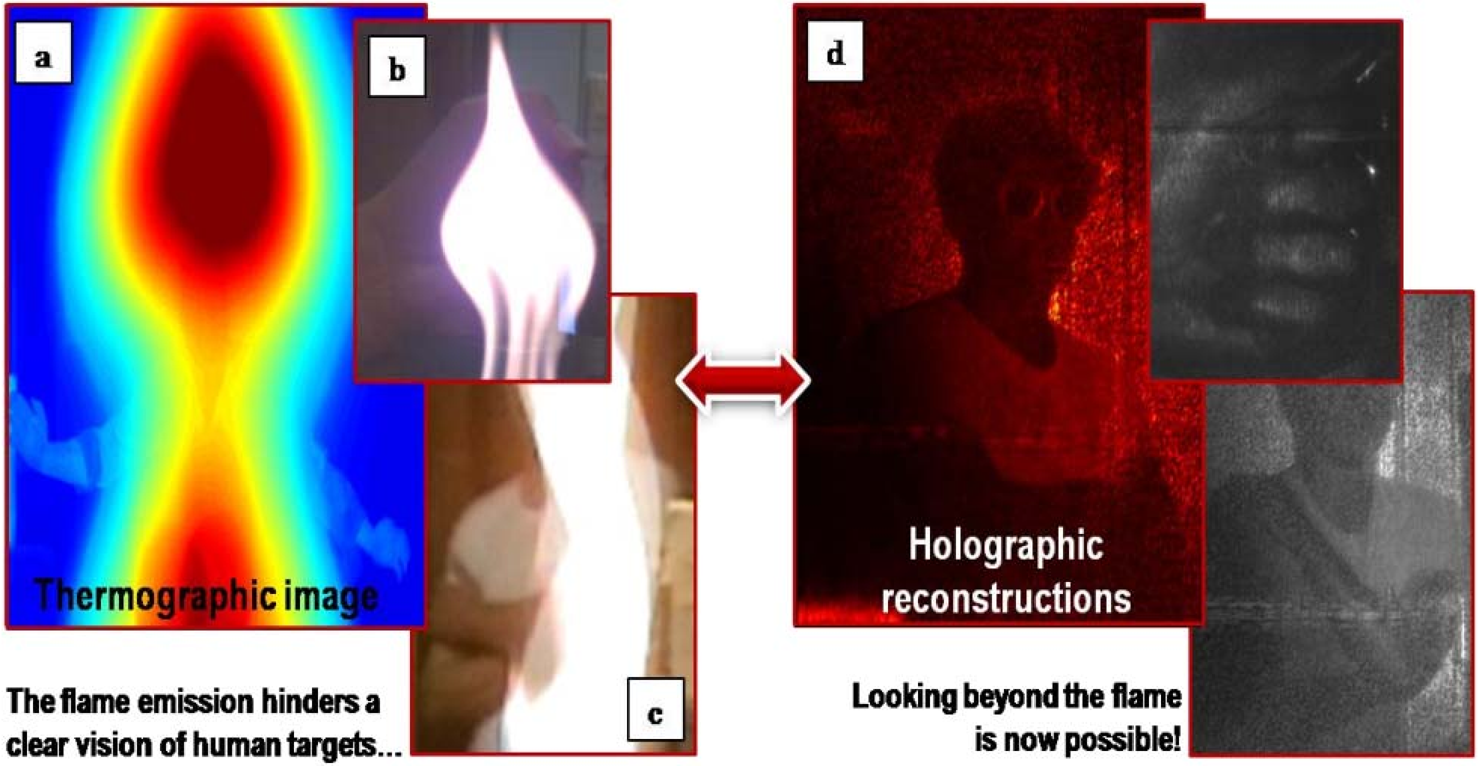
Interferometric set-up in lensless off-axis configuration: beam splitter (BS), lenses (LI, L2), variable attenuator (VA), mirrors (M1, M2)

Imaging of a metal object seen through flames of candles



Thermographic acquisition and corresponding image (a), holographic acquisition and amplitude reconstruction (b). A small bronze statue 10 cm high was used as a target

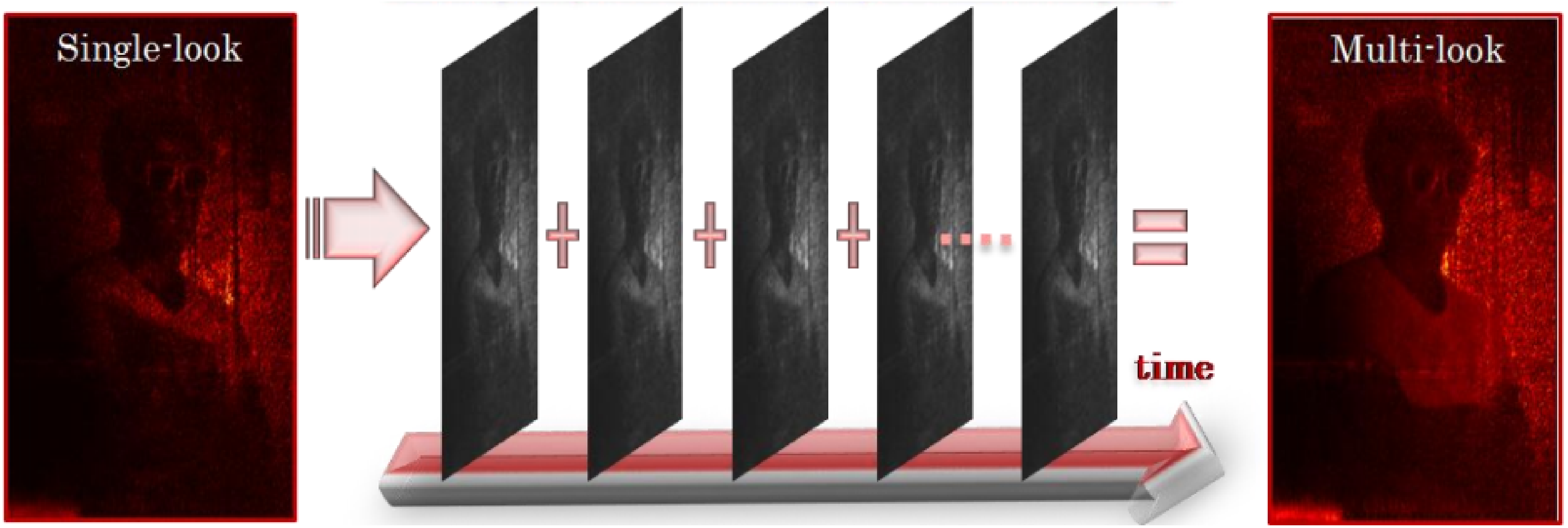
Imaging of a live human seen through flames of candles



Thermographic image (a), white-light images of a live hand and the man with his arms in a different position (b-c), and holographic imaging (d)

Locatelli M., Pugliese E., Paturzo M., Bianco V., Finizio A., Pelagotti A., Poggi P., Miccio L., Meucci R., Ferraro P. Imaging live humans through smoke and flames using far-infrared digital holography // Optics express. – 2013. – V. 21. – No. 5. – P. 5380–5390.

Quality improvement by speckle averaging



Imaging of a human target behind a flame: single-look holographic reconstruction (left) and multi-look amplitude image (right)

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Thank you for your attention!