ИНСТИТУТ ЗА ФИЗИКУ | БЕОГРАД
УНИВЕРЗИТЕТ У БЕОГРАДУ
ИНСТИТУТ ОД НАЦИОНАЛНОГ ЗНАЧАЈА ЗА РЕПУБЛИКУ СРБИЈУ
www.ipb.ac.rs
Број 0801-1135/1
Датум 25-06-2024

Научном већу
Института за физику у Београду

Предмет: Молба за избор у звање истраживач сарадник

МОЛБА

Пошто испуњавам услове прописане Законом о науци и истраживањима, молим Научно веће Института за физику у Београду да ме изабере у звање истраживач сарадник.

У прилогу достављам:

1. мишљење руководиоца лабораторије са предлогом комисије која ће писати извештај,
2. кратку стручну биографију,
3. кратак преглед научне активности,
4. списак објављених радова и других публикација,
5. уверење о уписаним докторским студијама физике,
6. уверење о завршеним основним и мастер студијама физике и просечној оцени,
7. потврда о пријављеној теми докторске дисертације,
8. копије објављених радова и других публикација.

Са поштовањем,

Н. Бабуцић

Неда Бабуцић
мастер физичар

ИНСТИТУТ ЗА ФИЗИКУ | БЕОГРАД
УНИВЕРЗИТЕТ У БЕОГРАДУ
ИНСТИТУТ ОД НАЦИОНАЛНОГ ЗНАЧАЈА ЗА РЕПУБЛИКУ СРБИЈУ
www.ipb.ac.rs

Број 0801-1135/2
Датум 25-06-2024

Научном већу Института за физику у Београду

Предмет: Мишљење руководиоца лабораторије о избору Неде Бабуцић у звање истраживач сарадник

Неда Бабуцић је ангажована у Лабораторији за неравнотежне процесе и примену плазме, у оквиру Центра изузетних вредности за изучавање неравнотежних процеса Института за физику у Београду, где ради на својој докторској тези из области неравнотежних пражњења под руководством др Невене Пуач. У свом истраживачком раду бави се дијагностиком неравнотежне плазме на атмосферском притиску и применом у биомедицини.

С обзиром да испуњава све предвиђене услове у складу са Законом о науци и истраживањима и Правилником о поступку, начину вредновања и квантитативном исказивању научноистраживачких резултата истраживача МПНТР, што се види из приложеног материјала, предлажем да Научно веће изабере Неду Бабуцић у звање истраживач сарадник.

За састав комисије за избор Неде Бабуцић у звање истраживач сарадник предлажем:

(1) др Невена Пуач, научна саветница, Институт за физику Београд
(2) др Никола Шкоро, научни саветник, Институт за физику Београд
(3) др Милош Скочић, доцент Физичког факултета Универзитета у Београду

др Гордана Маловић
научни саветник
руководилац Лабораторије за
неравнотежне процесе и примену плазме

Стручна биографија Неде Бабуцић

Неда Бабуцић је рођена у Панчеву 1995. године, где је завршила гимназију „Урош Предић“, 2014. године. Исте године уписује Физички факултет Универзитета у Београду где 2020. године завршава основне студије на смеру Примењена и компјутерска физика са просеком 8,57/10,00.

Након завршетка студија, исте године, и на истом факултету уписује мастер студије на смеру Примењена физика. Мастер рад „Унапређење интерферометрије методом сопственог мешања сигнала ласерске диоде“, урађен је под менторством др Ненада Сакана, вишег научног сарадника у Лабораторији за спектроскопију плазме и ласере Института за физику у Београду. Мастер рад је одбранила у септембру 2021. године, чиме завршава мастер студије са просеком 10,00/10,00.

У октобру 2021. године уписује докторске студије на Физичком факултету у Београду из уже научне области Примењена физика и свој научно истраживачки рад наставља у Лабораторији за неравнотежне процесе и примену плазме, Института за Физику у Београду, под менторством др Невене Пуач. Своје досадашње резултате у области плазме, као и будуће, планира да представи кроз своју докторску дисертацију под називом „Неравнотежна микроталасна плазма на атмосферском притиску са течним системима – конструкција извора, дијагностика плазме и примена у биомедицини“. Тема докторске дисертације одбрањена је на колегијуму Физичког факултета, 08. маја 2024. године.

Преглед научне активности Неде Бабуцић

Главна област истраживања Неде Бабуцић је конструкција и дијагностика извора неравнотежне плазме на атмосферском притиску у капљичним и аеросолним течним системима, као и примене у биологији и медицини.

2020. године, Неда уписује мастер студије на Физичком факултету Универзитета у Београду, и започиње израду мастер рада на тему "Унапређење интерферометрије методом сопственог мешања сигнала ласерске диоде", у Лабораторији за спектроскопију плазме и ласере Института за физику у Београду. Рад је одбранула у септембру 2021. године са највишом оценом. Током израде мастер тезе Неда се бавила изучавањем оптичког феномена познатог као интерференција. Главне предности овакве методе, у поређењу са конвенционалним, су једноставније подешавање оптичког пута и мањи броја елемената и димензије система. На једноставан начин мерен је померај покретне мете у зависности од удаљености од извора светлости и фреквенције побуде саме мете.

У наставку свог научног рада, Неда наставља стицање нових знања и развојем вештина у области физике неравнотежне плазме, у Лабораторији за неравнотежне процесе и примену плазме Института за физику у Београду. Тема докторске дисертације гласи „Неравнотежна микроталасна плазма на атмосферском притиску са течним системима–конструкција извора, дијагностика плазме и примена у биомедицини“, под менторством др. Невене Пуач. Тема је одбрањена пред колегијумом Физичког факултета, 8. маја 2024. године. Њен фокус у даљем истраживању биће конструкција високофреквентних плазма извора, као и анализа резултата добијених помоћу неколико различитих дијагностичких врста. Други део доприноса се односи на примене неравнотежне плазме у биологији и медицини.

Саопштења са међународних скупова:

1. (M33) Goleš N., **Babucić N.**, Sakan N., Ivković M. (2022), “Self-Mixing Interferometry for Plasma Diagnostics”, Publ. Astron. Obs. Belgrade No. 102 (2022), 1-4, 31^{st} Summer School and International Symposium on the Physics of Ionized Gases (SPIG) (pp. September 5-9, 2022. Beograd, Srbija)
2. (M34) **Babucić, N.,** Škoro, N., & Puač, N. (2022), „Nonthermal Plasma at atmospheric pressure with aerosols: applications in biomedicine“, In Proceedings of the 25th International School on Low Temperature Plasma Physics (October 2–6, Bad Honef, Nemačka)
3. (M34) **Babucić, N.**, Škoro, N., & Puač, N. (2023), „Nonthermal Plasma at atmospheric pressure with aerosols: applications in agriculture“, In Proceedings of the 2nd Training School "Cold plasmas to fight microorganisms, viruses & toxins for medical and agricultural applications" (pp. February 13–17, Bari, Italija).
4. (M34) **Babucić, N.,** Jovanović, O., Škoro, N., & Puač, N. (2023), ”Creation of reactive species by two atmospheric pressure plasma sources while treating water for biomedical applications”, In Proceedings of the 3rd Workshop on Plasma Applications for Smart and Sustainable Agriculture and the 8th International Conference on Plasma Technologies (pp. May 14–18., Gozd Martuljek, Slovenia).
5. (M34) Škoro, N., **Babucić, N.,** Kutasi, K., Spasić, K., & Puač, N. (2023), “Characterization of a plasma system with microwave launcher used for treatment of liquids”, In Proceedings of the XXXV International Conference on Phenomena in Ionized Gases (pp. Jul 09–14, Egmond aan Zee, Holandija).
6. (M34) **Babucić, N.,** Škoro, N., Kutasi, K., Spasić, K., & Puač, N. (2023), “Low-temperature Microwave Plasma at Atmospheric Pressure with Aerosols: Treatment of Liquid Samples”, In Proceedings of the 23rd International Summer School on Vacuum, Electron and Ion Technologies (pp. Septembar 18–22, Sozopol, Bulgaria).
7. (M34) **Babucić, N.,** Škoro, N. & Puač, N. (2024), “Characterization of 2.45GHz Surface-Wave Low Temperature Plasma Devices for Cancer Cells Treatments”, In Proceedings of the 3rd Training School “Cold plasma and combined anticancer therapies” (pp. April 18–22, Orlean, Francuska).

Република Србија
Универзитет у Београду
Физички факултет
Д.Бр.2021/8013
Датум: 17.10.2023. године

На основу члана 161 Закона о општем управном поступку и службене евиденције издаје се

УВЕРЕЊЕ

Бабуцић (Божа) Неда, бр. индекса 2021/8013, рођена 13.08.1995. године, Панчево, Република Србија, уписана школске 2023/2024. године, у статусу: финансирање из буџета; тип студија: докторске академске студије; студијски програм: Физика.

Према Статуту факултета студије трају (број година): три.
Рок за завршетак студија: у двоструком трајању студија.

Ово се уверење може употребити за регулисање војне обавезе, издавање визе, права на дечији додатак, породичне пензије, инвалидског додатка, добијања здравствене књижице, легитимације за повлашћену вожњу и стипендије.

Овлашћено лице факултета

Република Србија
Универзитет у Београду
Физички факултет
Д.Бр.2021/8013
Датум: 17.10.2023. године

На основу члана 161 Закона о општем управном поступку и службене евиденције издаје се

УВЕРЕЊЕ

Бабуцић (Божа) Неда, бр. индекса 2021/8013, рођена 13.08.1995. године, Панчево, Република Србија, уписана школске 2023/2024. године, у статусу: финансирање из буџета; тип студија: докторске академске студије; студијски програм: Физика.

Према Статуту факултета студије трају (број година): три.
Рок за завршетак студија: у двоструком трајању студија.

Ово се уверење може употребити за регулисање војне обавезе, издавање визе, права на дечији додатак, породичне пензије, инвалидског додатка, добијања здравствене књижице, легитимације за повлашћену вожњу и стипендије.

Овлашћено лице факултета

Универзитет у Београду
Физички факултет
Број индекса: 2014/3118
Број: 2522020
Датум: 13.10.2020.

На основу члана 161 Закона о општем управном поступку ("Службени лист СРЈ", бр. 33/97, 31/2001 и "Службени гласник РС", бр. 30/2010) и службене евиденције, Универзитет у Београду - Физички факултет, издаје

У В Е Р Е Њ Е

Неда Бабуцић

име једног родитеља Божа, ЈМБГ 1308995865287, рођена 13.08.1995. године, Панчево, Република Србија, уписана школске 2014/15. године, дана 30.09.2020. године завршила је основне академске студије на студијском програму Примењена и компјутерска физика, у трајању од четири године, обима 241 (двеста четрдесет један) ЕСПБ бодова, са просечном оценом 8,57 (осам и 57/100).

На основу наведеног издаје јој се ово уверење о стеченом високом образовању и стручном називу **дипломирани физичар.**

Република Србија Универзитет у Београду · Физички факултет · Београд

Декан

Проф. др Иван Белча

Универзитет у Београду
Физички факултет
Број индекса: 2020/7006
Број: 2472021
Датум: 01.10.2021.

На основу члана 161 Закона о општем управном поступку ("Службени лист СРЈ", бр. 33/97, 31/2001 и "Службени гласник РС", бр. 30/2010) и службене евиденције, Универзитет у Београду - Физички факултет, издаје

У В Е Р Е Њ Е

Неда Бабуцић

име једног родитеља Божа, ЈМБГ 1308995865287, рођена 13.08.1995. године, Панчево, Република Србија, уписана школске 2020/21. године, дана 27.09.2021. године завршила је мастер академске студије на студијском програму Примењена и компјутерска физика, у трајању од једне године, обима 60 (шездесет) ЕСПБ бодова, са просечном оценом 10,00 (десет и 00/100).

На основу наведеног издаје јој се ово уверење о стеченом високом образовању и академском називу **мастер физичар.**

Декан

Проф. др Иван Белча

ДОКТОРСКЕ СТУДИЈЕ		

ПРЕДЛОГ ТЕМЕ ДОКТОРСКЕ ДИСЕРТАЦИЈЕ КОЛЕГИЈУМУ ДОКТОРСКИХ СТУДИЈА

Школска година 2023/2024

Подаци о студенту

Име	Неда
Презиме	Бабуцић
Број индекса	8013/2021
Научна област дисертације	Примењена физика

Подаци о ментору докторске дисертације

Име	Невена
Презиме	Пуач
Научна област	Примењена физика
Звање	Научна саветница
Институција	Институт за физику Београд

Предлог теме докторске дисертације

Наслов

Неравнотежна микроталасна плазма на атмосферском притиску са течним системима – конструкција извора, дијагностика плазме и примена у биомедицини

Уз пријаву теме докторске дисертације Колегијуму докторских студија, потребно је приложити следећа документа:

1. Семинарски рад (дужине до 10 страница)
2. Кратку стручну биографију писану у трећем лицу једнине
3. Фотокопију индекса са докторских студија

Потпис ментора [signature]

Датум 01. 04. 2024.

Потпис студента Neda Babić

Мишљење Колегијума докторских студија

Након образложења теме докторске дисертације Колегијум докторских студија је тему

прихватио ☒ није прихватио ☐

Датум

08.05.2024

Продекан за науку Физичког факултета

[signature]

Република Србија
Универзитет у Београду
Физички факултет
Број индекса: 2021/8013
Датум: 08.05.2024.

На основу члана 29. Закона о општем управном поступку и службене евиденције издаје се

УВЕРЕЊЕ О ПОЛОЖЕНИМ ИСПИТИМА

Неда Бабуцић, име једног родитеља Божа, рођена 13.08.1995. године, Панчево, Република Србија, уписана школске 2021/2022. године на докторске академске студије, школске 2023/2024. године уписана на статус финансирање из буџета, студијски програм Физика, током студија положила је испите из следећих предмета:

Р.бр.	Шифра	Назив предмета	Оцена	ЕСПБ	Фонд часова**	Датум
1.	ДС15ПФ3	Изабрана поглавља примењене физике	10 (десет)	15	I:(8+0+0)	13.06.2022.
2.	ДС15ФРНД1	Рад на докторату 1. део	П.	30	I:(0+0+12) II:(0+0+12)	
3.	ДС15ЈП4	Физика електричних гасних пражњења	10 (десет)	15	I:(8+0+0)	13.06.2022.
4.	ДС15ПФ10	Примена плазме у биологији и медицини	10 (десет)	15	III:(8+0+0)	21.09.2023.
5.	ДС15ЈП3	Дијагностика плазме	10 (десет)	15	III:(8+0+0)	22.09.2023.
6.	ДС15ФРНД2	Рад на докторату 2. део	П.	30	III:(0+0+12) IV:(0+0+12)	
7.	ДС15ФРНД4	Рад на докторату 4. део	П.	15	V:(0+0+20)	
8.	ДС15ФРНД3	Рад на докторату 3. део	П.	15	V:(0+0+20)	

* - еквивалентиран/признат испит.
** - Фонд часова је у формату (предавања+вежбе+остало).

Општи успех: 10,00 (десет и 00/100) , по годинама студија (10,00, 10,00, /).

Овлашћено лице факултета

Publ. Astron. Obs. Belgrade No. 102 (2022), 1 - 4 *Poster*

SELF-MIXING INTERFEROMETRY FOR PLASMA DIAGNOSTICS

Nikola Goleš[1], Neda Babucić[2], Nenad M. Sakan[2] and Milivoje Ivković[2]

[1]*Faculty of Physics, Studentski trg 12, 11001 Belgrade, Serbia*
[2]*Institute of Physics, Pregrevica 118, 11080 Belgrade, Serbia*
E-mail: ivke@ipb.ac.rs

Abstract. The feature of the diode laser that it, besides producing coherent light, has an integrated photodiode, was exploited as the reference branch of interferometers in several applications. A set of continuous laser diodes, emitting at various wavelengths, was initially calibrated by measuring the mechanical motion of an external mirror mounted on a speaker, controlled by a signal generator. Afterwards, the possibility of applying this so-called self-mixing interferometer for the study of low-pressure pulsed discharge and laser-produced plasmas was investigated and assessed.

1. INTRODUCTION

Since they could be stable and coherent light sources, lasers are unavoidable in optical interferometric investigations and sensors. In contrast to most of the other laser systems, a laser diode has very large gain of active medium (Ma et al., 2013), allowing its optical resonator cavity to have an exit mirror of lesser reflection. This unique construction detail reflects both on their multi-mode regime of operation, as well as on the possibility of strongly coupling them with an external optical system. In more complex optical systems, effort is made to avoid this coupling as much as possible, usually using optical isolators, because of its influence on the inverse population in active media and hence on the laser behavior. Here, on the contrary, the coupling effect is used as a method of producing interference, an approach which was studied with gas discharge lasers for plasma electron density measurement (Rasiah, 1994). Experimental, as well as theoretical studies of the effect of strong coupling with the external resonator could be found in a variety of papers for earlier references, see (Salathé, 1979), (Kobayashi et al., 1981). Various applications of this, so called self-mixing effect, could be seen in the PhD thesis (Alexandrova, 2017), for instance.

The optical path of the self-mixing interferometer is shown on Figure 1. It is important to emphasize the fact that the only external component of the system that needed to be adjusted was the external mirror 3. The low reflectivity of the laser diode exit mirror (numbered 2. on Figure 1), which is on the order of 20% up to 50% (in contrast to, for example, a He-Ne laser exit mirror with a reflectivity close to 99%), enables simple coupling of the external mirror, which in turn becomes part of the resonator of the more complex system.

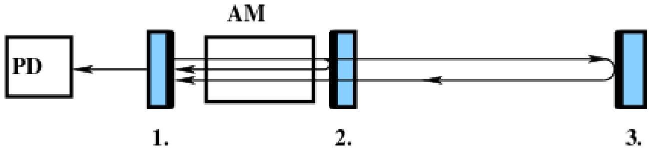

Figure 1: The simplified optical scheme of the self-mixing interferometer: AM – active medium, PD – monitoring photodiode, 1. – back mirror and 2. – front mirror are constructive parts of the laser diode, mirror 3. – external part.

2. EXPERIMENTAL RESULTS

The experiment presented here was a two-phase investigation. First, a study of the applicability and capabilities of the available diodes for the self-mixing effect detection was carried out. An external mirror (denoted by 3. on Figure 1) was mounted on the membrane of a speaker for its position to be mechanically modulated, leading to the detection of an interferometric figure on the monitoring photodiode of the laser diode module. Not all laser diodes showed equal potential for producing the self-mixing effect; the desired effect could only be observed in the case of pure continuous emitting laser diodes that are produced with integrated monitoring photodiodes. In addition, only a limited number of laser diodes was capable of producing coherence high enough to induce a measurable interference effect on the monitoring diode signal. In order to characterize a laser diode, work has been carried out to determine the conditions and limits where it can produce detectable interference (see for instance Figure 2 for the measured signals). In addition, the displacement of the speaker membrane versus time was measured from the interferograms, and the frequency of the movement of the membrane was compared to the one applied from the generator.

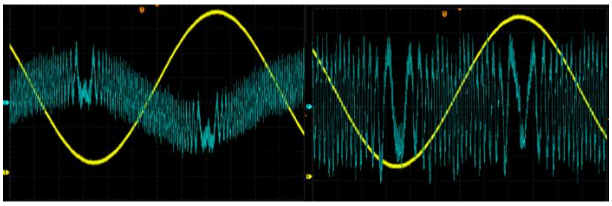

Figure 2: Self-mixing interferograms (thin blue line) for different sound frequencies applied to the speaker (thick yellow line).

The possibility of applying the laser diodes for plasma interferometry was investigated on two experimental setups, the pulsed discharge source described in detail in (Stankov et al., 2018), as well as in laser-induced breakdown spectroscopy (LIBS).

In the first step the interferometer, i.e., the external mirror, is adjusted so that an interference pattern appears in the signal on the photodiode. For easier observation of the effect measured by the interferometer, a large difference in intensity between bright and dark fringes is needed, therefore the alignment of the optical system is adjusted to produce fringes of maximum intensity. A sample interferogram of small mechanical disturbances of a properly adjusted system is shown on Figure 3. Such patterns were obtained for interferometers ranging in length from 15 cm to 50 cm, indicating that the low coherence length of the laser diodes (as compared to gas lasers) does not prevent them from being used in these applications.

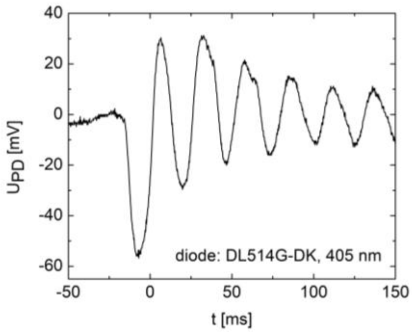

Figure 3: Interferogram of a mechanical disturbance of a properly aligned optical system.

An evaluation of the background plasma glow intensity was performed, to determine whether narrow-band filtering of the combined laser and plasma light is necessary. In the case of the pulsed discharge, the plasma background signal was several orders of magnitude greater that the intensity of the fringes, making the implementation of this diagnostic technique unattainable without additional isolation of the laser signal, which was not attempted as part of this study. However, in the case of LIBS the background glow of the plasma has minimal effect on the output signal, making it possible to test the diagnostic without modifications.

In the case of LIBS, which is suitable for testing the application of the self-mixing interferometer for the diagnostics of a spatially non-homogenous plasma, the axis of the optical setup was positioned 1 mm above a Si target irradiated by a second harmonic (532 nm) Nd:YAG laser beam, with an energy of 150 mJ and a 7 ns pulse duration. The target was positioned inside a T-shaped chamber with a diameter of 38 mm such that the distance from the window to the target was 50 mm, placed on an x-y computer-controlled stage. Due to the small dimensions of the chamber, multiple reflections of the acoustic emission waves off its walls are anticipated, see (Burger et al., 2015). All measurements were performed in air, so the glass windows of the chamber which lie on the optical path were removed. Having in mind that the plasma emission lasts on the order of tens of μs, we can conclude that the signal shown on Figure 4a is integrated, i.e., that the response time of the photodiode is too short for it to be used for plasma electron density diagnostics, even though it exhibits fringing likely arising from the changing N_e. On the other hand, the fringes seen in the millisecond time range (Figure 4b) encourage further study of potential implementation of this diagnostic method for opto-acoustical or simple acoustical investigation of plasma propagation dynamics (Burger et al., 2015), as well as several potentially accurate methods for measuring various dynamic mechanical processes. As a control, a measurement was made with the axis of the setup positioned 3 cm above the target, outside of the plasma volume, where none of the effects on Figure 4 were observed.

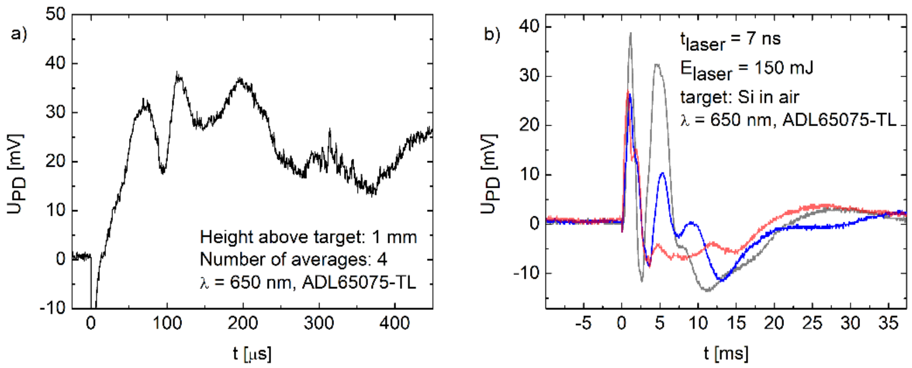

Figure 4: Photodiode signals in the LIBS setup on the a) μs and b) ms timescales.

3. CONCLUSION

The application of the self-mixing method as a means of measuring mechanical movement (disruption of setup and/or controlled movement of external mirror by a frequency generator), and for plasma diagnostics purposes, was proposed and evaluated. The requirements for laser diode characteristics, the necessity of narrow-band optical filtering, as well as the types of pulsed discharges and their characteristics which can be studied by this method (due to the limitations brought about by the response time of the integrated photodiode) were determined.

ACKNOWLEDGEMENTS

This research was funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia, Contract: 451-03-68/2022-14/200024 and supported by the Science Fund of the Republic Serbia, Grant no. 3108/2021.

References

Alexandrova, A. : 2017, *Investigation into laser self-mixing for accelerator applications*, PhD thesis, University of Liverpool.
Burger, M., Nikolić, Z. : 2015, *Spectrochimica Acta Part B*, **110**, 70-78.
Kobayashi, S., Kimura, T. : 1981, *IEEE Journal of Quantum Electronics*, **17**, 681.
Ma, M., et al. : 2013, *Opt. Express*, **21**, 10335.
Rasiah, I. J. : 1994, *Review of Scientific Instruments*, **65**, 1603.
Salathé, R. P. : 1979, *Applied Physics*, **20**, 1.
Stankov, B. D., et al. : 2018, *Review of Scientific Instruments*, **89**, 053108.

Nonthermal Plasma at atmospheric pressure with aerosols: applications in biomedicine

N. Babucić[1], N. Puač[1], N. Škoro[1]
[1]Institute of Physics, University of Belgrade, Pregrevica 118, 11080 Belgrade, Serbia
e-mail: nedab@ipb.ac.rs

Nonthermal plasmas at atmospheric pressure hold great promise for applications in environmental control, biomedicine, and material processing. Even at room temperature, nonthermal plasmas produce energetic and reactive species that can initiate surface modifications at a plasma−surface interface, including thin-film nanoparticle assemblies, in a nondestructive and effective way. [1] The interaction between non-thermal plasmas and liquids has recently encouraged intensive research into fundamental processes and emerging technological applications including plasma medicine, nanomaterials synthesis, and decontamination among others. Stability and control of the plasma in contact with liquid is a key challenge in this highly non-equilibrium state. Recently, water sprays or jets have been injected into the plasma zone to enhance the surface area of the liquid and improve energy efficiency for bacterial inactivation or to enable continuous nanoparticle production. [2] In plasma medicine, plasma activated droplets will also enhance the scope for remote delivery of therapeutic agents to biological tissue and organs. Furthermore, biological responses initiated by cold plasma have been shown to be of use in wound care, specifically for healing chronic wounds. [3] For example, wound healing remains a challenge in diabetic or immune-compromised patients and often requires the use of advanced biologic dressings to treat slow healing ulcers. The emergence of plasma medicine has provided some hope for advancement in wound closure rates for non-healing patients and some positive clinical results have already been observed. In one of the methods, nebulised collagen solution was introduced into a non-thermal plasma discharge and the activated materials were deposited onto a surface to produce a dry, adherent and coagulated biomolecule coating. The plasma device was subsequently used to deliver collagen on to chronic wounds in a compromised animal wound healing model and the healing rate was compared to untreated controls and to wounds that were treated with plasma but without the collagen deposition. [4] In this work we will present construction of atmospheric pressure plasma sources and diagnostic methods with addition of aerosols for treatments of biological samples, bacteria inactivation and decontamination of samples, depending on different plasma setups and operating parameters. The setups were designed to enable precise determination of power delivered to the plasma and the sample. We studied the influence of the input power, as well as aerosol addition, on production of RONS. Understanding and optimizing the production of RONS in the plasma system is important due to their roles in major biological processes, thus fine tuning of the produced species is of great importance.

References

[1] N. Turan, M. Saeidi-Javash, J. Chen, M. Zeng, Y. Zhang, D. B. Go, *Atmospheric Pressure and Ambient Temperature Plasma Jet Sintering of Aerosol Jet Printed Silver Nanoparticles* , ACS Applied Materals and Interfaces, 2021, 13, 47244−47251

[2] P. D. Maguire, C. M. O. Mahony, C. P. Kelsey, A. J. Bingham, E. P. Montgomery, E. D. Bennet, H. E. Potts, D. C. E. Rutherford, D. A. McDowell, D. A. Diver and D. Mariotti, *Controlled microdroplet transport in an atmospheric pressure microplasma* , APPLIED PHYSICS LETTERS 106, 224101, 2015

[3] Ivana Sremački, *Atmospheric Pressure Plasma Coupled with Aerosol for Biomedical Applications* , Department of Applied physics, Ghent, Belgium, 2022

[4] Liam O'Neill , Peter Dobbyn , Mangesh Kulkarni , Abhay Pandit, *1. Wound Healing using Plasma Modified Collagen*, Clinical Plasma Medicine, 2018

P2

Nonthermal Plasma at atmospheric pressure with aerosols:applications in agriculture

Neda Babucić[1], Nikola Škoro[1], Nevena Puač[1]

[1]Institute of Physics, University of Belgrade, Pregrevica 118, 11080 Belgrade, Serbiae-mail: nedab@ipb.ac.rs

Applications of low temperature plasma (LTP) are investigated due to its versatile use in water decontamination, wound treatment by using plasma activated water (PAW) and in agriculture. One of the key challenges in plasma-water interaction is to increase flux of reactive species from the plasma. The addition of micrometer-scale droplets of aerosols immersed in plasma provides a high surface-to-volume ratio, increases the contact area for a given amount of water and potentially enhancing the rates for chemical interaction between plasma in gas phase and liquid. Apart from development of plasma–liquid applications, the plasma–aerosol configuration is also enabling greater scientific insights into a complex problem with potentially thousands of transient and non-equilibrium chemical reactions[1]. In this regard, we made the first step in assembling an experiment where microwave (MW) plasma source is used for aerosol treatment. The setup will enable characterization of the plasma, interaction between the plasma and droplets and characterization of treated water in order to better understand gas-liquid reactions of high chemical reactivity. At the moment, MW plasma is operated using Ar flow from 1-7 slm without addition of aerosols. Optical emission spectroscopy together with images of plasma provided information about the distance from the source where role of reactive species is important. After introducing aerosol into the reactive volume, in this setup we will be able to assess the influence of droplets to the plasma. The main idea is to better understand the interaction of plasmas with aerosols as there is potential of plasma-aerosol interaction at atmospheric pressure in treatment of biology samples. This research will be linked to the topics of WG 3 (tretament of plants with PAW made through aerosol) and WG4 (determination of PAW properties) of PlAgri COST action.[2,3].

Acknowledgements: This work was supported by MSTDI Republic of Serbia grant number 451-03-68/2022-14/200024,and The Science Fund of the Republic of Serbia, grant No. 3114/2021 - Project APPerTAin-BIOM.

Keywords: *Nonthermal plasma, aerosols, MW source, activated water*

References

1. Stancampiano A., Gallingani T., Gherardi M., et al., Applied Sciences, 9(18) (2019), 3861, 10.3390/app9183861
2. Kruszelnicki J., Lietz A., Kushner M., journal of Physics D: Applied Physics, 52 (2019), 355207, 29pp, 10.1088/1361-6463/ab25dc
3. Palumbo F., Lo Porto C., Fracassi F., et al., MDPI coatings, 10(5) (2020), 440, 10.3390/coatings10050440

Nonthermal plasma at atmospheric pressure with aerosols: applications in agriculture and biomedicine

Neda Babucić*, Nevena Puač, Nikola Škoro

Institute of Physics, University of Belgrade, Pregrevica 118, 11080, Belgrade, Serbia

Due to its diverse usage in water purification, wound treatment with plasma-activated water (PAW) and agriculture, low-temperature plasma (LTP) applications are being researched. Increasing the flux of reactive species from the plasma is one of the main difficulties in the interaction between plasma and water. A high surface-to-volume ratio, an increase in the contact area for a given amount of water, and the inclusion of micrometer-scale aerosol droplets immersed in plasma all have the potential to speed up chemical reactions between plasma in the gas phase and liquid. The plasma-aerosol arrangement is enabling deeper scientific understanding of a complicated subject with possibly hundreds of transient and non-equilibrium chemical reactions, in addition to the development of plasma-liquid applications. In this sense, we started putting together an experiment and completed the first phase of setting up using a microwave (MW) plasma source to treat aerosols. To better understand gas-liquid reactions of high chemical reactivity, the setup will allow for the analysis of the plasma, interaction between the plasma and droplets, and characterization of treated water. MW plasma is currently conducted without the addition of aerosols using an Argon flow from 1 to 7 slm. Images of the plasma and optical emission spectroscopy data were used to determine how far away from the source reactive species play a key role. In this configuration, after adding aerosol to the reactive volume, we will be able to evaluate the impact of droplets on the plasma. The major goal is to comprehend plasma-aerosol interactions better because they can be involved in the treatment of biology samples when applied at atmospheric pressure.

Characterization of a plasma system with microwave launcher used for treatment of liquids

N. Škoro[1], N. Babucić[1], K. Kutasi[2], K. Spasić[1] and N. Puač[1]

[1] *Institute of Physics, University of Belgrade, Belgrade, Serbia*
[2] *Wigner Research Centre for Physics, Budapest, Hungary*

In this work we present first steps in characterization of a MW plasma system used for water treatment and PAW creation. We performed spatially resolved optical emission measurements of a MW plasma operating with Ar as working gas and also determined properties of the treated water.

1 Introduciton

In the last decade a new research direction in the scientific field of non-thermal plasmas developed towards treatments of liquid targets. The motivation stems from the fact that plasma-activated liquid (PAL) has versatile applications in plasma medicine and agriculture. PAL contains reactive species with the pH of the solution reduced [1] and consequently have antimicrobial and antibacterial effect with an influence to the cells at different levels. Attaining positive effects in treatments of particular samples using PAL depend on properties which are directly connected to the conditions of the plasma treatment. Thus, for tuning of the PAL properties, among else, different plasma sources should be used [2].

In this regard, this work is a continuation of our plasma activated water (PAW) studies, now involving a microwave (MW) excited plasma. The setup will enable characterization of both the plasma and treated water thus enabling investigation of chemical reactivity properties of PAW.

2 Experimental setup

The plasma is created using an inductively coupled wave launcher and a microwave generator with precise control of an input power. The surface wave launcher is operated using Ar (with flow range 1-7 slm). Plasma is created inside the quartz tube with the plume formed at the tube ending. We analysed recordings of emission originating from different regions of plasma - images that show the spatial structure and optical emission spectra. For determination of reactive nitrogen and oxygen species in PAW colorimetric techniques were used.

3 Results and discussion

Optical measurements showed that the size of the plasma plume protruding depended on operating conditions. These measurements were conducted in order to establish distances from the source where role of reactive species is important which is important for water treatment. The optical spectrum recorded from the active volume of the plasma had lines of several excited species: Ar, O, N_2^+ and OH radical. In Fig. 1 we show change in the line intensity for argon 811 nm line depending on the position along the tube axis for 3 power values. The positions shown in the x-axis are with the respect to the tube ending (x=0) with positive values marking the outside zone.

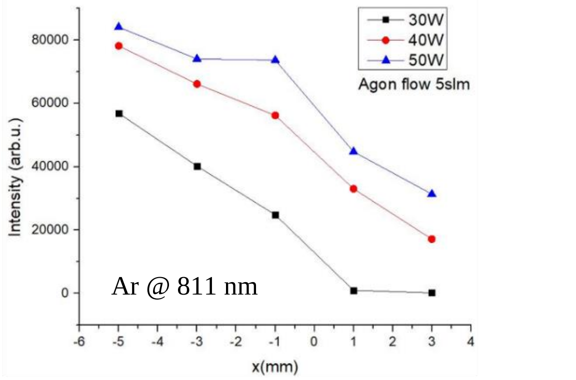

Fig. 1. Spatial change in the Ar 811 nm line intensities along the tube axis for 3 input powers. Ar flow 5 slm.

At a certain position, intensities increase with increasing power. Absence in intensities outside the tube at lower powers is due to reduced length of plasma plume. This type of measurements enables comparison of properties between existing surfatron and the new wave launcher.

Acknowledgment

This work was supported by the Sci. Fund of the RS, no. 7739780 - APPerTAin-BIOM and MSTDI Republic of Serbia grant number 451-03-68/2022-14/200024.

References

[1] Bradu C., Kutasi K., Magureanu M., Puač N., Živković S. Reactive nitrogen species in plasma-activated water: generation, chemistry and application in agriculture. J. Phys. D: Appl. Phys. **53(22)**, 223001 (2020)

[2] Kutasi K., Popović D., Krstulović N., Milošević S. Tuning the composition of plasma-activated water by a surface-wave microwave discharge and a kHz plasma jet. Plasma Sources Sci. Tech. **28(9)**, 095010 (2019)

POST DEADLINE CONTRIBUTION

PB-27

LOW-TEMPERATURE MICROWAVE PLASMA AT ATMOSPHERIC PRESSURE WITH AEROSOLS: TREATMENT OF LIQUID SAMPLES

N. Babucić, N. Škoro and N. Puač

Institute of Physics, University of Belgrade, Belgrade, Serbia

The investigation of low-temperature plasma (LTP) has revealed a wide range of applications, particularly in water decontamination, wound treatment using plasma-activated liquid (PAL), and agricultural practices. PAL contains reactive species and, consequently, has antimicrobial and antibacterial effect influencing the cells at different levels. However, one of the main challenges in plasma-water interaction is enhancing the flux of reactive species from the plasma. To address this challenge, the introduction of micrometer-scale aerosol droplets immersed in plasma has proven promising. This configuration offers a high surface-to-volume ratio, significantly increasing the contact area for water and potentially leading to higher rates of chemical interaction between the plasma in the gas phase and the liquid. [1]
To optimize the properties of PAL, it becomes necessary to employ various plasma sources, one of them being microwave plasma source. In the current phase of the experiment, the plasma operates with an argon flow ranging from 1 – 7 slm, without the addition of aerosols. The inductively-coupled surface-wave launcher facilitates the transfer of energy from the microwave generator to the plasma, allowing for uniform plasma formation within the quartz tube. This configuration offers advantages, such as high efficiency, plasma stability, and reduced risk of electrode contamination, making it a possible preferred choice for generating LTP in research and industrial applications.
Our analysis involved studying recordings of emissions originating from various regions of the plasma, using images to capture the spatial structure and optical emission spectra. To determine the presence of reactive nitrogen and oxygen species in plasma-activated liquid (PAL), colorimetric techniques were employed.
By assembling an experiment utilizing a microwave (MW) plasma source for aerosol treatment, we aim to characterize the plasma, study the interaction between plasma and droplets, and analyze the treated water to gain a better understanding of the high chemical reactivity gas-liquid reactions.

Acknowledgment:
This work was supported by the Sci. Fund of the RS, no. 7739780 - APPerTAin-BIOM and MSTDI Republic of Serbia grant number 451-03-68/2022-14/200024. This article is basedupon work from COST Action PlAgri, CA19110, supported by COST (European Cooperation in Science and Technology).

References:

1. Stancampiano A., Gallingani T., Gherardi M., et al., Applied Sciences, 9(18) (2019), 3861, 10.3390/app9183861c

Characterization of 2.45GHz Surface-Wave Low Temperature Plasma Devices for Cancer Cells Treatments

Neda Babucić[1], Nikola Škoro[1], Nevena Puač[1]

[1] Institute of Physics Belgrade, Serbia

Plasma devices offer a distinctive technological alternative, characterized operational flexibility, low maintenance costs, and the production of high-quality products with minimal by-products. The key merit of Microwave Plasma (MWP) stands out among other discharge types, as it operates without the need for electrodes, also exhibits versatility by functioning across a broad pressure range, spanning from 10^{-5} mbar to 1 bar, with an impressive power-to-plasma efficiency up to 90%. Notably, the high frequencies at which MWP systems operate result in elevated electron densities and temperatures, making MWP an exceptionally reactive medium for chemical reactions and enhancing its performance in various applications. [1]

The study demonstrates that plasma, specifically cold atmospheric plasma (CAP) generated by microwave power,has a selective effect on cancer cells, inducing apoptosis in colorectal (HCT-116) and thyroid (BCPAP) cancer cells while leaving normal cells, such as endothelial cells, unaffected or even promoting their growth. The research focused on determining the optimal plasma power and exposure time for effective ablation of cancer cells. Using argon gas and microwave-generated plasma, the study observed a significant decrease in the viability of cancer cells (HCT-116 and BCPAP) after a 30-second exposure to 100 Watts of microwave power, indicating a potential role of reactive species generated by the plasma in inducing apoptosis in cancer cells(WG5). This approach highlights the efficient energy transfer directly into gas molecules' electron bonds, showcasing the promise of CAP as a targeted and effective method for cancer treatment.[2]

Therefore, Cold Atmospheric Plasma (CAP) has been proven to trigger apoptosis, necrosis, cell detachment, and senescence in tumor cells by disrupting the S phase of cell replication, highlighting its distinctive potential for oncology therapy(WG1). The promising results from both in vivo and in vitro studies suggest that CAP could play a significant role in the future treatment of cancer patients (WG4). Nonetheless, further research is required to fully understand the mechanism of action and optimize its application in cancer treatment.[3]

This work was supported by the Sci. Fund of the RS, no. 7739780 - APPerTAin-BIOM and MSTDI Republic of Serbia grant number 451-03-68/2022-14/200024.

Keywords: *Microwave Plasma, Cancer treatment, Low Temperature Plasma*

References

1. de la Fuente J.F., Kiss A.A., Radoiu M.T., Stefanidis G.D., Journal of Chemical Technology & Biotechnology, 92(10):2495-2505 (2017), DOI: 10.1002/jctb.5205
2. Yoon Y., Ku B., Lee K., Jung Y.J. et al., ANTICANCER RESEARCH 39: 2405-2413 (2019), DOI:10.21873/anticanres.13358
3. Hoffmann C., Carlos Berganza B., Zhang J., Medical Gas Research 3: 21.Published online 2013, DOI: 10.1186/2045-9912-3-21