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EVIDENCE OF EXPLOSIVE PROCESSES IN THE PARAMETERS OF A LOW-CURRENT VACUUM ARC

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The well-known experimental facts on the nonstationary nature of the vacuum arc.

Almost the all parameters of vacuum discharge are unstable. The discharge current , potential fall and plasma light emission have significant oscillations, intense bursts and falls.

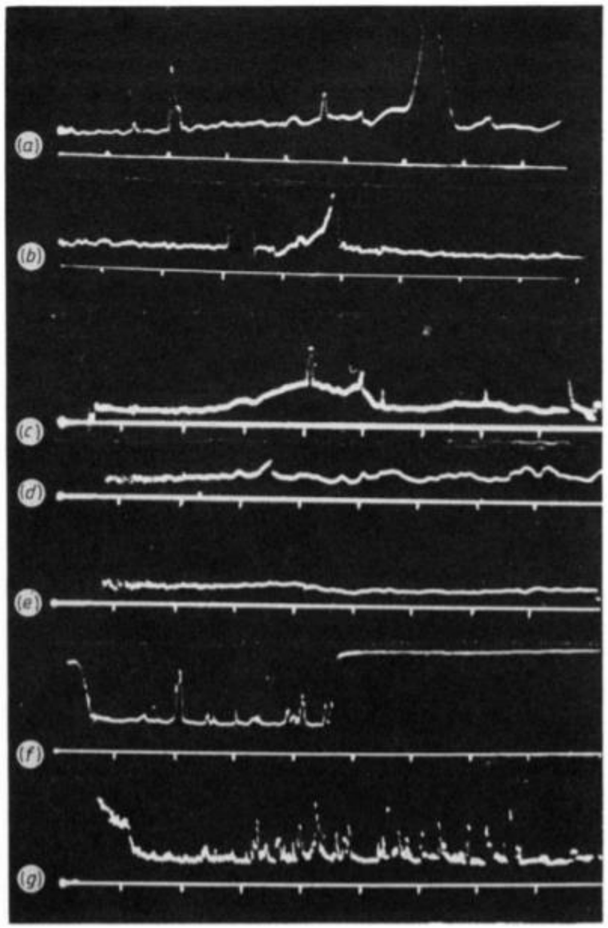


Figure 1. Oscillograms of the arc voltage fluctuations [7]: (*a*)–(*e*) a tungsten cathode; (*f*), (*g*) a copper cathode; (*a*), (*b*) $I_a = 3$ A; (*c*), (*f*), (*g*) $I_a = 4$ A; (*d*), (*e*) $I_a = 10$ A. Time: (*a*) 20 ns/division, (*b*) 50 ns/division, (*c*)–(*g*) 100 ns/division.

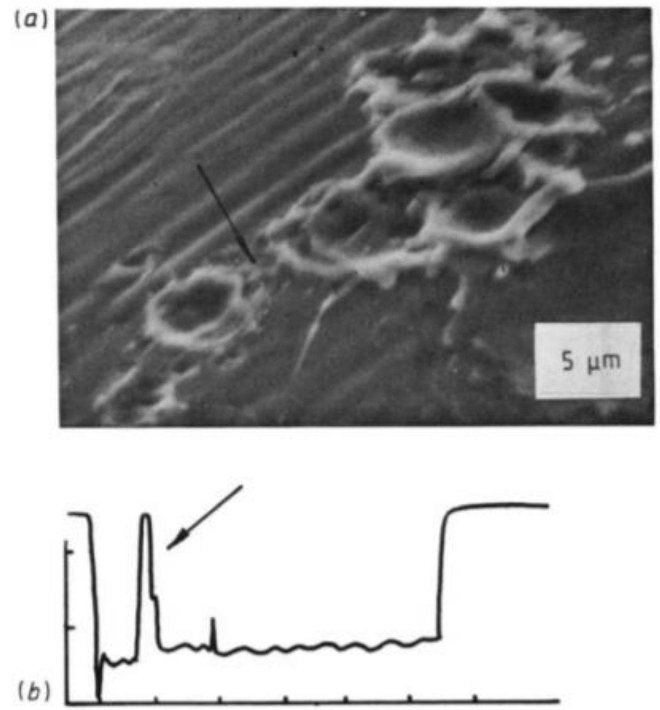


Figure 11. (*a*) The track of a 2 A arc. $H = 0$. (*b*) A waveform of the arc voltage (50 V/division). Time: 50 ns/division. The arrow shows the moment of cs death.

Current density and the cathode spot lifetime in a vacuum arc at threshold currents

V F Puchkarev and A M Murzakayev

Journal of Physics D: Applied Physics, Volume 23, Number 1

Noise measurements of vacuum arc discharge parameters

The noise of the vacuum arc current has several distinct frequencies that correspond to the supposed cathode spot lifetime.

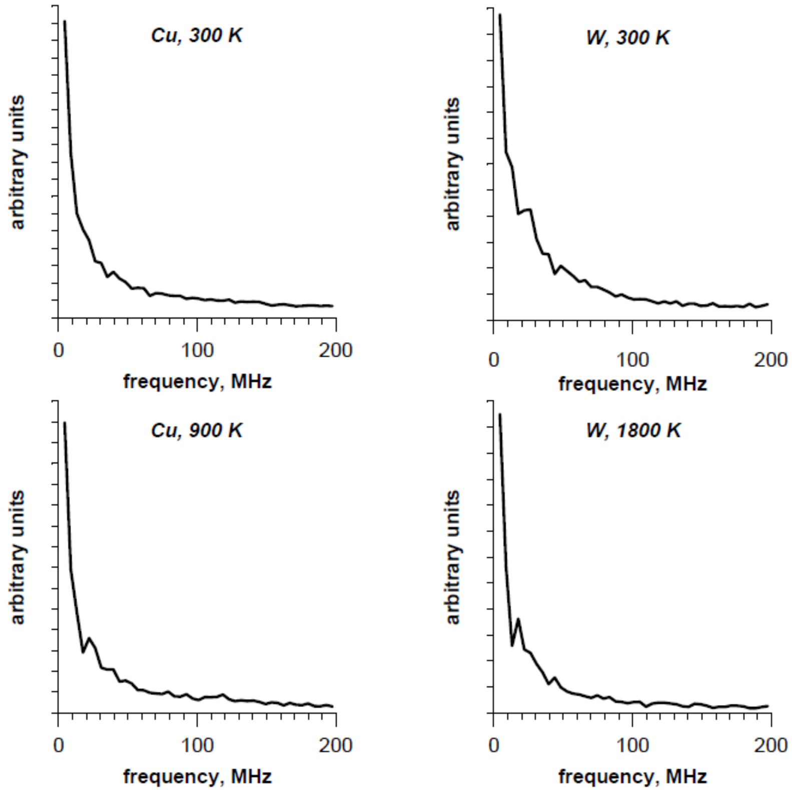
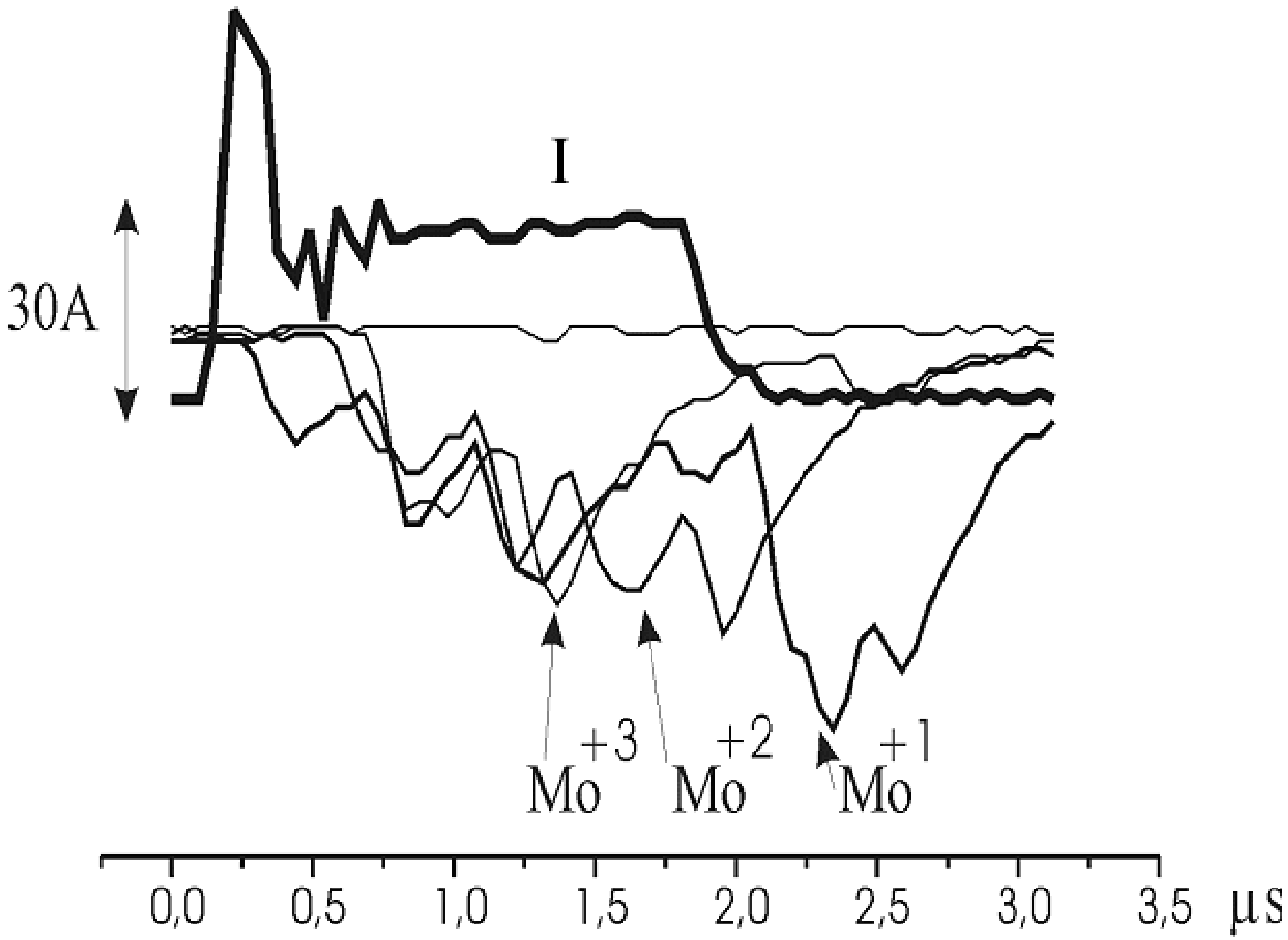


Figure 11. Amplitude spectra of arc voltage of low-current (4 A) vacuum arc on copper and tungsten [17].

INVESTIGATIONS OF VACUUM ARC CATHODE SPOTS WITH HIGH TEMPORAL AND SPATIAL RESOLUTION
Maxim B. Bochkarev and Aidar M. Murzakaev

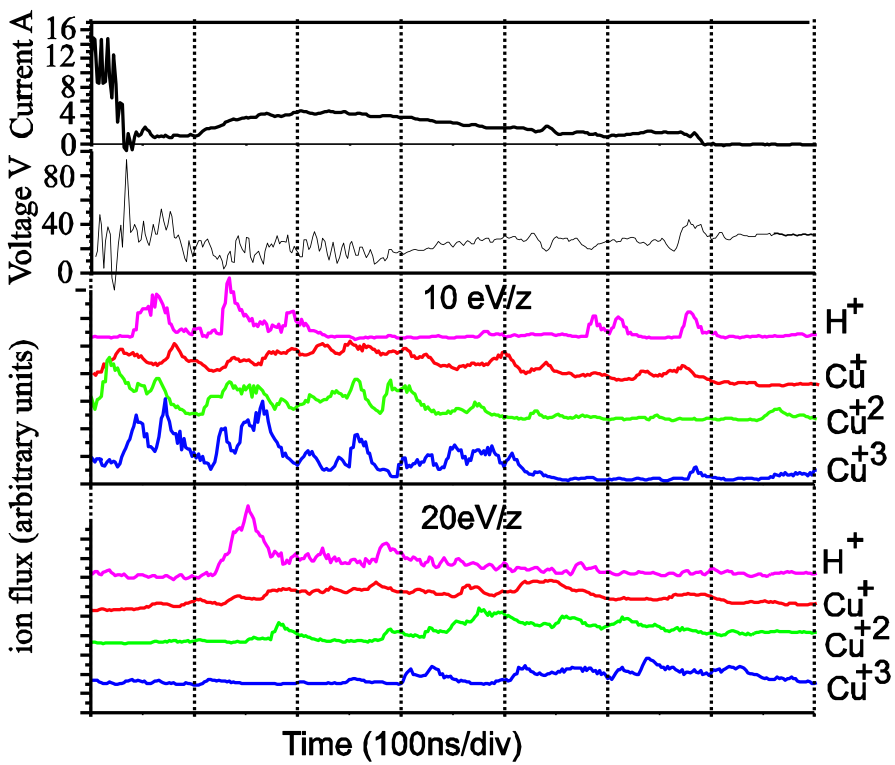
The time resolving investigations of ion flow with submicrosecond time resolution.

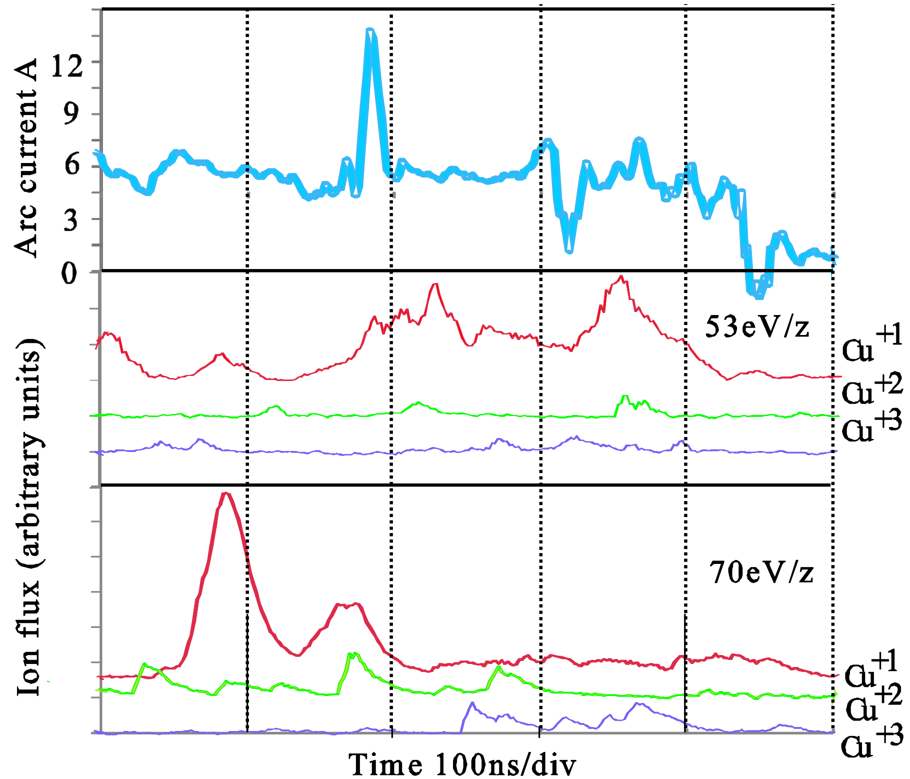
The investigation of ion flow with submicrosecond resolution show that ion flow contains intensive bursts with 150-200 ns duration.



The use of multichannel time resolving spectrometer for revealing the nature of ion flow of the vacuum arc.

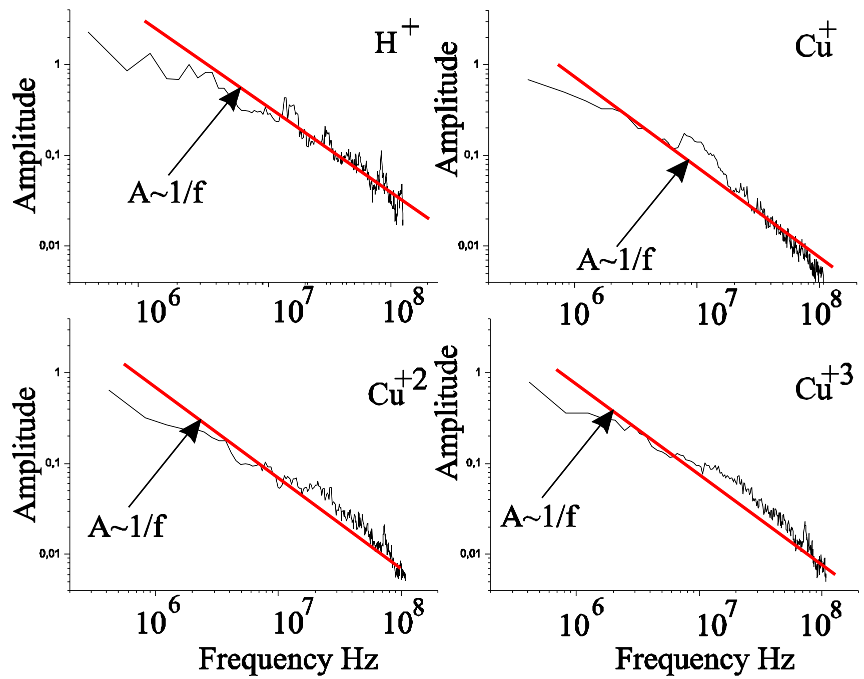
The basis of ion flux with narrow energy range is constituted by 10-30 ns elementary bursts. The elementary burst combinations form both subsequent burst groups and super-bursts. The occurrence of super-bursts usually precedes non-stabilities in arc current and the attempts of the discharge to extinct. The elementary bursts have durations which generally coincide with life time of cathode spot estimated by the "ecton" theory. However in contrast with "ecton" model each ion flux burst have unique energy and charge composition.

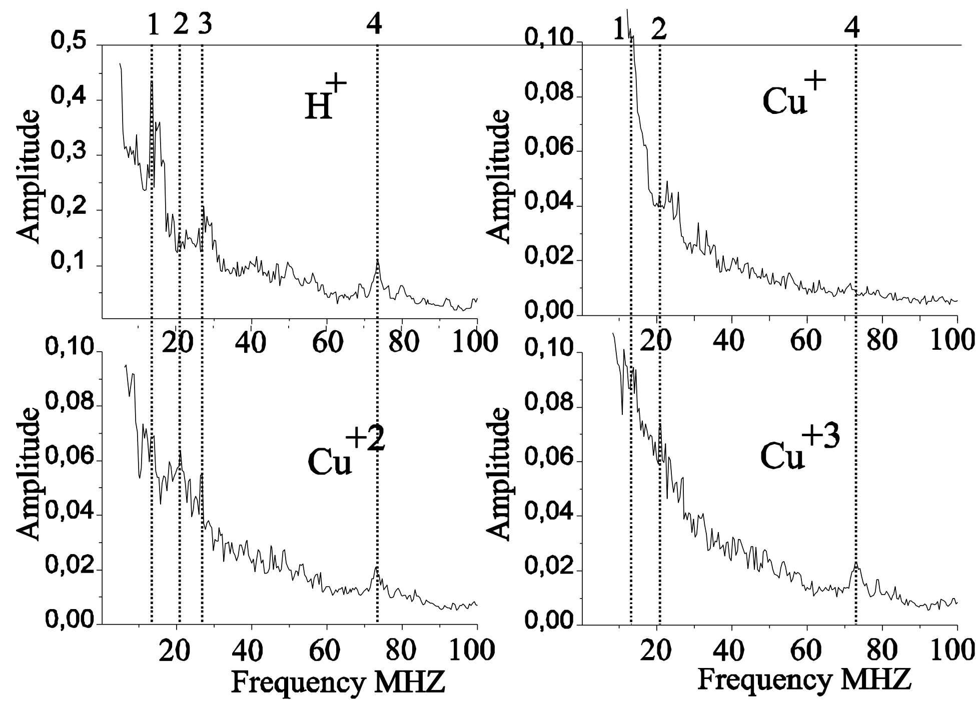




The Fourier analysis of the vacuum arc ion flow.

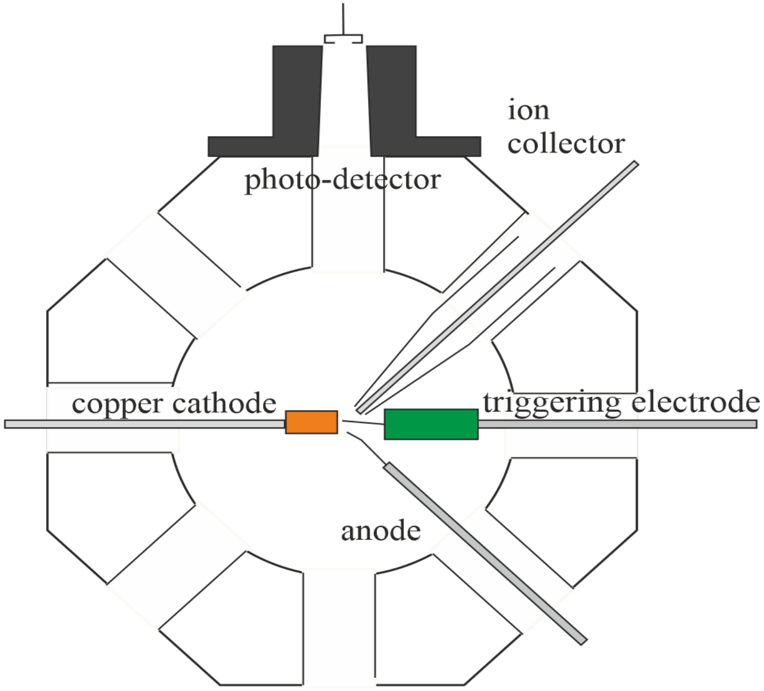
Fourier spectra of H^+ Cu^{+2} Cu^{+3} clearly show local maxima corresponding to burst repetition periods that are in the range from 10 to 100 ns. The few peaks are highlighted (1-14Mhz(70 ns), 2-21MHz(48ns), 3-28Mhz(35ns),4-74MHz(14ns)).The peaks 3 and 4 may correspond to mean elementary bursts repetition period. The 1 and 2 local maxima may corresponding to mean burst groups repetition period of 50-70 ns.

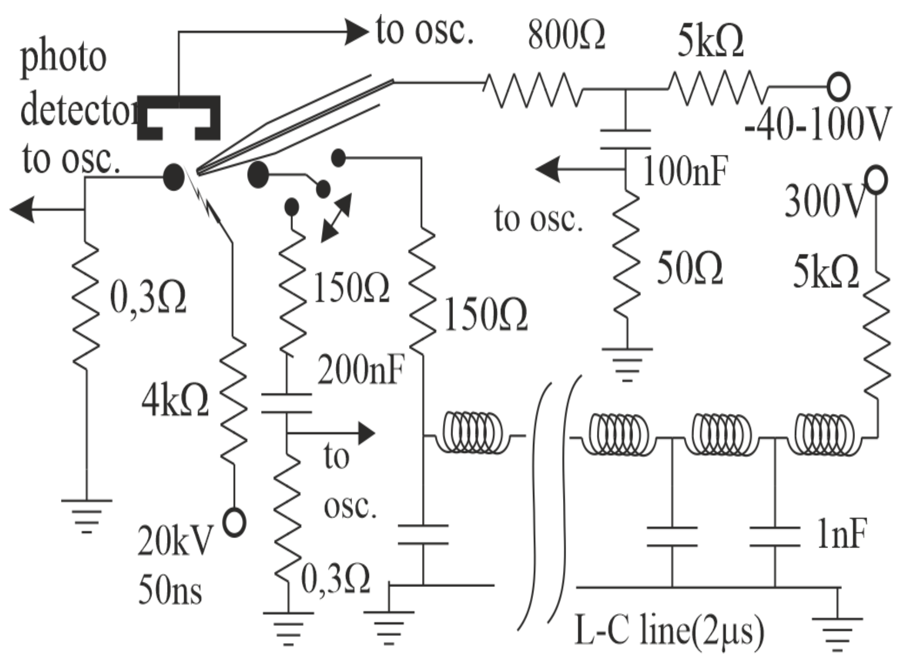




The use of small sized ion collector to achieve nanosecond resolution in ion flow measurements

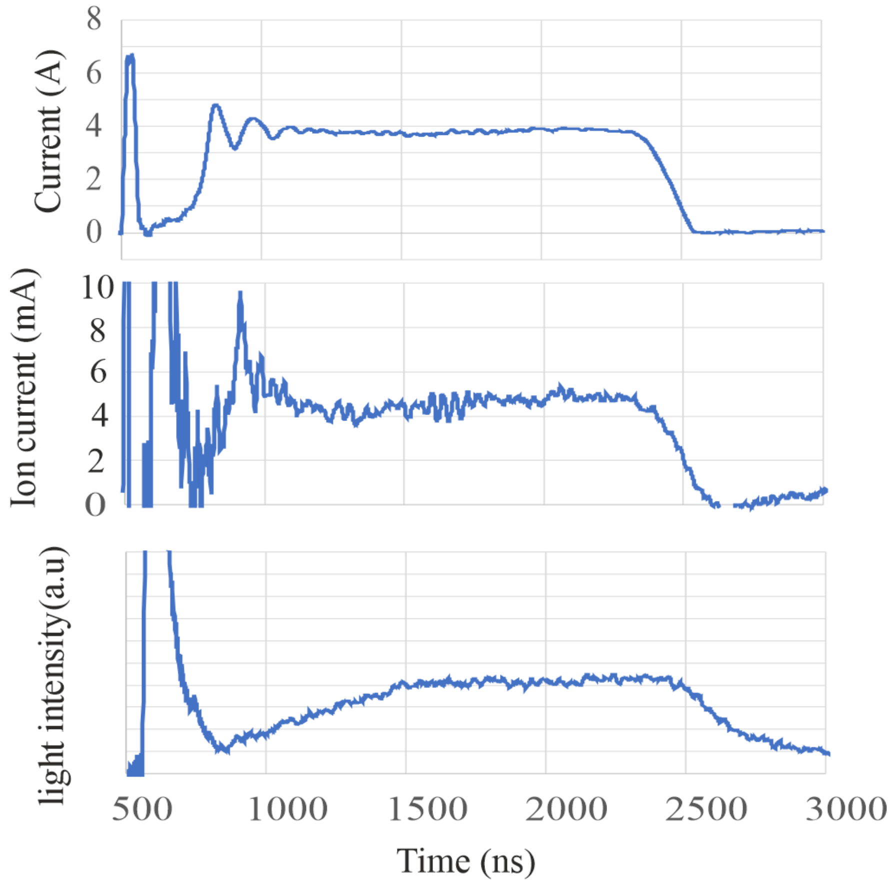
The experimental vacuum chamber configuration is presented in the left figure. The measurements were performed in a small vacuum chamber with moveable coaxial inlets. Vacuum discharge was initiated by a trigger electrode by applying a short high voltage pulse (20kV, 50ns). The trigger pulse was applied via the 5kΩ resistor mounted just near the tungsten trigger pin. The initial discharge current was about 5A. Arc voltage was applied to the anode. The ion current was measured by small size coaxial collector pin. The collector edge had a diameter of 300μm and it was placed at 300μm above the cathode surface. The collector electrode was shielded by a molybdenum cone tube, so as the plasma could contact the collector edge only. The own glow intensity of vacuum arc plasma was measured by photoelectron multiplier, mounted outside the vacuum chamber window. The electric scheme of the discharge supply circuit and ion current measurement circuit is presented in the right figure.





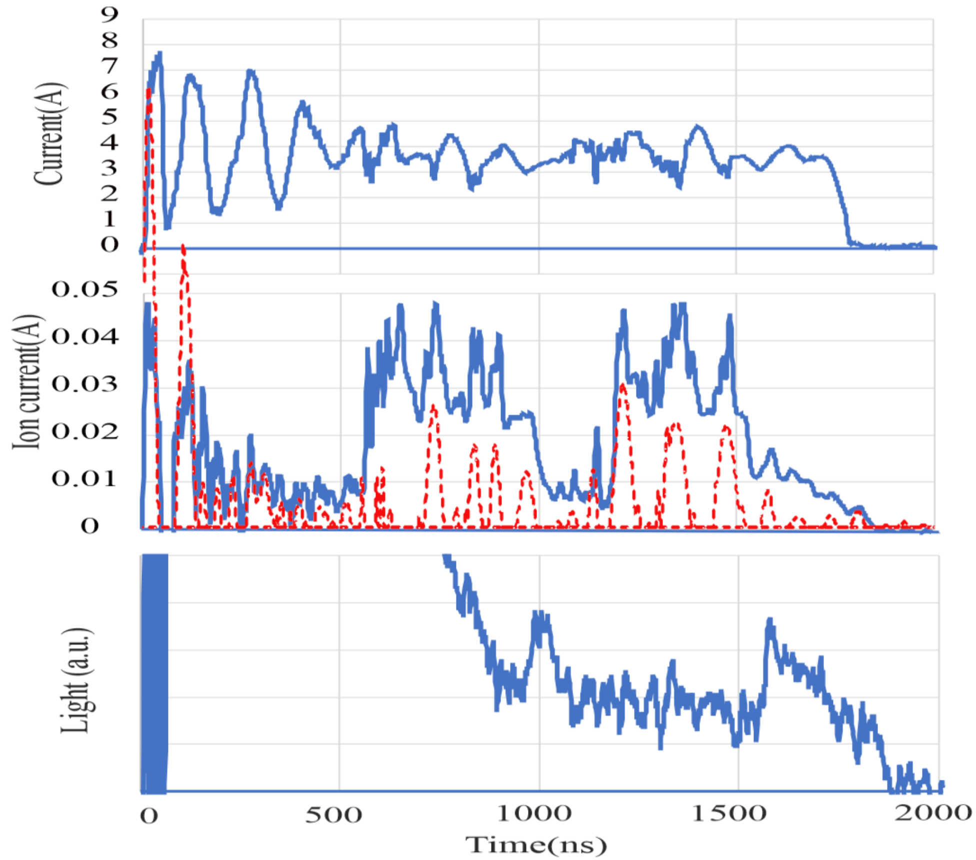
The experimental results of measurement of vacuum arc current , ion flow, plasma luminescence for the currents significantly exceeding the threshold current.

The waveforms of vacuum arc operation in stable mode. The discharge current, the ion current and the own glow intensity was stabilized in 1μs after the discharge ignition. When the vacuum arc current is significant exceeds the threshold one the parameters of discharge become stable after several microseconds after discharge ignition. In this case ion current and own plasma glow just copy the discharge current waveform.

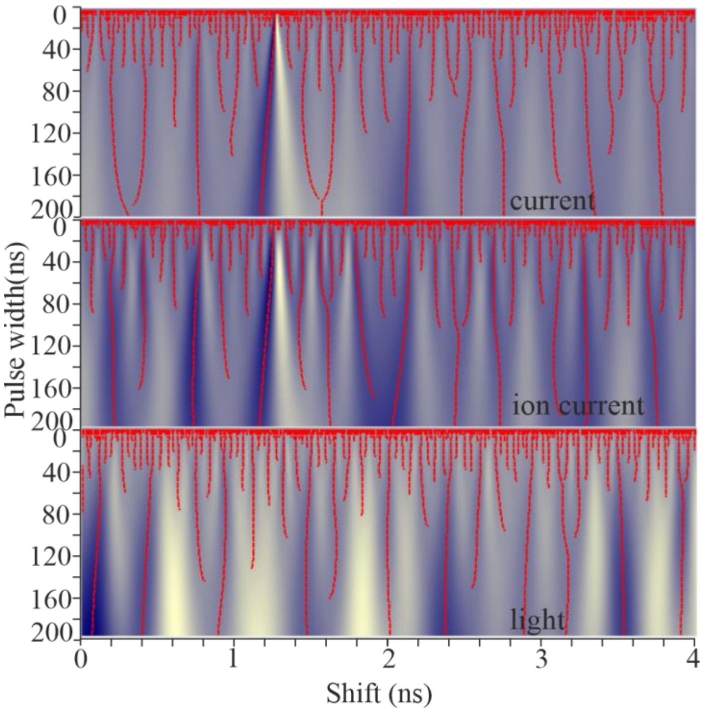


The experimental results of measurement of vacuum arc current , ion flow, plasma luminescence for the currents significantly exceeding the threshold current (unstable mode)

The waveforms of vacuum arc operation in unstable mode. The ion current contains intensive peaks at the moments of local discharge current falls. Plasma glow intensity also contains high intensity peaks that highly likely correspond to ion current peaks. Dashed line-the reconstruction with wavelet maxima with pulse durations -10-100ns



The wavelet analysis of waveforms



•The wavelet transformation used in the present paper was as follows:

$$\omega(a,b) = a^{-0.5}\int_{-\infty}^{+\infty} f(t)\psi\left(\frac{t-b}{a}\right)dt,$$

In the paper the results for "Mexican Hat" are presented:

$$\psi(t) = (1-t^2)e^{-\frac{t^2}{2}}$$

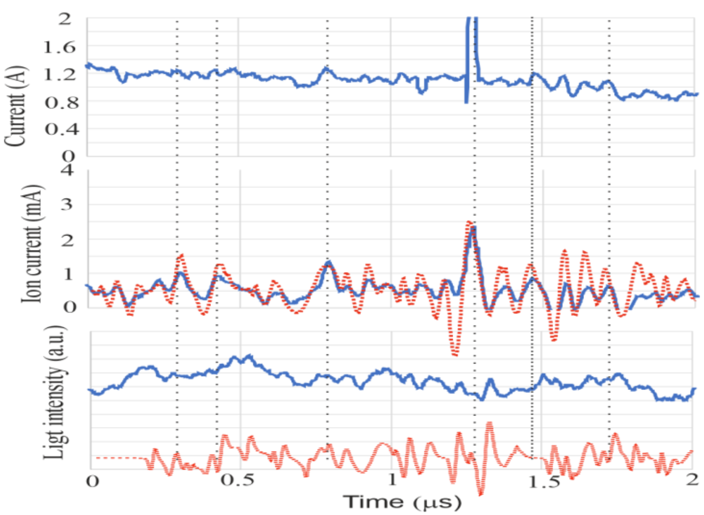
The red(dark) marks over the wavelet spectrum represent the so-called "skeleton diagram". The "skeleton diagram" is formed with local maxima along the shift axis. The form of the "skeleton diagram" suggests that the ion flow signal has self-similarity property because it represents the vertical line set in which density is proportional to scale factor. The self-similarity of ion flow recently was found with Fourier analysis. The form of Fourier spectra law of ion flow is close to that of the Brownian process. This fact was first found by Anders [5] and was interpreted as evidence of the fractal nature of the cathode spot of the vacuum arc.

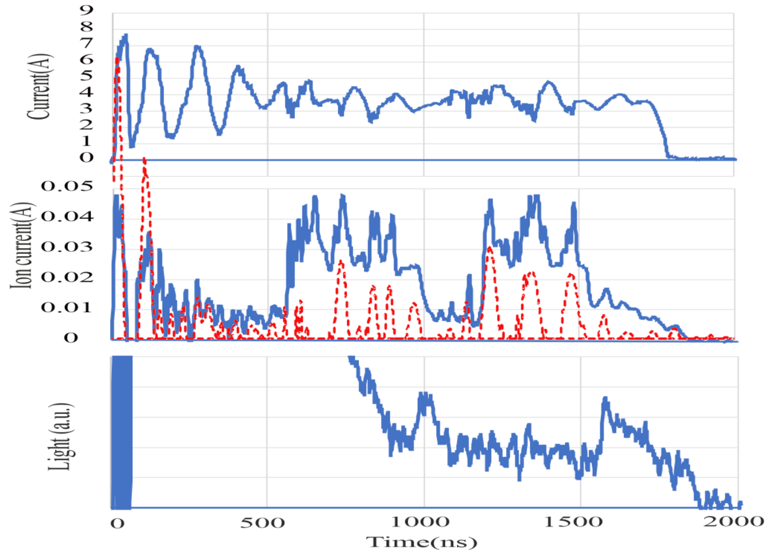
Anders André" The fractal nature of vacuum arc cathode spots" IEEE Transactions on Plasma Science 33 5 1456,2005, 10.1109/TPS.2005.856488

The use of local maxima approach to reconstruct the original signal as a sequence of local bursts

$$f(t)=\frac{1}{C_f}\iint\limits_{-\infty}^{+\infty}\omega(a,b)\frac{\psi\left(\frac{t-b}{a}\right)}{\sqrt{a}}db\frac{da}{a^2}=>f(t)=\frac{1}{C_f}\sum\frac{A_{max}^i}{\sqrt{a}a^2}\psi\left(\frac{t-b}{a}\right)$$

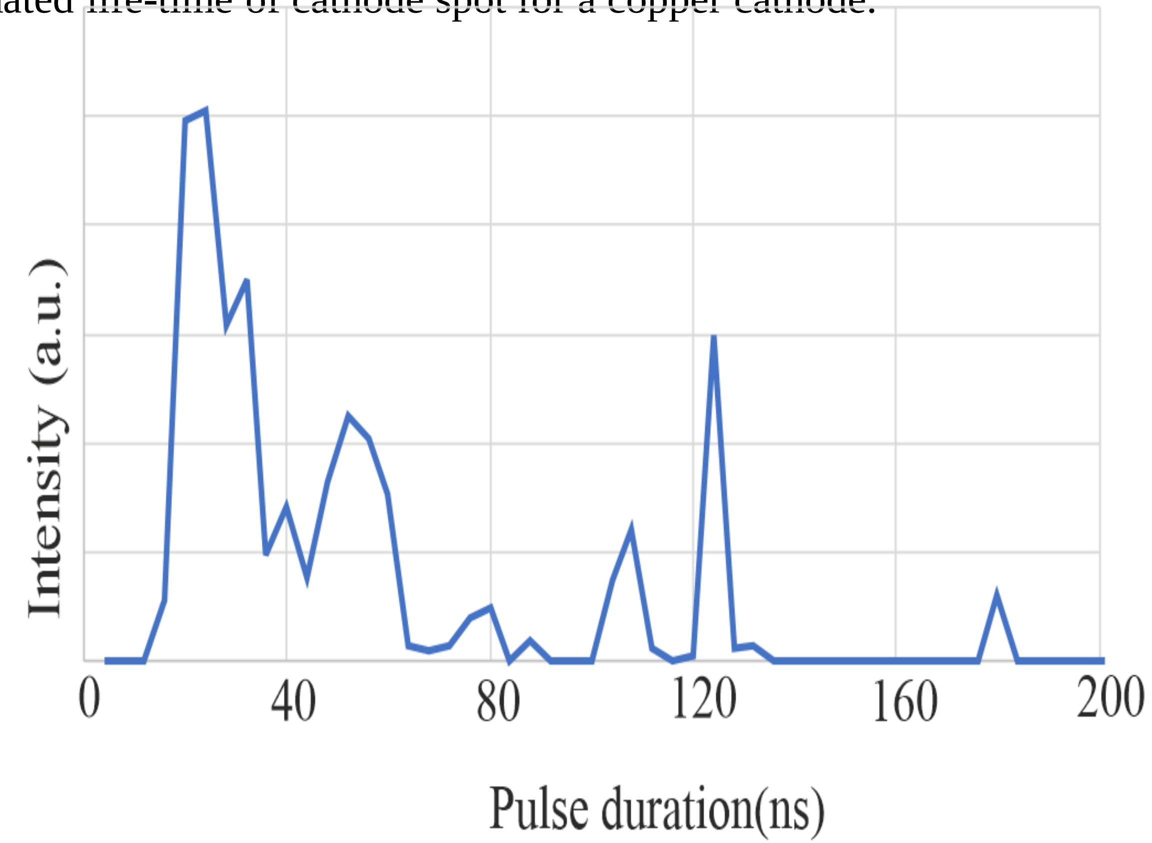
- Where C_f – is admissible constant. The results are represented in figures below. The dotted lines represent the sum of local maxima in the wavelet spectrum ranging from 1ns to 100ns. The result shows that the original signal can be reconstructed with short pulses for ion current at threshold discharge currents.





The pulse duration spectra calculated using local maxima approach

To reveal what pulse duration is most probable the probability distribution of maxima of wavelet spectra was obtained. This distribution is presented in the diagram. The diagram suggests that most probable pulse durations are at 20ns and 50ns. The most probable pulse durations are in the same range that previously estimated life-time of cathode spot for a copper cathode.



Conclusions

- **The plasma flow of the low current vacuum arc can be represented as the sequence intensive plasma bursts with durations of 20-60ns;**
- The complex investigation of vacuum arc current, ion current, and own plasma luminescence show that there are three general cases of waveforms character and correlations between these parameters:
- When the vacuum arc current is significant exceeds the threshold one the parameters of discharge become stable after several microseconds after discharge ignition. In this case ion current and own plasma glow just copy the discharge current waveform.
- In some cases, the arc discharge with a current exceeding the threshold one becomes unstable. At the moments of current instabilities, the intensive peaks of ion current appear. The durations of these current bursts are about several tens of nanoseconds. These instabilities are usually accompanied by own plasma glow splashes.
- When the arc current approaches the threshold one the ion current and plasma luminescence become significantly unstable. In this case, ion current can be described as a sequence of short (20-60ns) pulses. These pulses usually correspond to local peaks in arc discharge current. The plasma luminescence also contains short peaks, but it is hard to reveal a strong correlation between these peaks and peaks in discharge and ion currents.
- The wavelet analysis reveals that only ion current at threshold discharge current level can be represented as a sequence of short bursts. The most probable burst durations are in the range from 20ns to 60ns. This duration range is almost the same as the cathode spot (“ecton”) lifetime.