Conclusions. The influence of sample orientation on FMR spectra, namely value of resonance magnetic field and FMR linewidth, was investigated. It was shown that the magnitude of $4\pi M_{eff}$ depends on film thickness. Angular dependence of FMR linewidth has a strong peak and can be qualitatively explained by intrinsic Gilbert damping. The contribution of two magnon process to linewidth was shown too.

Reference

1. Gurevich A., Melkov G. Magnetic oscillations and waves. // Moscow: Nauka, 1994. – pp. 464. 2. McMichael R.D., Stiles M.D., Chen P.J., Egelhoff W.F., Jr. Ferromagnetic resonance studies of NiO-coupled thin films of Ni80Fe20.// Phys. Rev. B.– 1998. – Vol. 58. – P. 8605–8612. 3. McMichael R.D., Stiles M.D., Chen P.J., Egelhoff W.F., Jr. Ferromagnetic resonance linewidth in thin films coupled to NiO // J. Appl. Phys. – 1998. – Vol. 83. – P. 7037–7045. 4. Mizukami S., Ando Y., Miyazaki T. Effect of spin diffusion on Gilbert damping for a very thin permalloy layer in Cu/permalloy/Cu/Pt films // Phys. Rev. B.– 2002.– Vol. 66. – P. 104413(1–9). 5. Mizukami S., Ando Y., Miyazaki T. The Study on Ferromagnetic Resonance Linewidth for NM/80NiFe/NM (NM=Cu, Ta, Pd and Pt) Films // Japan J. Appl. Phys.– 2001. – Vol. 40. – P. 580–585. 6. Sparks M., Loudon R., Kittel C. Ferromagnetic Relaxation. I. Theory of the Relaxation of the Uniform Precession and the Degenerate Spectrum in Insulators at Low Temperatures // Phys. Rev. – 1961. – Vol. 122.– P. 791–803. 7. Urban R., Woltersdorf G., Heinrich B. Gilbert Damping in Single and Multilayer Ultrathin Films: Role of Interfaces in Nonlocal Spin Dynamics // Phys. Rev. Lett. – 2001.– Vol 87.– P. 217204(1–4). 8. Wigen P. E. Dipole-narrowed inhomogeneously broadened lines in ferromagnetic thin films // Physical Review. – 1964. – Vol. 133, № 6A. – P. 1557–1562. 9. Yuan S.J., Sun L., Sang H., Du J., Zhou S.M. . Interfacial effects on magnetic relaxation in Co/Pt multilayers // Phys. Rev. B. – 2003. – Vol. 68. – P. 134443(1–6).

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КУТОВА ЗАЛЕЖНІСТЬ ФЕРОМАГНІТНОГО РЕЗОНАНСУ В ТОНКИХ ПЛІВКАХ ПЕРМАЛОЮ

Проведено вимірювання феромагнітного резонансу (ФМР) в широкому діапазоні кутів в тонких плівках пермалою товщиною 25, 50, 75 та 100 нм. Кутова залежність ФМР була проаналізована за допомогою рівняння Ландау-Ліфшиця-Гільберта. Із збільшенням товщини плівки, внесок двомагнонного розсіяння у напівширину лінії також збільшується.

Ключові слова: феромагнітний резонанс, пермалой, тонкі плівки, напівширина лінії.

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УГЛОВАЯ ЗАВИСИМОСТЬ ФЕРРОМАГНИТНОГО РЕЗОНАНСА В ТОНКИХ ПЛЕНКАХ ПЕРМАЛЛОЯ

Проведено измерение ферромагнитного резонанса (ФМР) в широком диапазоне углов в тонких пленках пермаллоя толщиной 25, 50, 75и 100 нм. Угловая зависимость ФМР была проанализирована при помощи уравнения Ландау-Лифшица-Гильберта. При увеличении толщины пленки, вклад двухмагнонного рассеяния в полуширину линии также возрастает.

Ключевые слова: ферромагнитный резонанс, пермаллой, тонкие пленки, полуширина линии.

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PECULIARITIES OF PLASMA SOURCES IN PLASMA MEDICINE

This paper has two goals. The first one is the characterization of the plasma source: the plasma power outflux must be known in order to control the conditions under which biology samples are treated. This is especially important in the treatment of living cells, which may not receive high energy doses. Thus, measurements of various plasma parameters relevant for cell treatment have been performed and analyzed. Special attention was given to the acoustic power transmission of the plasma source through internal media. Mechanisms of acoustic transmission in a external medium are discussed.

Key words: plasma source, biology samples, acoustic power transmission.

Introduction. Low temperature non-equilibrium atmospheric pressure plasmas for air and surface cleaning technologies have proven to be robust and safe enough for use indoors. This is partly due to high bactericidal effectiveness of plasmas and partly to their ability to penetrate into narrow and confined spaces, small cracks and microscopic openings.

Such plasmas have been used for a long time for sterilization of medical instruments, bacterial inactivation, blood coagulation, wound healing, oral hygiene, etc. [2]. Recently, with the rapid advances in the multidisciplinary research areas of cold atmospheric-pressure plasmas and plasma health care/medicine, interactions of such low-temperature, non-equilibrium plasmas with a large number of biologic objects, have attracted a major attention [1]. These objects include but are not limited to eukaryotic (mammalian) and prokaryotic (bacterial) cells, viruses, spores, fungi, DNA, lipids, proteins, cell membranes, as well as living human, animal, and plant tissues and organs.

Of particular interest are the plasma interactions with cancerous cells. It has been shown by several groups that the plasma is able to induce death (the programmed death, apoptosis or the necrotic cell rupture) in a number of cancer cell types [3]. This offers exciting prospects for clinical applications of cold atmospheric plasmas for aggressive treatment of malignant cells and ultimately as a viable alternative to the present-day interventional oncology that is capable of cancer resolution without surgery.

Application of plasma treatment in dental restoration procedures may effectively disinfect cavity-causing bacteria; reduce the use of the painful and destructive drilling currently practiced in dental clinics, and consequently save healthy dental tissues. Not only is there the vision of rapid, contact free sterilization, which can access even small pores and microscopic openings, but also one may envisage new possibilities of drug delivery at the molecular level in the dental tissues. New bio-medical effects due to ions and, in the distant future, maybe even new plasma drug developments operating at the cellular level that may act selectively might be expected [6].

Plasma sources. Atmospheric pressure plasmas are very promising tools for biomedical applications and are expected to bring new therapeutic options in surgery, dentistry and dermatology. Each scope of application requires specific, adapted plasma sources. In most cases, basic geometric criteria can be met by choosing a proper discharge type. Locally active plasmas are easily realized with single corona, jet or micro hollow cathode setups whereas large-area treatments may require arrays of these or the use of dielectric barrier discharges. Although physical modes of action like electric current and field, temperature or non-ionizing radiation may have a specific share in the desired biomedical effect, the plasma should not be irritating, if living tissue has to be treated, especially in veterinary and human medicine.

Two approaches are being pursued in the use of non-thermal atmospheric pressure plasmas in medicine. In the first, the plasma is produced remotely, and its afterglow is delivered in a plume to the biological tissue. The sterilizing or therapeutic effects are likely produced by relatively long-lived neutral species and radicals as most of the charged particles do not survive outside the plasma generation region. Usually operated heavily diluted with helium to avoid plasma instabilities, the discharge is doped with a few percent of molecular gases such as O_2. These resulting oxygen-containing active species may play a role via de-excitation and subsequent energy transfer onto the microorganism's surface. Different devices exist for these treatments, from plasma needles [5] to plasma jets [6]. Potential applications of the remote plasma sources are surface sterilization in a more targeted way than is possible with large volume plasmas.

In the second approach, plasmas are generated in direct contact with living tissue. When dielectric barrier discharges (DBDs) are used for this purpose, the plasma device typically contains the powered electrode while the tissue is the counter electrode [4]. The direct method fundamentally differs from the indirect technique in two respects. First, plasmas propagate and touch the biological surface, providing the possibility of charging the surface and delivering energetic ions. The second is the magnitude of the electric field produced at the surface – many orders of magnitude larger in the direct method.

These two general categories of plasma sources (indirect and direct) imply different compositions of the plasma species and activation energy delivered to the surface, particularly when surfaces are rough and nonplanar.

It has been mentioned also, that direct application of the high-voltage (10–40 kV) non-thermal plasma discharges in atmospheric air to treat live animals and people requires a high level of safety precautions. Safety and guaranteed non-damaging regimes are the crucial issues in the plasma medicine. Discharge current should be obviously limited below the values permitted for the treatment of living tissue. That is the way to the essential complication of plasma sources design. At this work the main attention is directed on the I-st plasma sources type.

Generation of gas plasmas is associated with production of energetic particles (e.g. electrons, ions, and photons), chemical reactive species (e.g. free radicals and metastables), and a myriad of transient fields (e.g. heat, shock and acoustic wave, electrostatic and electromagnetic fields). Some of the earlier applications of plasma in medicine relied mainly on the thermal effects of plasma. Heat and high temperature have been exploited in medicine for a long time for the purpose of tissue removal, sterilization, and cauterization (cessation of bleeding).

Plasmas generation is a highly coupled process of complexity and dynamics. For example, through Poisson's equation, a nonuniform or non-neutral spatial distribution of charged particles can set up a local electrostatic field and its role near the electrodes can outweigh the contributions of the externally applied electric field. Photons and some charged particles (e.g. superoxide O_{2-}) are also chemically reactive. In fact, production of different plasma agents and fields is closely coupled and it is usually not possible for one plasma agent to be produced without many other agents also being produced.

When used for treating and processing materials, and biological materials in particular, these plasma agents and electric fields tend to work synergistically in their interaction with, and their effects on, the material that is brought in contact with the gas plasma. The synergistic effect is distinct in the extent and the richness of physiochemical functionalities facilitated and is not usually accessible with other techniques for materials treatment. This is an important aspect of gas plasmas from an application standpoint, and a key reason why gas plasmas have been used.

At present the production and applications of cold plasmas are strongly developed areas of research all over the world. In most cases, cold atmospheric plasmas are produced by electric discharges in inert gases (helium, argon). The voltages used are high alternative or pulsed voltages. There are a few situations where continuous voltages are used (see [2] f.e.) Alternative voltages may have frequencies of tens of kHz or may be radiofrequency or super high frequency voltages. The amplitudes of these voltages are of hundreds-thousands of V.

When high voltage pulses are used for producing cold atmospheric plasma jets, they have amplitudes of tens of kV, durations of tens-hundreds of ns and repetition frequencies of hundreds-thousands of pulses per second (pps). It is well-known that plasma jets produced in pure helium or argon have a low chemical activity, thus being inappropriate for certain applications (e.g. biomedical applications, food/surface treatment applications). Their chemical activation is necessary, this implying that some chemically active species such as: oxygen atoms, OH radicals, nitrogen atoms, NO radicals, nitrogen ions, excited atoms, etc. have been existed in the plasma jet.

The most important chemically active species are oxygen atoms and OH radicals. That is why the introduction of the oxygen and water in the discharge area is of greatest importance to chemical activation. When obtaining chemically active species, the electrons obtained from electric discharges have the essential contribution. The collisions between the energized electrons and the heavy particles result in enhanced levels of excitation, dissociation, and ionization, i.e. enhanced plasma chemistry.

The most important chemical activation reactions are as follows:

- Dissociation of oxygen molecules by electron impact;
- Reactions with water/nitrogen molecules from the air crossed by the plasma jet;
- Penning ionization reaction;
- Charge transfer reaction.

Most of problems, mentioned above, can be solved by ignition of discharge in wet air.

Plasma is a rich source of radicals and other active species. Free radicals have earned a bad name in biology and medicine, because of their capability of causing severe cell damage. Especially the ROS (reactive oxygen species) are well known as evildoers. The ROS family comprises radicals like O, OH and HO_2, peroxide anions O_{2-} and HO_{2-}, ozone and hydrogen peroxide. These species are easily created in ambient air and water (e.g. due to radiation), and they live long enough to reach the cell and attack the organic matter. When the ROS level in body fluids becomes too high, various types of damage occur, known under a common name of oxidative stress. It is believed that oxidative stress bears at least partial responsibility for diseases like arteriosclerosis, cancer and respiratory problems. Moreover, high concentrations of oxygen radicals accelerate ageing of cells and tissues. On the cellular level, several effects leading to cell injury have been identified:

- lipid peroxidation - the oxidation of unsaturated lipids in the cell membrane (damage to the membrane).
- DNA damage – oxidation of DNA bases, leading to breakage of the DNA strand.
- protein oxidation – generally not so harmful, because damaged proteins are efficiently replaced. However, it can temporarily decrease the enzyme activity.

On the other hand, free radicals have various important functions in the body. Small amounts of them are produced by the organism itself. For example, macrophages generate ROS to destroy the invading bacteria, and endothelial cells (inner artery wall) produce nitric oxide (NO) to regulate the artery dilation. It is not completely clear what radical concentrations are indispensable for the proper functioning of the body, and which are dangerous. There must always be a compromise between benefit and damage, but the numbers can vary from individual to individual. Radical production by the body during physical exercise can increase the ROS concentration in blood plasma even up to 0.1 mM, however, physical activity is generally considered wholesome.

In the last decade, atmospheric-pressure room-temperature plasma jets have attracted a lot of attention due to their widespread applications in plasma medicine, nanotechnology, as well as surface and materials processing. Such plasma jet devices generate stable plasma glows in open air rather than in confined discharge gaps. This gives them several advantages in direct treatment of hard, soft, and biological matter with outstanding flexibility in terms of the sizes and areas of the objects to be treated. Most of the applications require room-temperature operation while completely avoiding the glow-to-arc transitions.

To meet these requirements, the atmospheric plasma jets are usually sustained in noble gases. However, this is very challenging for the open-air operation. Moreover, the cross-sections of the plasma jet plumes are typically very small, which make large-area surface processing particularly difficult. One promising way to overcome this shortcoming is by using the plasma jet arrays. However, since the individual plasma plumes generated by the arrayed plasma jets are in most cases independent and do not merge in open air, it is very difficult to achieve uniform plasmas and surface treatment effects. But creation of an unique plasma source is first important step at this process.

The interesting solution of some problems, mentioned above, was reported in [7]. Plasma source consists of two metal electrodes which are separated from each other by a dielectric layer. The openings in the two electrodes are compare with electrodes thickness; length and diameter of plasma channel are compare too. That is a special feature of this source. The high-voltage electrode is completely embedded in the device and powered by a dc power supply.

The outer electrode is grounded for safety considerations. Although both positive and negative high voltages are able to generate and sustain the plasma microjet (PMJ), they primarily used a negative high voltage. They used also compressed air as the working gas at a gas flow rate of approximately 2 slm. The discharge sustaining voltage is in the range of 400–600 V with an operating current in the 20–35 mA range. The power efficiency of the device (defined as power deposited into the discharge relative to the total power drawn from the power supply) is approximately 80%. The temperature of the grounded electrode reaches approximately 100^{o}C at a current of 20 mA and a flow rate of 2 slm.

Optical emission spectroscopy was the main method in plasma parameters determination. It allowed determination of the electron excitation temperature, which also appeared to be approximately constant with power. Electron density and (excitation) temperature are important parameters that condition the plasma activity (excitation, ionization and formation of active radicals). Therefore, one can conclude that atmospheric plasmas operated at higher power have about the same activity and efficiency as the low-power ones. However, an upcoming drawback of increased power is the elevated gas temperature – when the plasma glow expands, cooling by thermal diffusion becomes less efficient and the temperature can reach even a few hundred degrees. Gas temperature of the plasma is one of the most important issues in treatment of heat-sensitive (biological) objects.

Optical emission is a typical gas-phase technique. The data it provides originate from the hottest part of the plasma: the active zone, which yields the highest emission intensity. Therefore it is not surprising that a temperature as high as a few hundreds of degrees is observed. In contrast, mass spectrometry provides downstream information, as it records the density of gas flowing into the mass spectrometer. The corresponding temperatures are lower. Nevertheless, the trends obtained by various methods are quite consistent. It is evident that gas heating occurs only at high power input; this is also coincident with an increase in the plasma glow size. The thermocouple and the temperature strip are not gas-phase methods. In fact, they are more relevant from the point of view of biomedical applications, because they provide the information about the heat that the treated object will suffer. Furthermore, convective cooling is of importance in sustaining a low plasma temperature.

Acoustic phenomena. In book [7] is mentioned non-thermal plasma jet formed by self-running pulsed periodically high-current spark generator. A distinctive feature of this jet is a formation of transient hot plasma clouds (plasma bullet) periodically flying to the target. Pulsed-periodical high-current (around 300 A) spark excited in a small cylindrical volume (typical sizes are 5 mm in a diameter and 5 mm in the length). Plasma jet is not forming due to blowing through the gap by plasma forming gas but because of strong expansion of the gas rapidly heating by spark (due to that operation the jet is accompanied with a loud noise).

Plasma jet (or plasma cloud) flying out the generator is very hot and has high outlet velocity close to sound velocity. High gas temperature in such cloud is transient. Because typical period-to-pulse duration ratio is extremely high (> 10^4), an average gas temperature at the treated area is close to room temperature. The duration of plasma cloud formation, its outlet temperature and composition of active species inside the cloud depend on electric power and amount of energy loaded into the spark by an external circuit. Repetition frequency of jet pulsation is also determined by parameters of external circuit.

It is known that spark occurs at pressures above atmospheric, and, in the intervals of the order near or more than 1 cm. For a breakdown of such gaps requires considerable voltage in the tens of kilovolts. Spark accompanied by a characteristic bang. This sound is a weak shock wave. Its source is the sharp increase in pressure from the intense Joule heat in the spark channel during the passage of a strong discharge current. This phenomenon creates a distinctive audible background in the plasma generators of this type.

But situation at the study [6], mentioned above, is more complicate. According to previous studies of other researches, mentioned in [6], the plasma jet, probably, is discontinuous under the such conditions and represents a series of propagating plasma bullets. In global physic model, this phenomenon resulted from ionization instability and it is very close to striates formation. Nonlinear stage of the instability usually leads either to a contraction or to the stratification of the discharge. In addition, at sufficiently high E/P may form a negative relaxation (second) viscosity reducing total dissipation of sound energy. But gas flow or sound wave with definitely intensity may have an essential influence onto main plasma parameters.

There are not only negative effects from acoustic field in gaseous discharges. It is well-known, that in the gas glow discharge with an acoustic wave along the positive column, the increase in sound intensity causes a decrease in the gas temperature in the middle of the tube and the radial temperature gradient in the plasma gas, according to the acoustic vortex flows generated in the plasma column. This is accompanied by an increase in the diameter of the constricted discharge.

When a discharge in nitrogen transits into constricted state, a reduction in its diameter, increasing the current density on the axis of the discharge tube and, accordingly, increase the temperature of the gas in the plasma is descending. But molecular gases (e.g. nitrogen) have complex connection between inner degrees of freedom (especially vibrational) and such macroscopic parameters as gas temperature and density. If the vibrational relaxation time is much shorter than the period of sound waves, the intensity of the heat caused by this process will be effectively modulated by the sound wave. This can lead to a substantial increase in the initial modulation depth of temperature and density, and undular jump of the sound wave. The presence of molecular oxygen (at least in the form of a 1% impurities) provides an order of magnitude faster relaxation compared with pure nitrogen. Vapour of H_20 (as a 0.1% impurity) gives the same effect.

It is also known that at sufficiently high pressures (p >> 10 Torr), only process the bulk neutralization of charged particles in a gas-discharge plasma, which is an actual competitor to the diffusion process, is the dissociative recombination of electrons and molecular ions. These processes take place at high speed and cause the formation of highly excited atoms of the working gas. Atomic levels have large quantum numbers (n >> 1) have a significant lifetime. Life expectancy t_n depends on the principal quantum number n as $t_n \sim n^4$. If the working gas is present in the oxygen, this process is an additional source of reactive particles.

That is, it can be argued that gas glow discharge with an acoustic wave along the positive column, the increase in sound intensity causes a decrease in the gas temperature in the middle of the tube and the radial temperature gradient in the plasma gas, thanks to the acoustic vortex flows generated in the plasma column. This is accompanied by an increase in the diameter of the constricted discharge. The peculiarities of these phenomena in plasma sources for medical purposes need for further study.

Conclusions. Plasma medicine is a new medical field with first very promising practical studies. However, basic research needs to be done to minimize risk and provide a scientific fundament for medical therapies. Therapeutic application of plasmas at or in the human body is a challenge both for medicine and plasma physics. To achieve selected effects and to avoid potential risks, it is necessary to know how to control composition and densities of reactive plasma components by external operation parameters. Therefore, a profound knowledge on plasma physics and chemistry must be contributed by physical research.

Therapeutic applications required cold, non-thermal plasmas operating at atmospheric pressure. These plasmas are a huge challenge for plasma diagnostics, because usually they are small scale, constricted or filamentary, and transient. Regarding the manageability in everyday medical life, not only atmospheric pressure plasma jets (APPJ) and dielectric barrier discharges (DBD) are of special interest for medical applications. Working in open air atmospheres, complex plasma chemistry must be expected. Considering that, a great deal of effort combining experimental investigation and modeling is necessary to provide the required knowledge on plasma sources for therapeutic applications.

It was previously shown that there is close analogy processes occurring in the discharge plasma in the propagation of sound waves therein, and the gas flow. It is therefore possible to produce a plasma with the required parameters in the aspect of its uniform excitation at high pressures and low temperatures, acoustic radiators of sound waves can be used instead of bulky blow-through devices (they create of a flow in the plasma column) that allow to control the parameters of the gas discharge.

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Reference

1. Dobrynin D., Fridman G., Lelkes P., Barbee K., Cooper M., Ayan H., Brooks A., Shereshevsky A., Balasubramanian M., Zhu P., Freedman B., Friedman G., Fridman A. Mechanisms of Plasma Interaction with Living Tissue // Drexel University Research Day, Philadelphia, USA -2007. 2.Fridman G.,Friedman G.,Gutsol A.,Shekhter A. B.,Vasilets V. N., Fridman A. Applied plasma medicine // Plasma Processes and Polymers - 2008 - Vol. 5. 3. Laroussi M. The biomedical applications of plasma: a brief history of the development of a new field of research // IEEE Transactions of Plasma Science. -2009. -Vol.36. 4. Machala Z., Hensel K., Akishev Yu. (editors) Plasma for Bio-Decontamination Medicine and Food Security. // Springer Publ. – 2012. 5. Nosenko T. Designing plasmas for chronic wound disinfection. // New Journal of Physics - 2009. -Vol. 11. 6. Smitha T., Chaitanya Babu N. Plasma in Dentistry : An update // Indian Journal of Dental Advancements – 2010 - Vol.2(2). 7. Solomenko Ok., Chernyak V.Ya., Lendel V.V. Micro-discharge System features // XX annual Conference NRI NASU. Kyiv – 2013.

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ОСОБЛИВОСТІ ПЛАЗМОВИХ ГЕНЕРАТОРІВ В ПЛАЗМОВІЙ МЕДИЦИНІ

Ця стаття переслідує дві мети. Перша стосується енергетичних характеристик джерел плазми: винесення потужності плазми повинно бути відомим, щоб контролювати умови, при яких обробляють біологічні зразки. Це особливо важливо при лікуванні живих клітин, які не можуть отримувати високі дози енергії. Таким чином, були проаналізовані вимірювання різних параметрів плазми по їх відношенню до обробки клітин. Особливу увагу було приділено випромінюванню акустичної потужності плазми у зовнішні середовища. Обговорюються різні механізми акустичної емісії в середовище.

Ключові слова: генератор плазми, біологічні зразки, акустична емісія.

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ОСОБЕННОСТИ ГЕНЕРАТОРОВ ПЛАЗМЫ В ПЛАЗМЕННОЙ МЕДИЦИНЕ

Эта статья преследует две цели. Первая касается энергетических характеристик источников плазмы: вынос плазменной мощности должен быть известным, чтобы контролировать условия, в которых обрабатываются биологические образцы. Это особенно важно при лечении живых клеток, которые не могут получать большие дозы энергии. Таким образом, были проанализированы измерения разных параметров плазмы по их отношению к обработке клеток. Особое внимание было уделено излучению акустической мощности плазмой во внешнюю среду. Обсуждаются различные механизмы акустической эмиссии в среду.

Ключевые слова: генератор плазмы, биологические образцы, акустическая эмиссия.