INSTITUTE OF SEMICONDUCTOR PHYSICS
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COMPARATIVE CHARACTERISTICS OF THE WORKING MEDIA OF KIVOTRONS

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The work was supported by the Russian Science Foundation under grant 19-19-00069

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  - efficiency dependences from medium
- Current–Voltage Characteristics for discharge in *He*, N_2, O_2 and their mixtures
- Discussion
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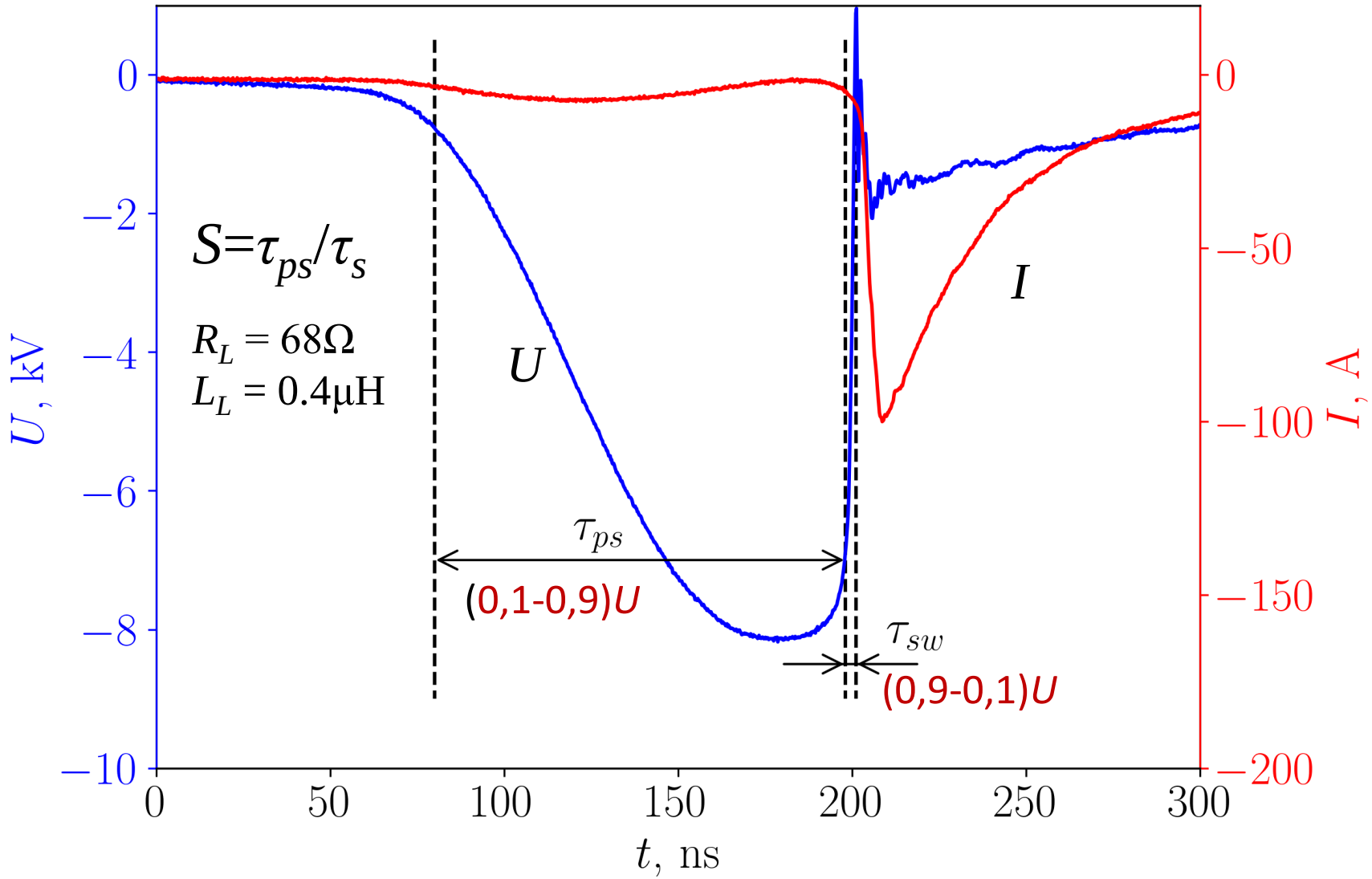
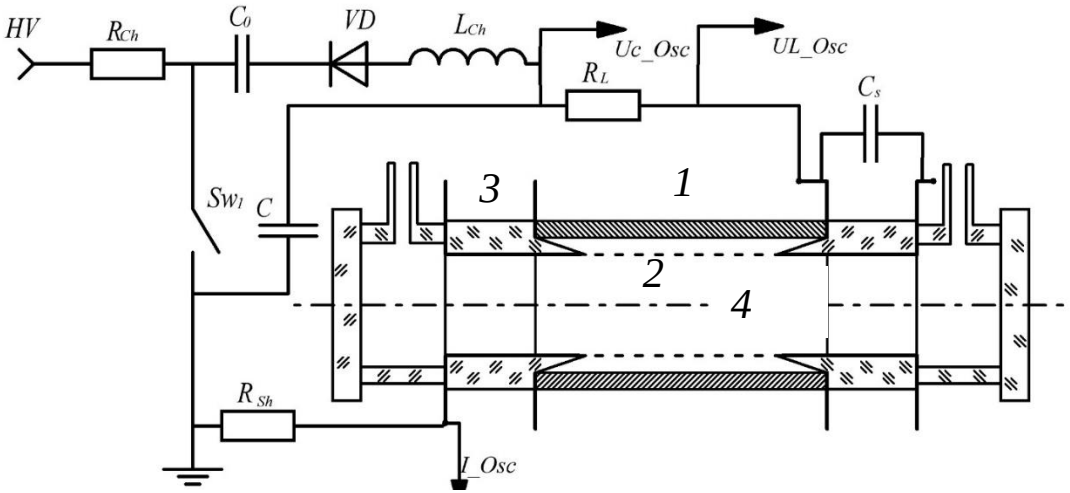
Introduction

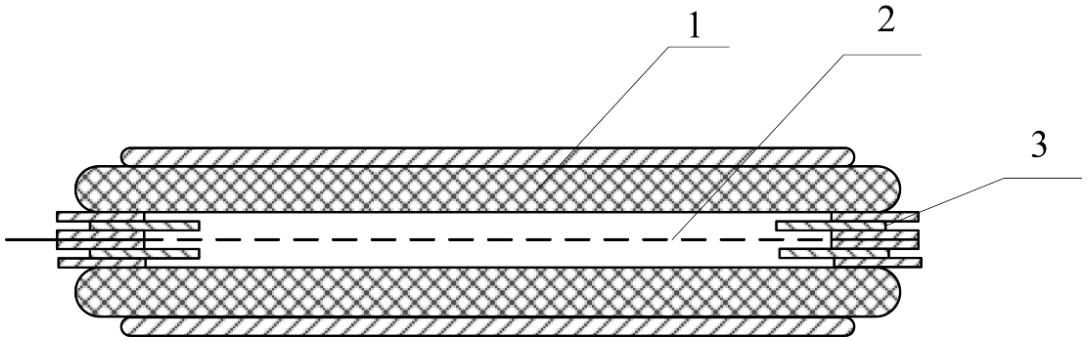
A kivotron is a switching device (switch), in which counter propagating electron beams (EB) are generated in the geometry of an open discharge (OD). The device operates in the pulse compression mode, which means that the duration of the voltage front τ_{ps} applied to the switch is many times greater than the duration of the leading edge of the voltage across the load that occurs after the switch was turned on.

Typical oscillograms describe kivotron operating

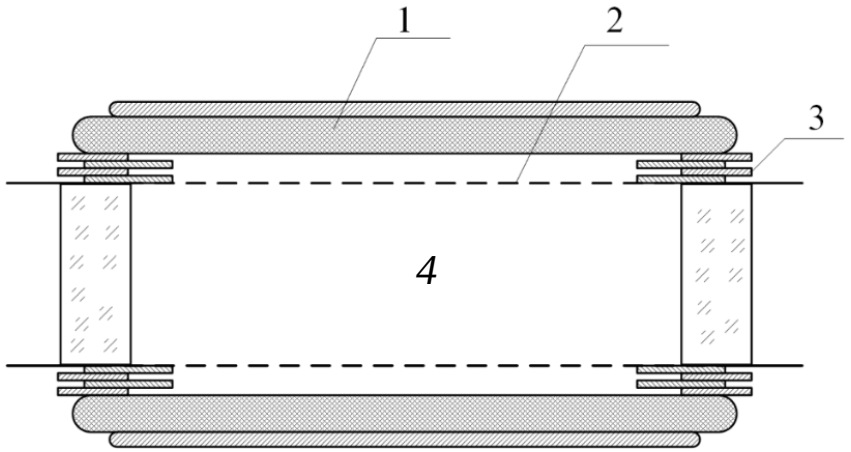


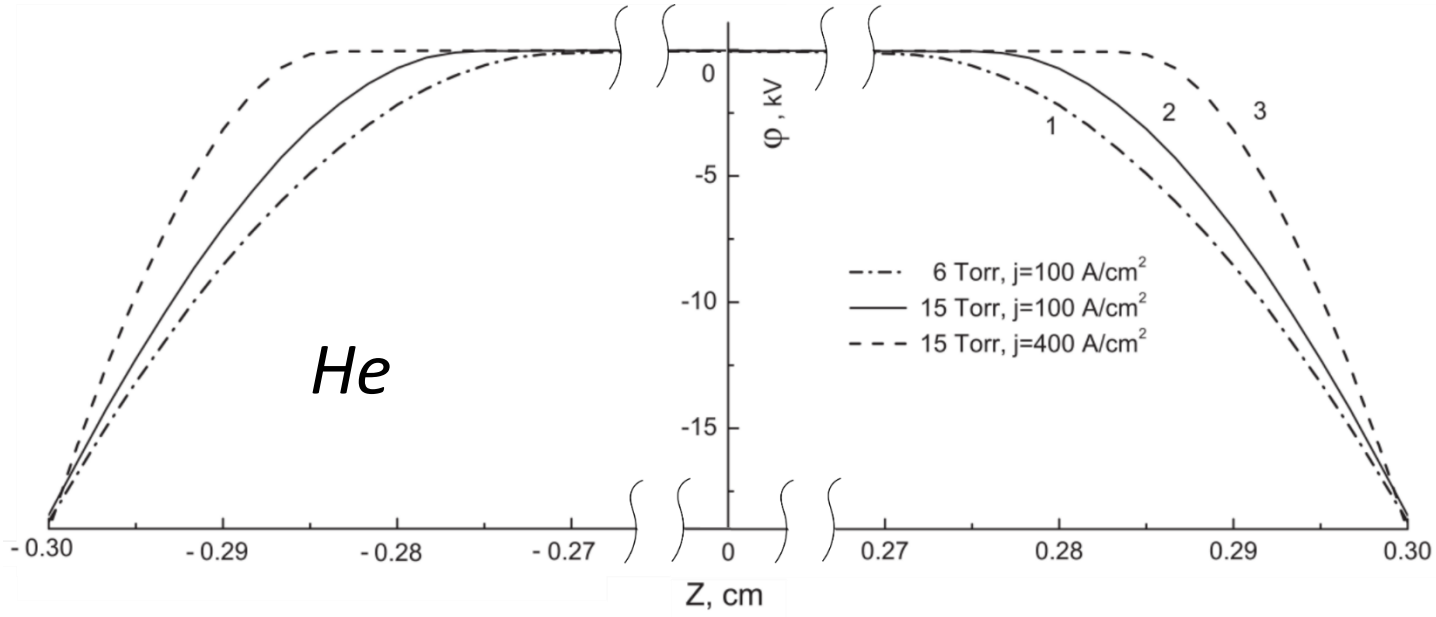
Electrical circuits of the switch devices and design of the kivotron cells





Potential distribution in the accelerating gaps





(*1*) cathode, (*2*) grid anode, (*3*) insulators
(*4*) drift space

Setting of a task

IOP Publishing

Plasma Sources Science and Technology

Plasma Sources Sci. Technol. **29** (2020) 084002 (12pp)

https://doi.org/10.1088/1361-6595/ab9d90

Investigation of the characteristics and mechanism of subnanosecond switching of a new type of plasma switches. I. Devices with counter-propagating electron beams—kivotrons

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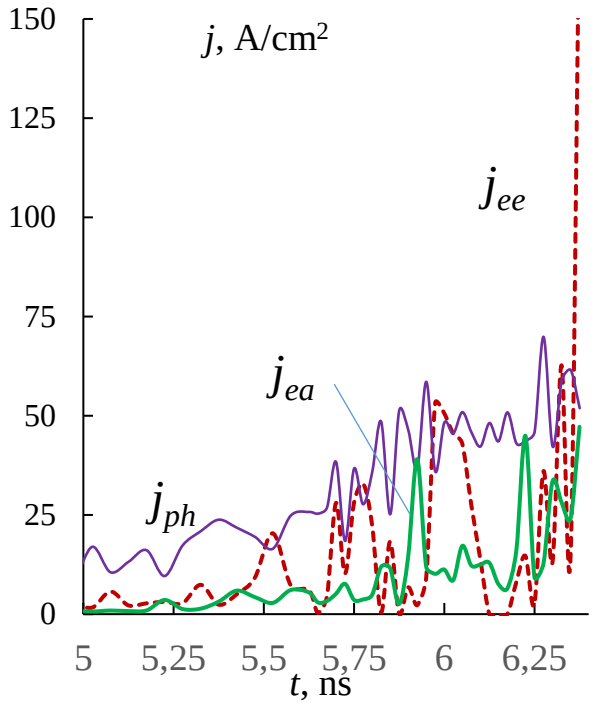
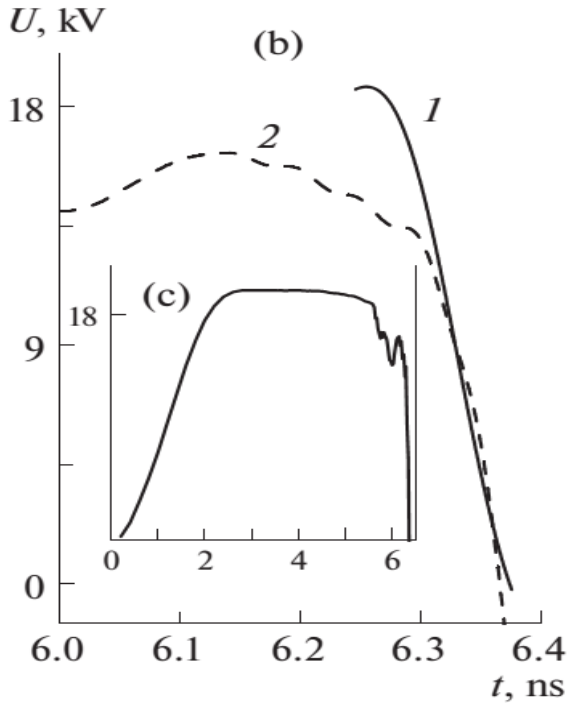
Debated problem:
electron emission mechanisms from cold cathodes





(a) Time dependence of electron emission currents caused by photoemission j_{ph}, fast atom impact (j_{ea}), secondary electron emission (j_{ee});
(b) experimental oscillogram (*1*) and simulated time behavior (*2*);
(c) the whole simulated in time profile of discharge voltage p_{He}=20Torr, U=20kV

In the subnanosecond stage and j < 50 A/cm^2 photoemission prevails

In the picosecond stage and j > 50 A/cm^2 electron-electron emission prevails

The primary source of contradictions: the wide scatter of published data on emission coefficients

He, $W_{i,a}$=1keV, γ=1.2 [H.C. Hayden et al, *Phys. Rev*. **135**, A1575 (1964)].

γ=0.02 [L. Xu et al. *Phys. Plasmas,* **24**, 093511 (2017)].

He, λ=58.4nm γ_{ph}=0.03 [A.V. Karelin et al. *Plasma Phys. Rep*. **31**, 519 (2005)].

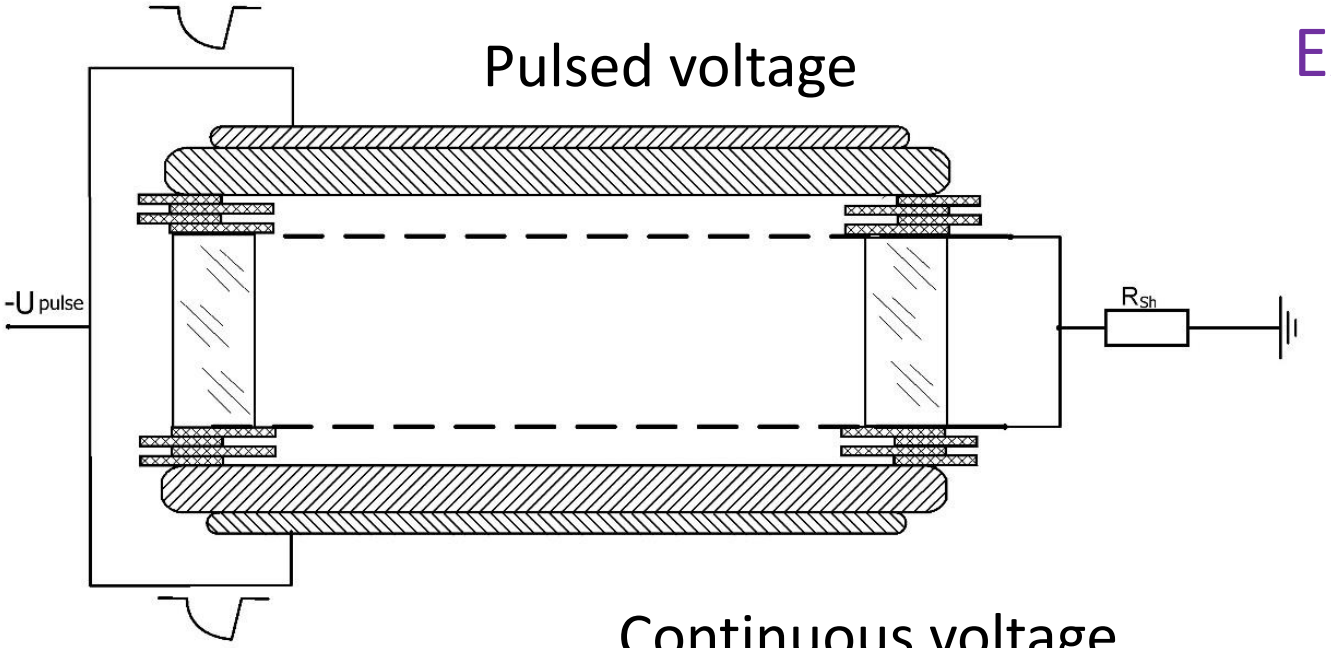
γ_{ph}=0.3 [P.A. Bokhan et al. *Phys Rev*. **88**, 013105 (2013)]

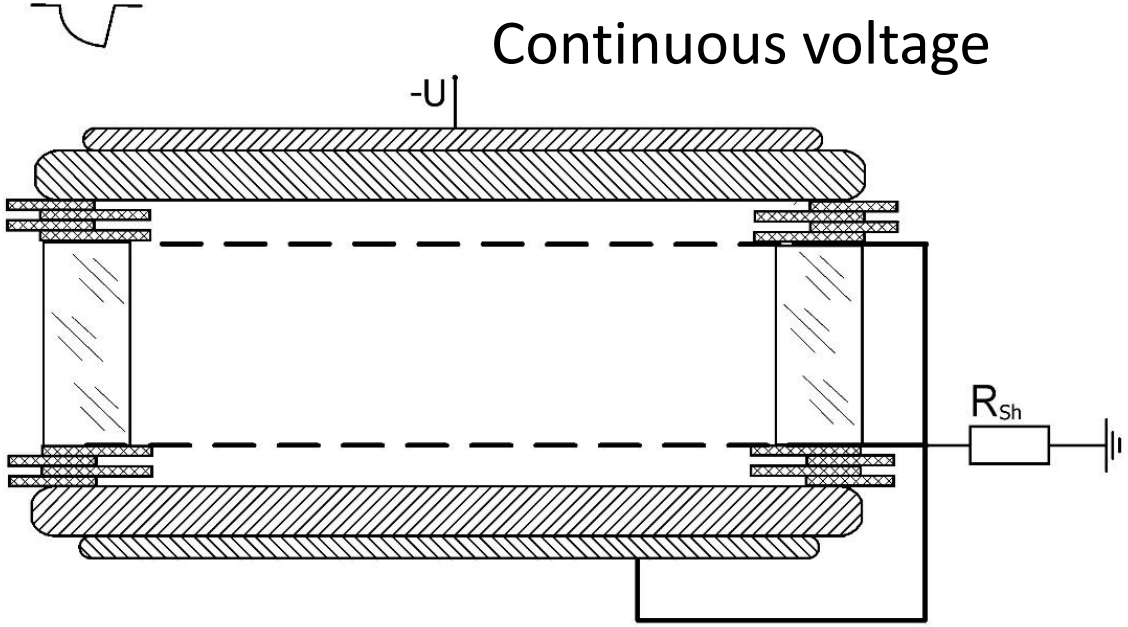
Our point of view

As a result of bombardment with heavy particles, the density of atoms in the near-surface layer of the cathode reaches the density of atoms in a liquid working gas, for example, in helium. Therefore, the emission properties of cathodes are mainly determined by the interaction of plasma emanations with a modified surface layer of the cathode rather than with the main material of the cathode.

It is quite obvious that comprehensive studies of emission mechanisms are needed to ensure further progress in the development of kivotrons. For this purpose, this work presents the results of studying the properties of kivotrons with different fillings: helium, nitrogen, oxygen, and their mixtures. The choice of these media is due to the fact that, on the one hand, the total emission coefficient under the action of fast heavy particles in *He*, at for example at operating voltage of U=4kV $\gamma<1$ [L. Xu et al. *Phys. Plasmas* **24**, 093511 (2017); P. Hartmann, et al. Jpn. J. Appl. Phys. **42**, 3633 (2003)] compared to $\langle\gamma\rangle=3.1$ for N_2 and $\langle\gamma\rangle=4.6$ for O_2 [P.A. Bokhan et al. *Plasma Physics Rep*, **45**,1035 (2019)]. On the other hand, resonance radiation dominates in *He*, while in N_2 and O_2 it is much weaker, since the resonance states are above the dissociation limit. Correspondingly, when photoemission predominates, kivotrons with helium filling should be faster, and if emission under the action of fast heavy particles predominated, kivotrons with nitrogen and oxygen filling should be faster.

Experimental chamber



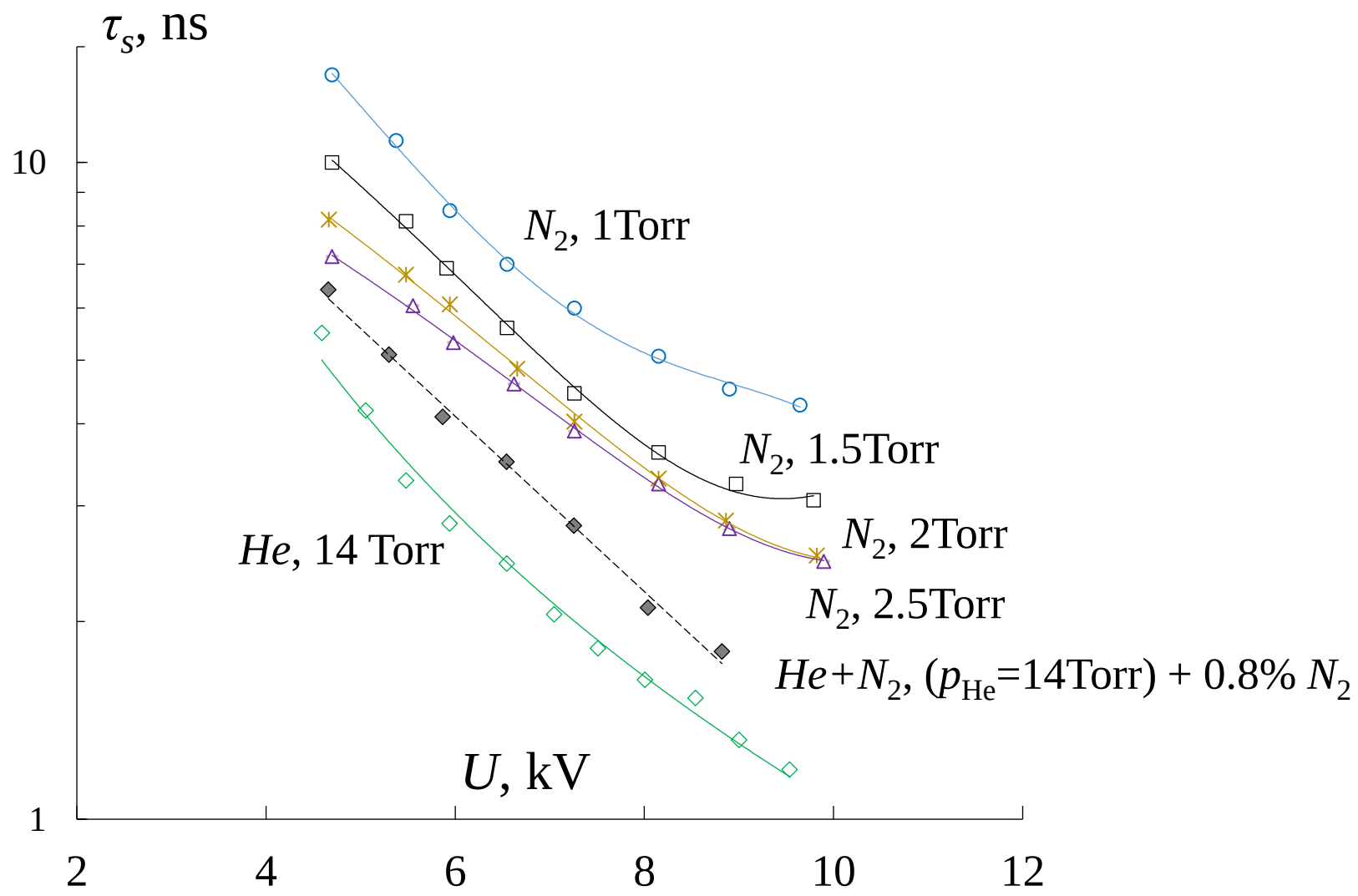


switch

d_c = 28 mm (*SiC*)
l_{ds} = 9 mm
l_g = 3 mm

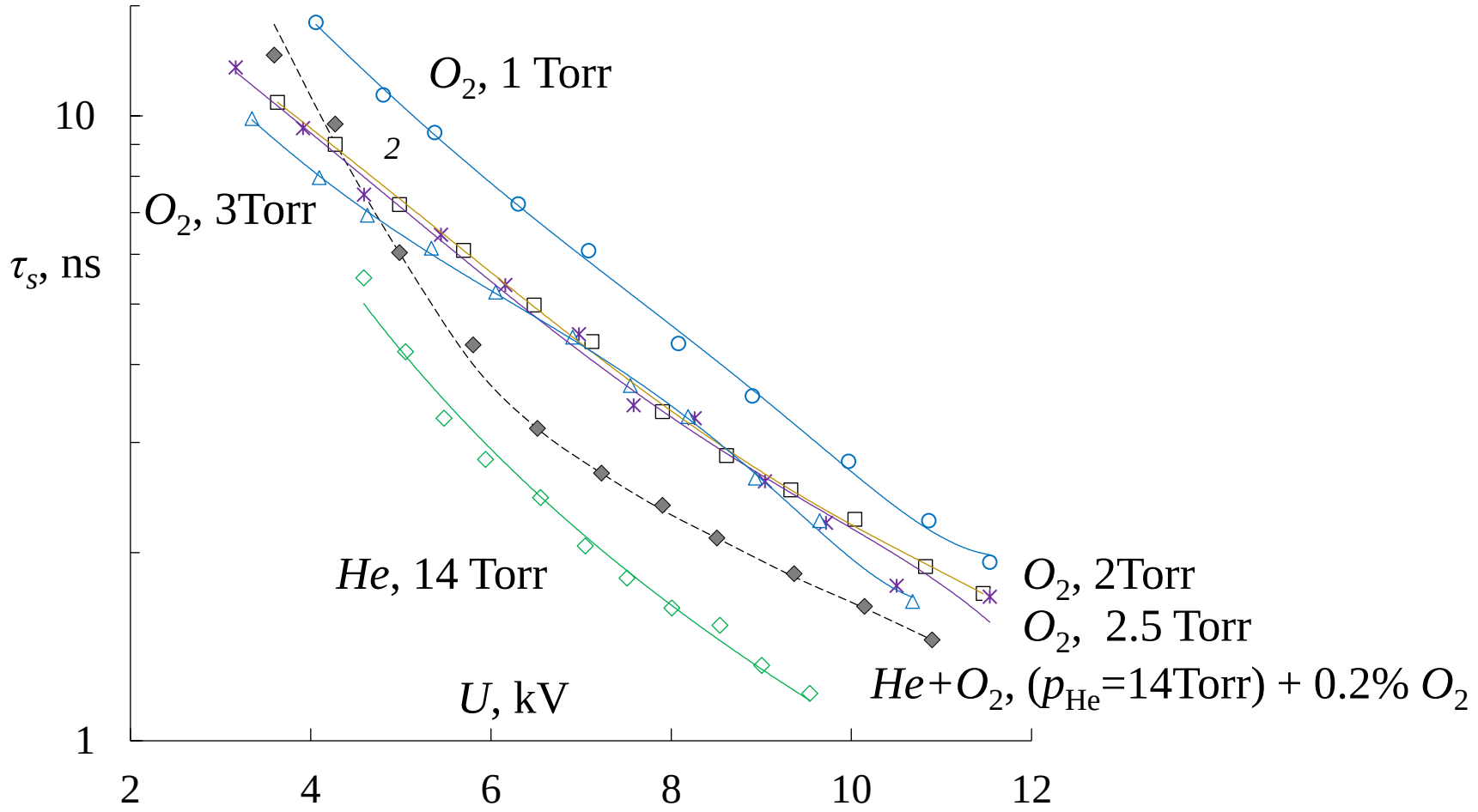
Open discharge

τ_s dependence on *U* in N_2, *He* and *He*+N_2.



Switching period increases τ_s in the subsequent media: *He* →*He*+N_2→ N_2

τ_s dependence on *U* in O_2, *He* and $He+O_2$

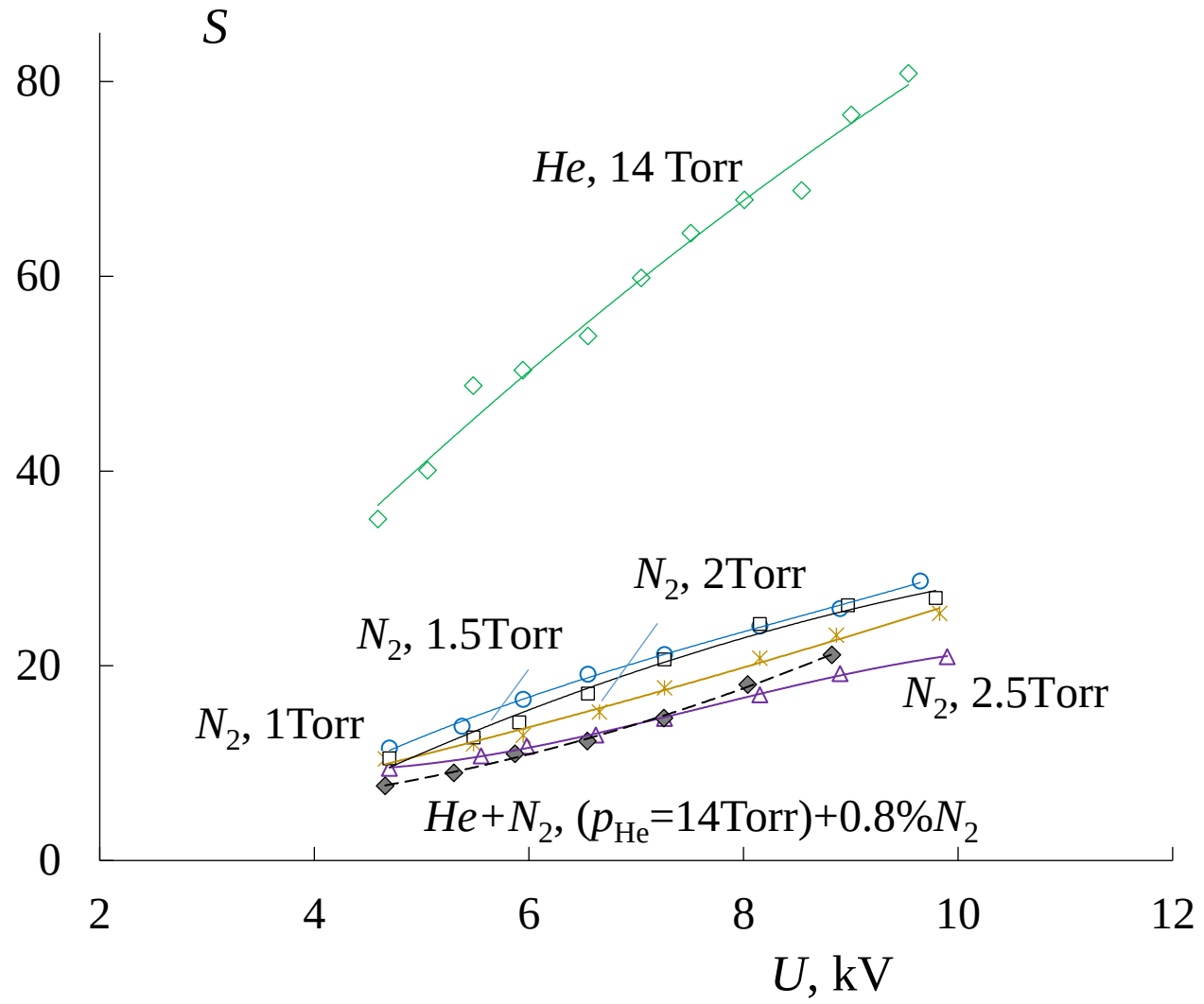


Switching period increases τ_s in the subsequent media: $He \rightarrow He+O_2 \rightarrow O_2$

Peculiarities: 1. τ_s does not depend from pressure at $p > 2.5$ Torr for N_2 and O_2

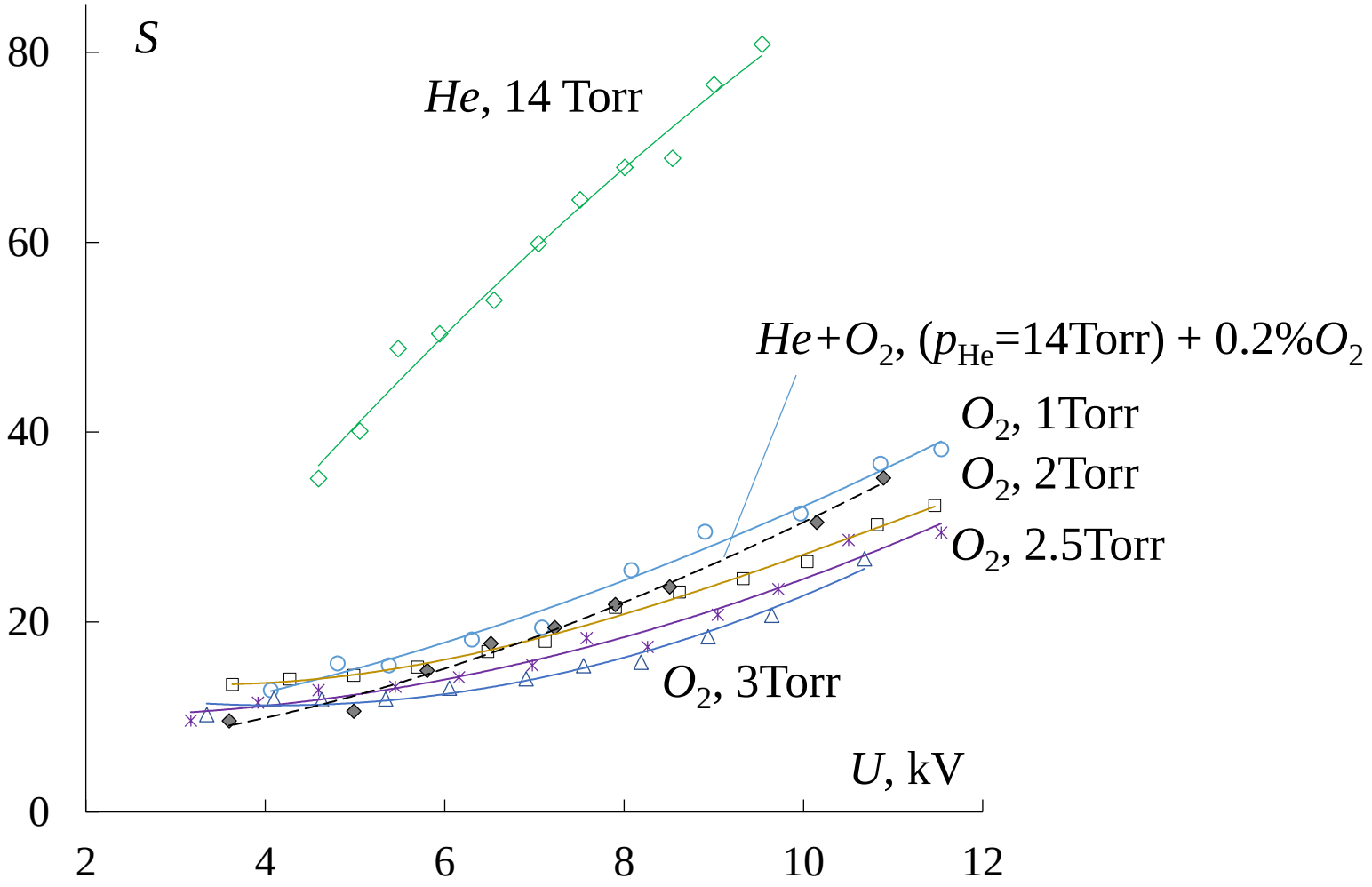
2. $\tau_s \sim 1/p$ up to at least 100ps [P. A. Bokhan, et al. Plasma Physics Rep, **42**, 666 (2016)]

The compression degree *S* dependence on *U* in N_2, *He* and *He*+N_2



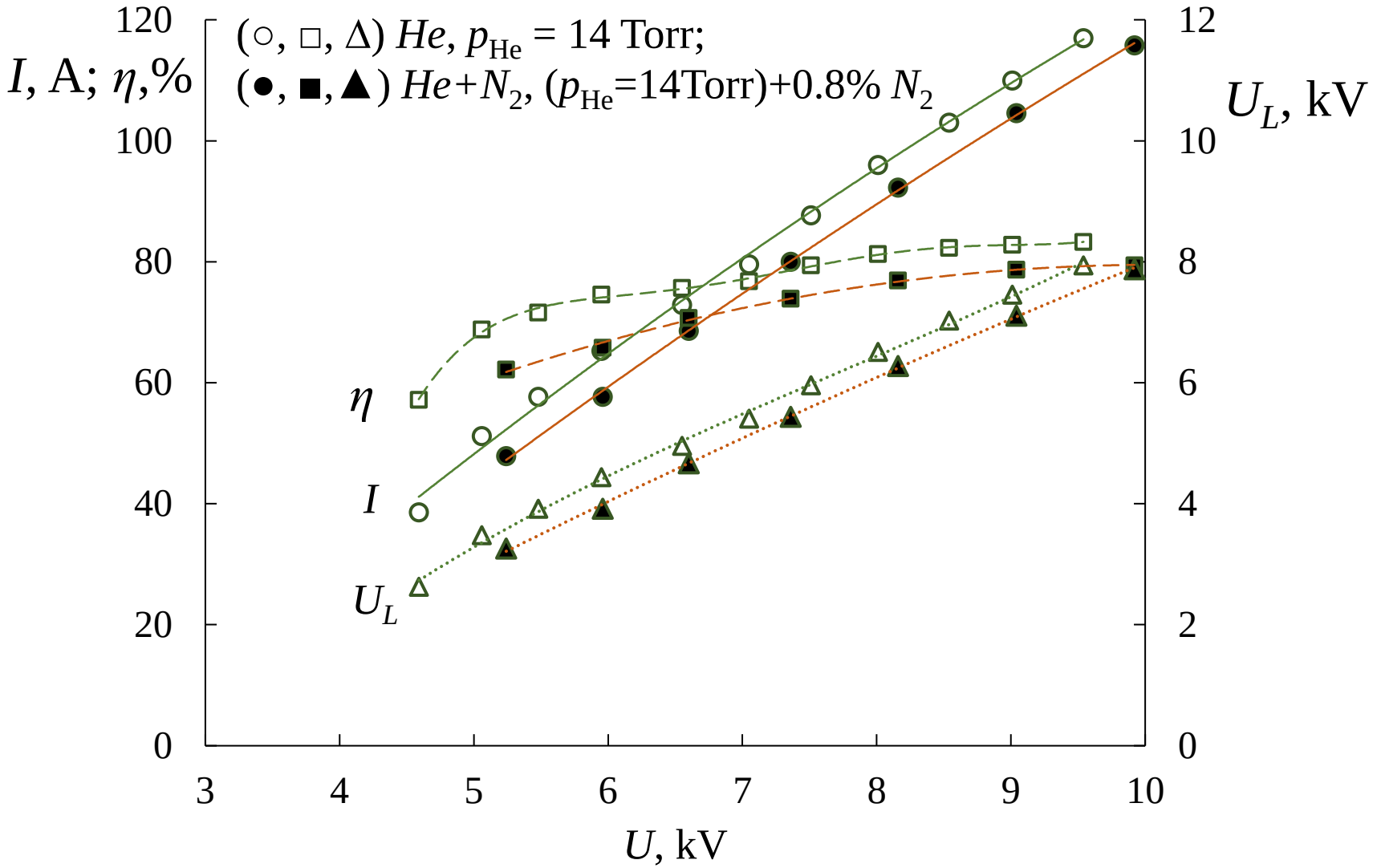
The compression degree *S is the greatest in He*

The compression ratio *S* dependence on *U* in O_2, *He* and *He*+O_2.



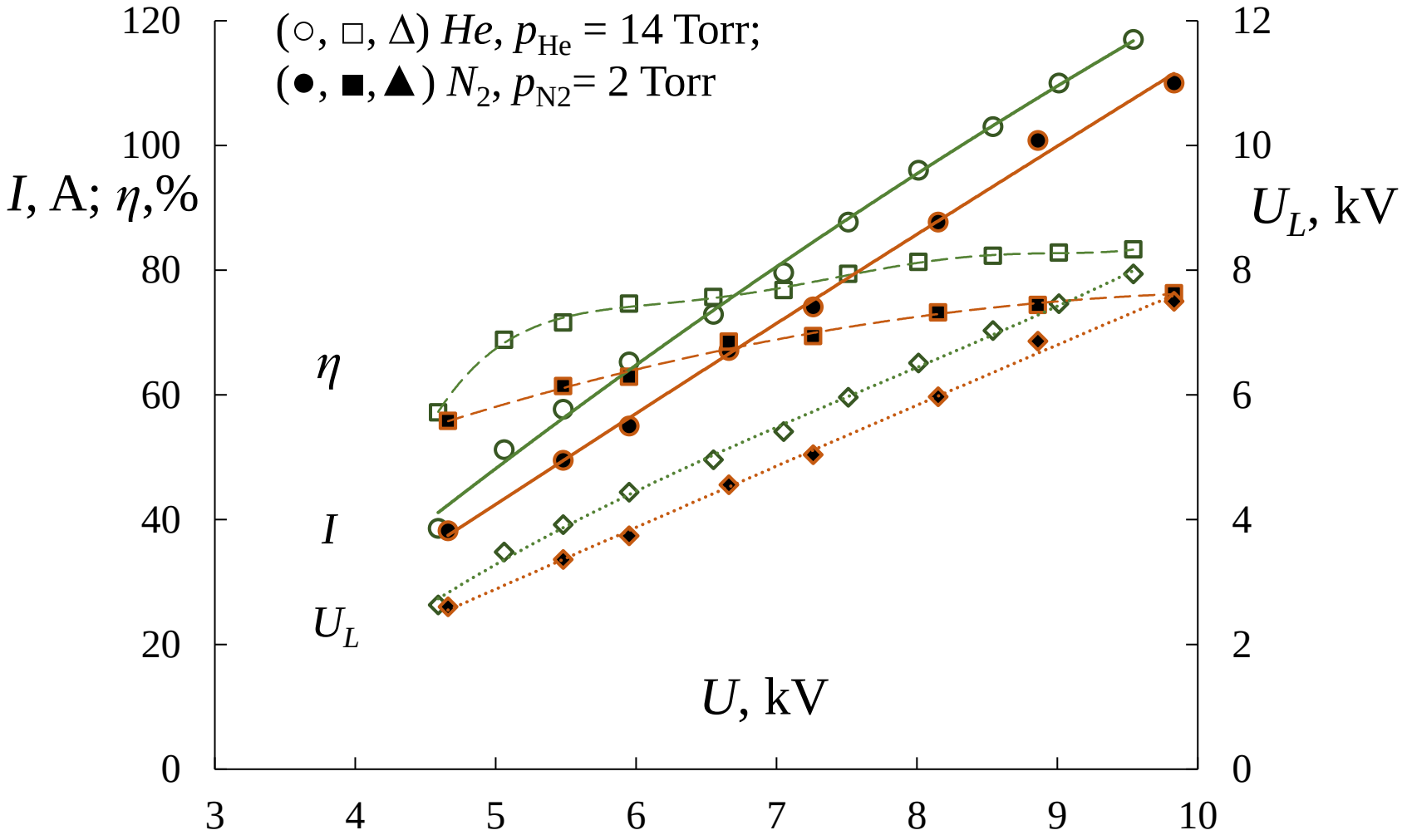
The compression degree *S is the greatest in He*

The current I, efficiency η and voltage on the load U_L at the max of I as functions of U



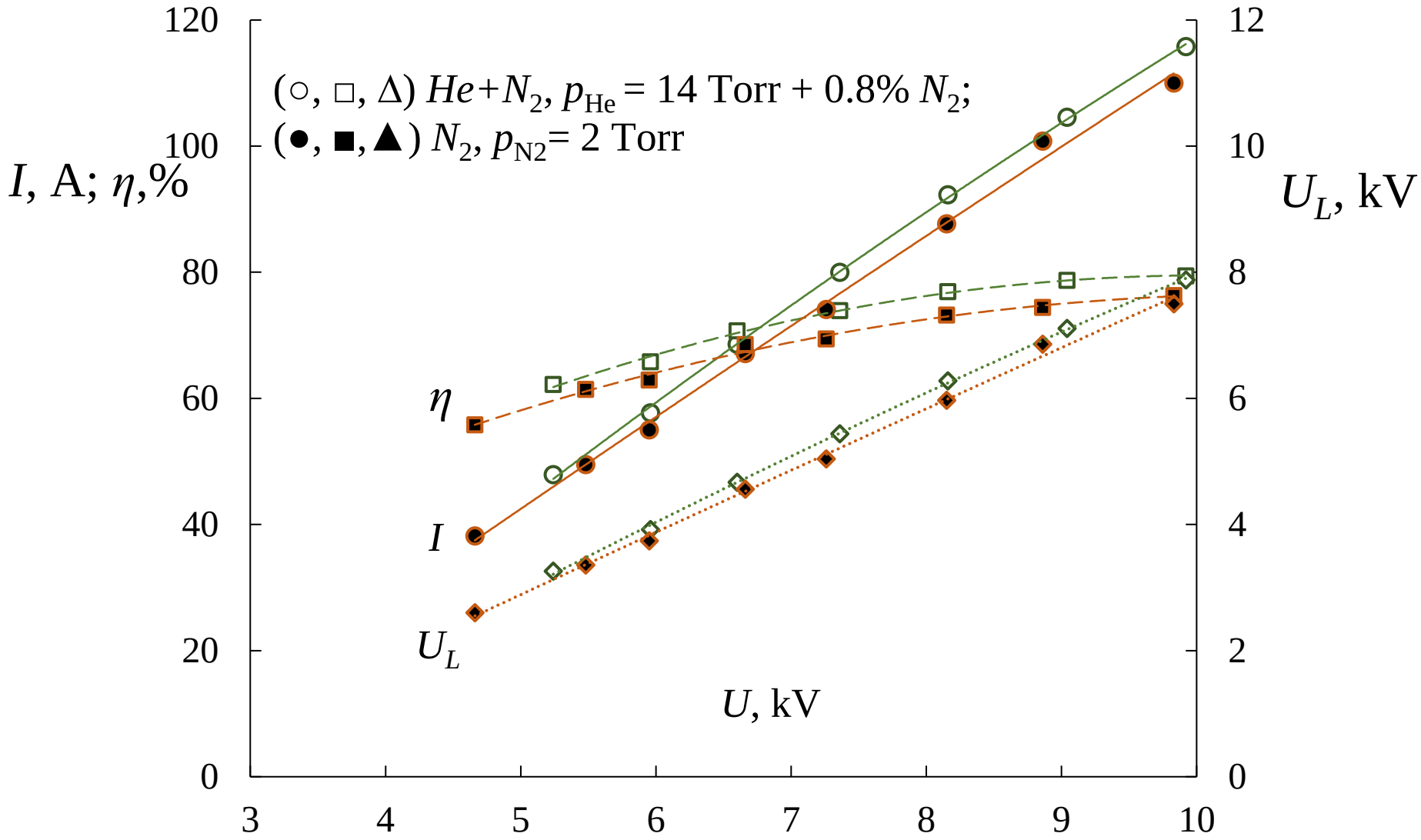
Admixture of N_2 in He impairs switching characteristics

The current I, efficiency η and voltage on the load U_L at the max of I as functions of U



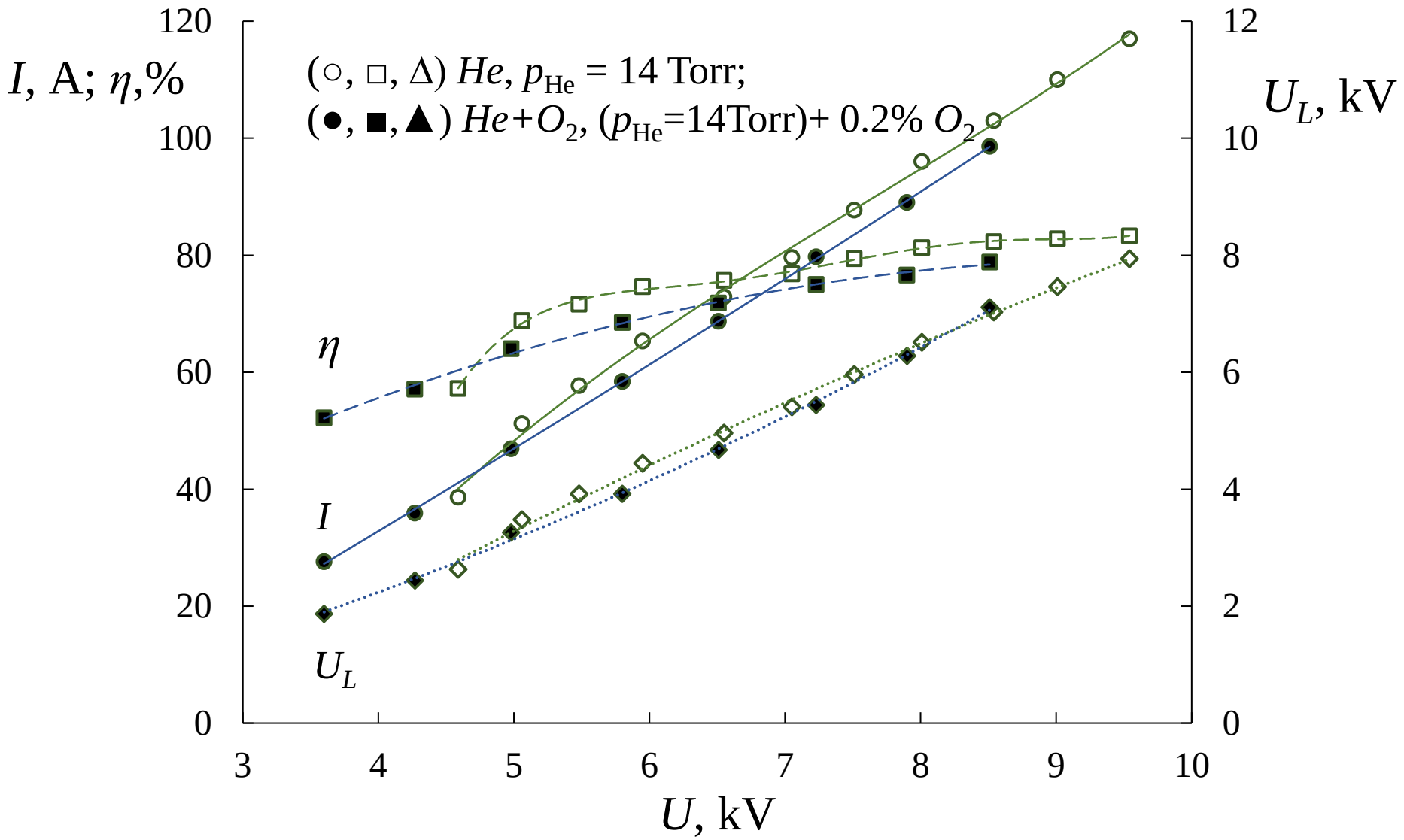
Switching parameters in He are superior to N_2

The current I, efficiency η and voltage on the load U_L at the max of I as functions of U



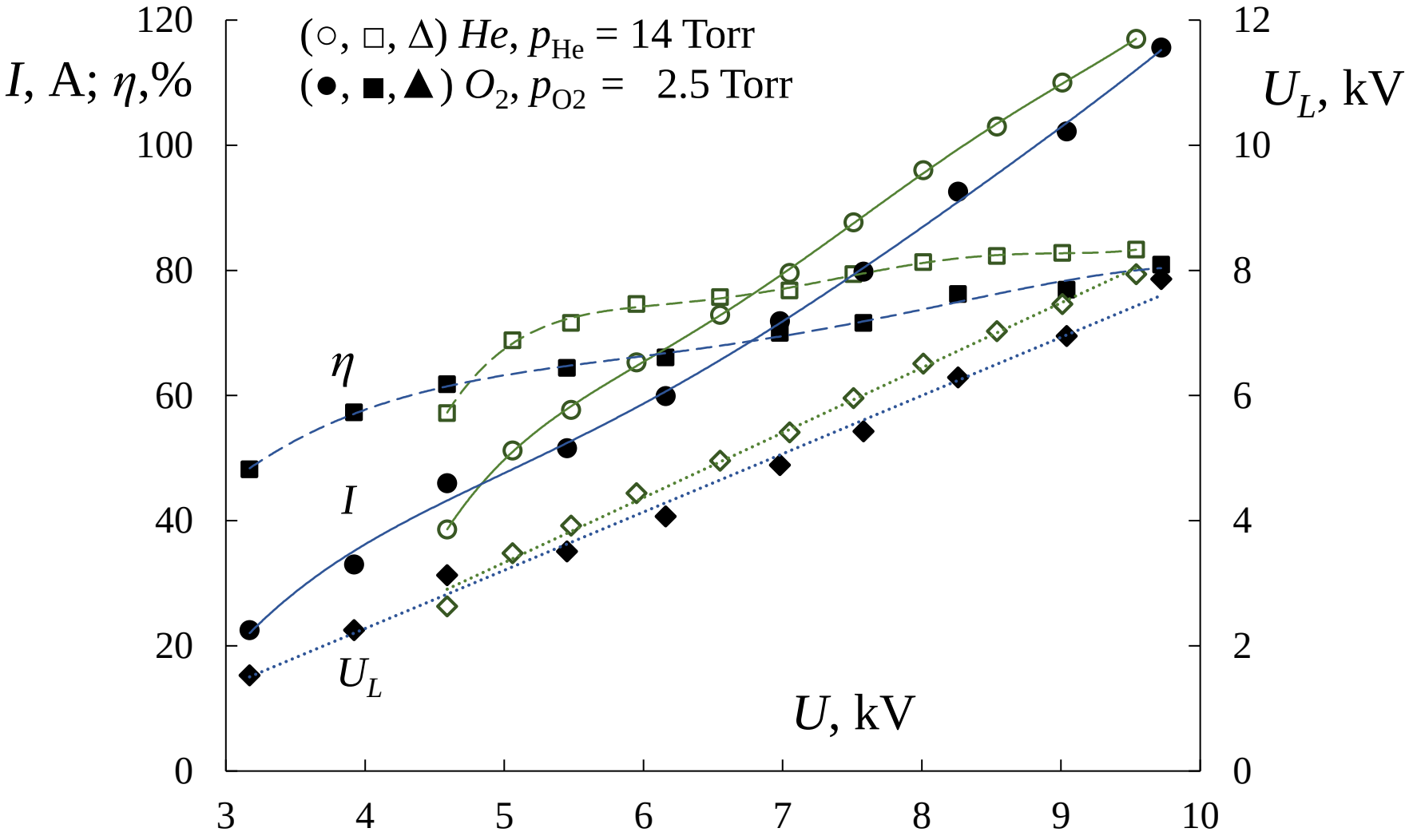
Switching parameters in $He+N_2$ are superior to N_2

The current I, efficiency η and voltage on the load U_L at the max of I as functions of U



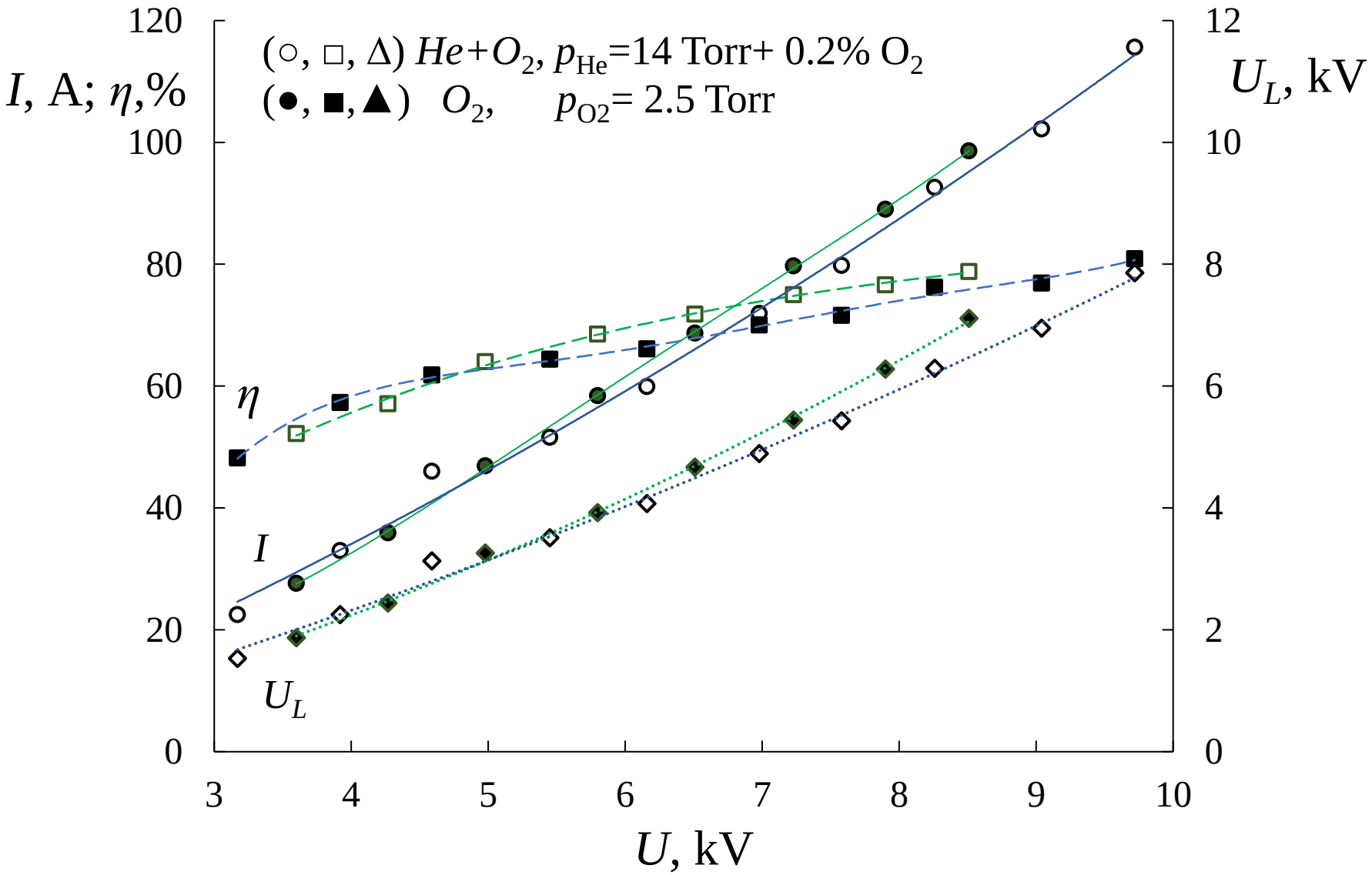
Admixture of O_2 in He impairs switching characteristics

The current I, efficiency η and voltage on the load U_L at the max of I as functions of U



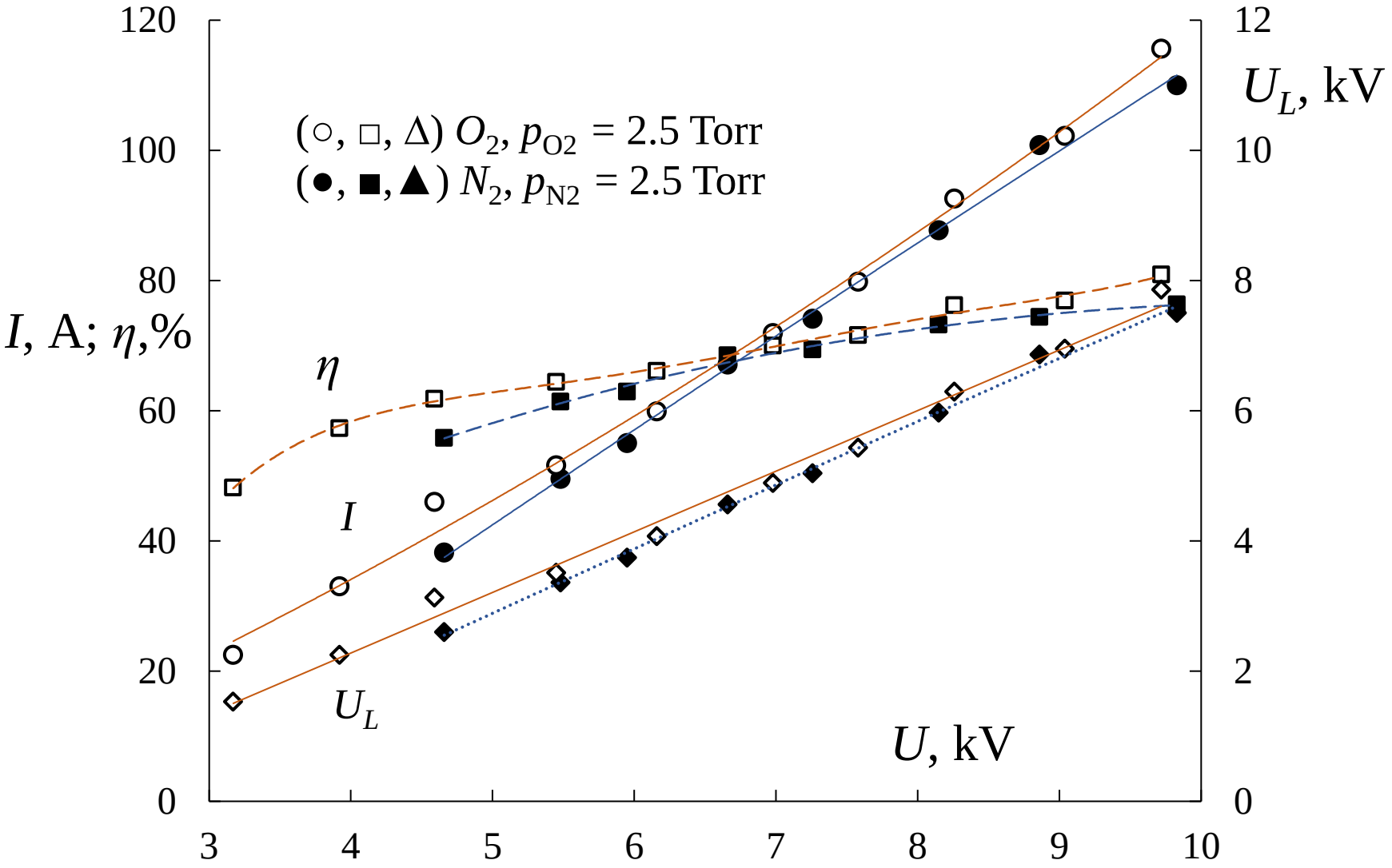
Switching parameters in He are superior to O_2

The current I, efficiency η and voltage on the load U_L at the max of I as functions of U



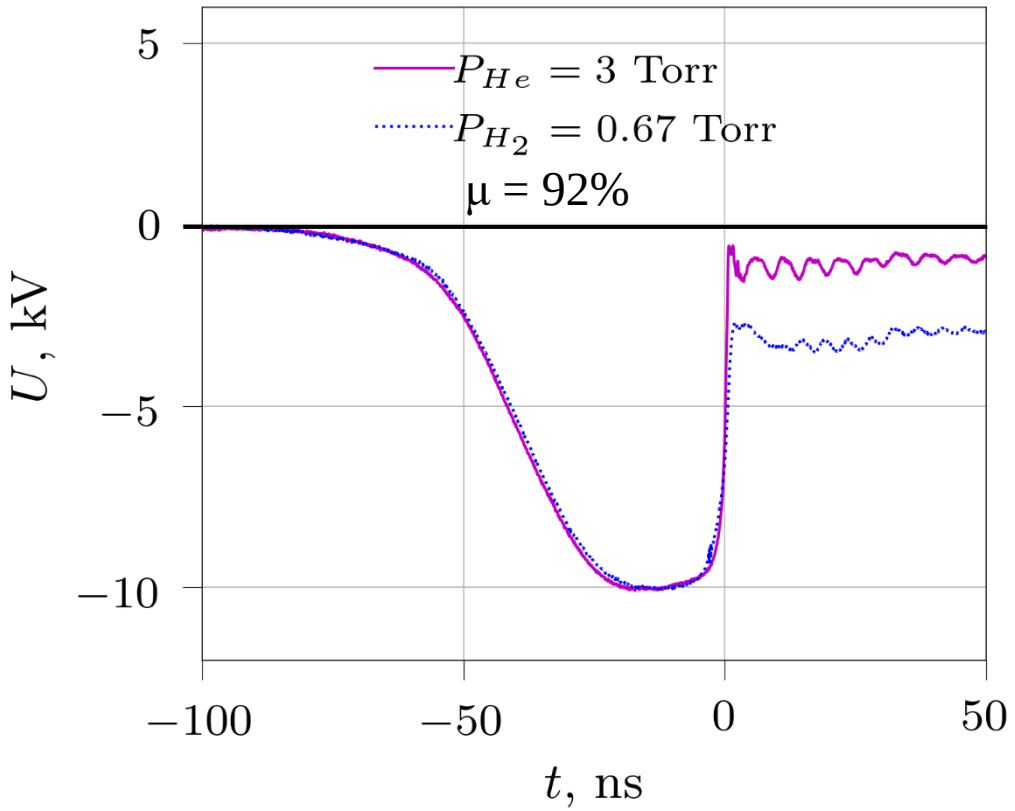
Switching parameters in $He+O_2$ are superior to O_2

The current I, efficiency η and voltage on the load U_L at the max of I as functions of U



Switching parameters in O_2 are superior to N_2

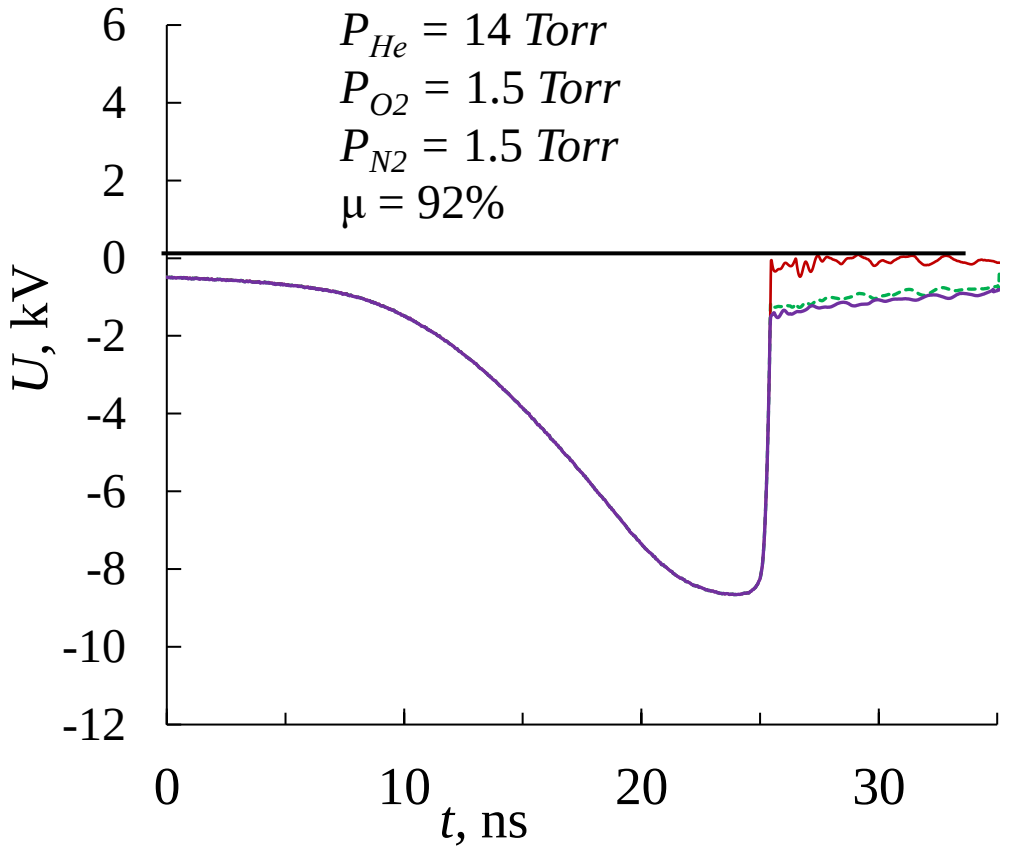
Voltage waveforms and switching efficiency



He, η = 89%; τ_s = 2.56 ns

H_2, η = 66%; τ_s = 4.56 ns

cell with drift space



He , η > 95%; τ_s = 0.28ns

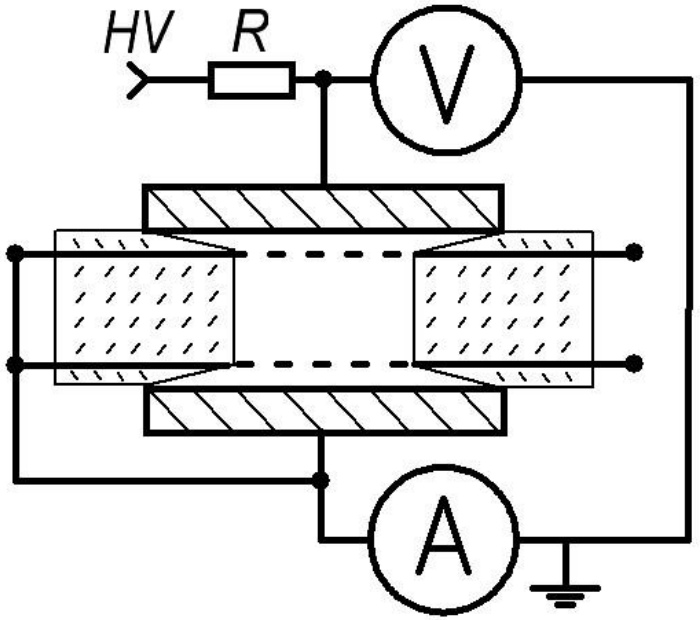
N_2 , η = 82%; τ_s = 1.8ns

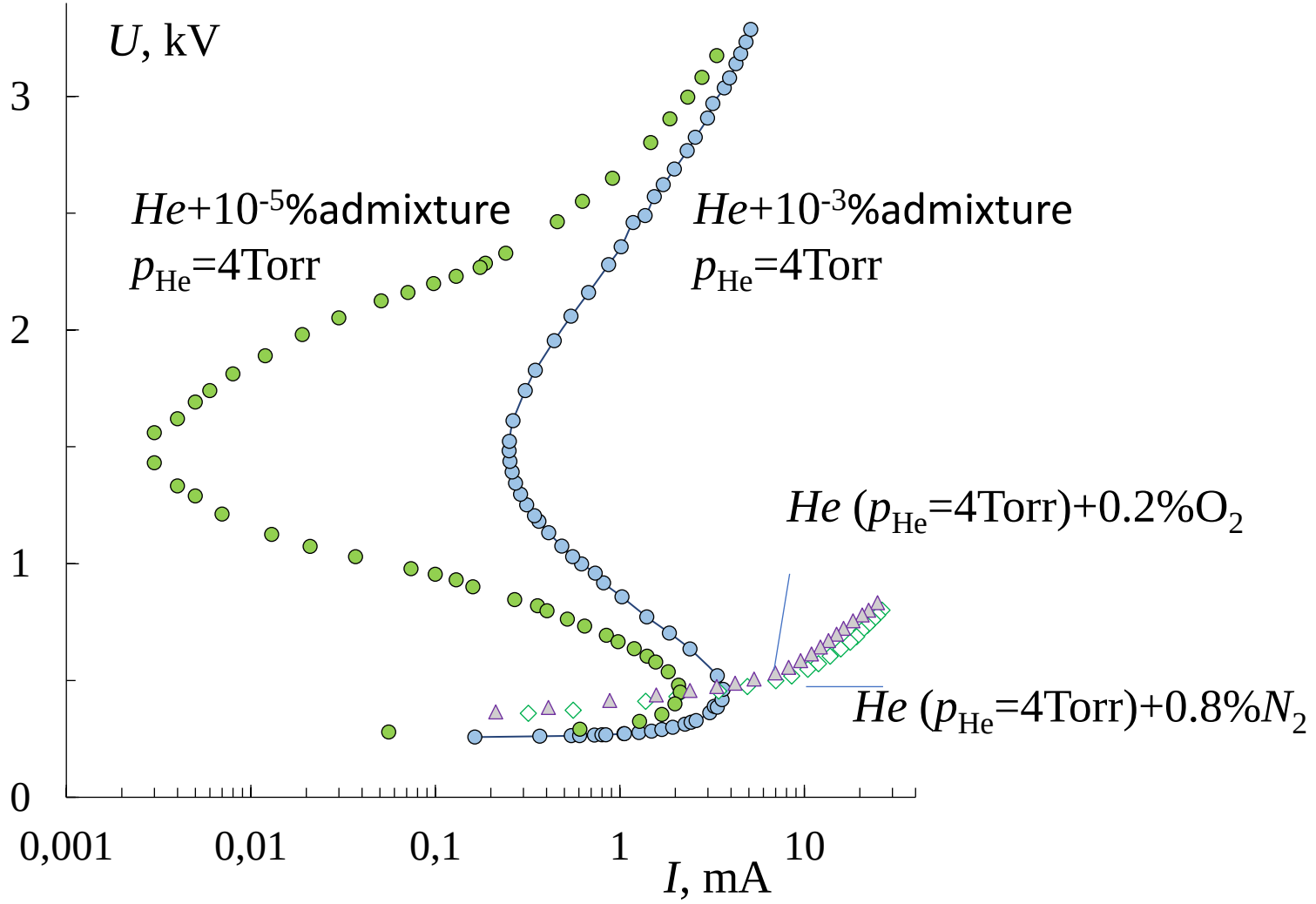
O_2 , η = 86%; τ_s = 1.4ns

cell without drift space

Discussion

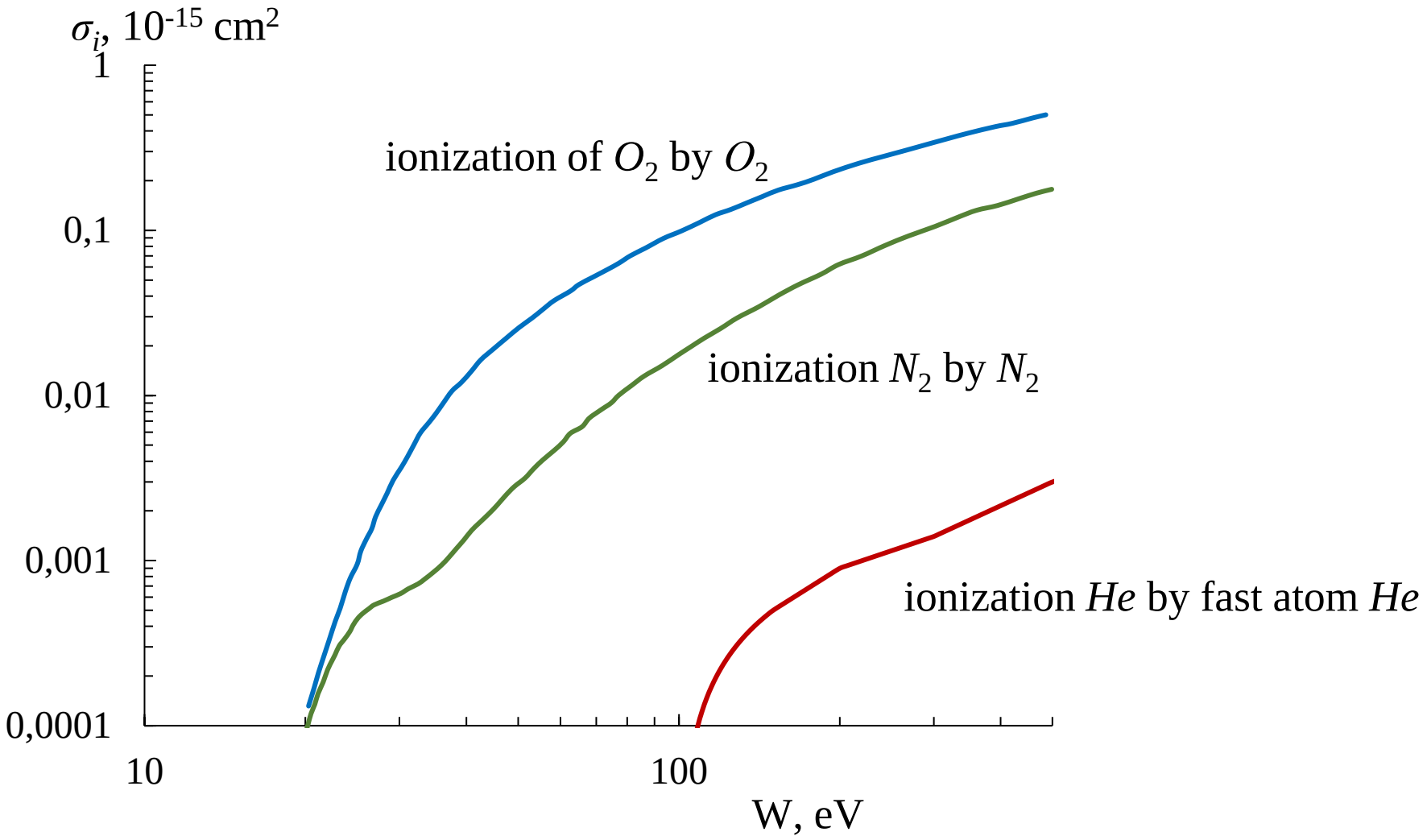
Current-Voltage characteristics





Admixtures of molecular gases to pure *He* **radically alter** current- voltage characteristics

Cross sections for ionization of atoms by fast atoms as functions of the colliding particles energy



Conclusion

- Fast switching when the kivotron is filled with helium is due to photoemission with weak charge multiplication in the gap. As result $\tau_s \sim 1/p$.

- Fast switching in N_2 and O_2 can be carried out only under the condition of intensive multiplication of charges in the accelerating gaps in the collisions of heavy particles, which leads to a decrease in compression value, in the switching efficiency in comparison with helium and independence of $\tau_s(p)$ at $p > 2.5$ Torr.

- The same switching times in nitrogen and oxygen as compared to helium are realized at a significantly higher voltage.

- The same switching times in nitrogen as compared to oxygen are realized at a higher voltage.

- The same delay in the development of a discharge in nitrogen and oxygen as compared to helium is realized with a much longer switching time

Thank you for the attention