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DEVELOPMENT OF PORTABLE DEVICE BASED ON COLD ATMOSPHERIC PLASMA FOR SKIN DISINFECTION AND TREATMENT OF CHRONIC WOUNDS

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A portable easy-to-use device based on cold atmospheric plasma (CAP) for skin disinfection and chronic wound treatment has been developed. Such an alternative treatment method for surface wounds utilizes charged and reactive species produced by a high energy source, such as dielectric barrier discharge (DBD), to eradicate bacteria in the wound. Due to technological innovations that enable more efficient production of CAP and its numerous beneficial properties, there has been great interest in developing portable plasma systems for wound care applications. Ozone, hydrogen peroxide, and UV radiation are sterilizing factors, and the discharge itself promotes blood clotting. The device uses a microprocessor that stabilizes the plasma generating modes and provides timing of the operating mode.

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INTRODUCTION

Non-thermal plasma (CAP) can be generated by exerting electrical energy to a feed gas. Most of the applied energy is in the form of highly energetic electrons [1]. These electrons ionize the feed gas molecules such as argon, helium, oxygen, nitrogen, or a mixture of such gases as found in the ambient air. The ionized gas molecules remain in a low-energetic state due to being heavier than the electrons, thus allowing the overall temperature of the plasma to be relatively low, typically below 40°C. The ionization processes of the feed gas give rise to the emission of electromagnetic radiations of several forms, e.g., ultraviolet (UV), and infrared or heat [3, 4].

The use of plasma treatment of wounds at atmospheric pressure is currently an actively developing area of both scientific research and practical application in medicine. The effect of cold plasma directly on wound tissue is much more effective than drug exposure and ozone therapy itself. The energy of the plasma discharge makes a positive contribution to the elimination of pathogenic agents. The plasma of a dielectric discharge is very non-equilibrium, the average electron temperatures can reach several electron volts, while the gas temperature remains close to the temperature of the dielectric barriers. An important process is the rate of gas ionization.

Barrier discharge is a highly non-equilibrium discharge that occurs rapidly. It has found its greatest application in the generation of ozone from atmospheric oxygen [4-10]. The advantage of barrier discharge is the absence of a destructive effect on the treated object, which is due to the small volumetric energy impact in the discharge due to the limitation of the integral discharge current by the dielectric. In addition, barrier discharge plasma is used to obtain ozone and UV-violet radiation, and currently used for disinfection and healing of wounds. The use of atmospheric pressure electrical discharges allows one to vary the plasma parameters in a wide range and choose the optimal treatment conditions.

Due to the benefits of CAP treatment, several efforts have been conducted toward the commercialization of this technology for wound care, including Terraplasma Plasma Care®, TDK Piezobrush PZ3®, and TPE PlasmaDerm® [11]. Medical personnel often use these systems as point-of-care treatment in clinical settings. Typically, the treatment is applied between 1…3 min once per day for multiple days directly onto the wound bed.

In this research a portable easy-to-use device based on cold atmospheric plasma (CAP) for skin disinfection and chronic wound treatment has been developed.

1. DESIGN OF THE DEVICE AND OPERATION

In this device the discharge in reactor is generated either between two electrodes covered with a dielectric with an air gap between them or one of the electrodes is isolated. The air gap determines the magnitude of the voltage at which a streamer discharge occurs when an alternating current is applied to the electrodes. Nitrogen oxides, ozone, hydrogen peroxide, and UV radiation are formed in the discharge gap. Such components are sterilizing factors, and the discharge itself can promote blood clotting with the following treatment and wound healing. Experiments have shown that for wound healing, a mode with lower power but longer duration is required.

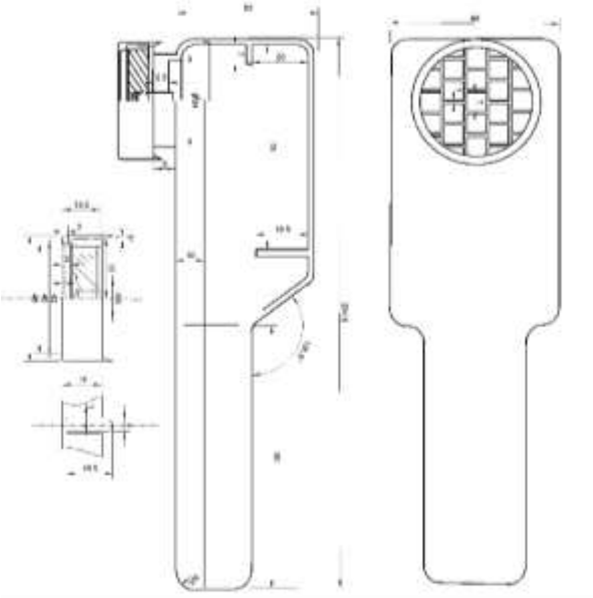

Fig. 1. Design of portable device based on cold plasma for wound healing

The treatment starts by pressing the “START” button and the operation timer is turned on. The device works while the button is pressed, and the timer counts down the set time (Fig. 1). After releasing the “START” button, the time is reset. The microprocessor automatically monitors the discharge voltage and current and maintains them in a stable preset mode.

An important factor is maintaining the distance between the upper electrode and the body of the patient. This distance is maintained with the help of a special nozzle and stabilizes the discharge mode. The nozzle is disposable and must be pre-sterilized before the use. It helps to level the treatment area to a flat state and maintains uniformity of the discharge over the surface.

Fig. 2. Reactor module with a nozzle manufactured by using 3D printer

The device uses a microprocessor that stabilizes the plasma generating modes and provides timing of the operation. The mode of the generator of exciting high-voltage pulses on a high-voltage transformer is short shock pulses that contribute to the oscillatory exponential process at the resonant frequency. The voltage at the discharge gap is about 10 kV, and the frequency of the shock pulses is about 14 kHz. The network power does not exceed 10 W. Thanks to the insulating ceramic gasket, the use of the device is absolutely safe (Fig. 2).

During the sterilization process, the position of the nozzle on the wound should be shifted several times to cover the unsterilized traces of the grid (see Figs. 2, 3).

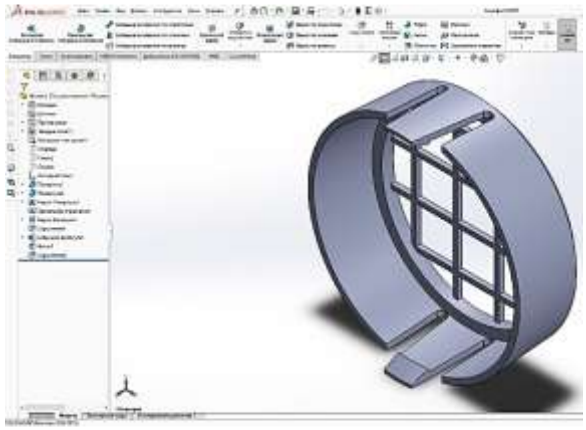

Fig. 3. 3D model of the nozzle

After finishing the procedure, one should remove the nozzle for re-sterilization. Plastic nozzles have a shelf life and are consumables (see Fig.3).

2. RECHARGEBLE BATTERY UNIT

It is well known, that lithium batteries are critical to recharging and can explode in some cases. If a non-single battery is used, there is either a parallel or serial connection in the block. It is advisable to use batteries from the same batch for shared use. They will not differ in parameters, since they are produced in a single technological cycle. When connecting the battery block, this is the most important thing. Circuit plate of the rechargeable power block is shown in Fig. 4.

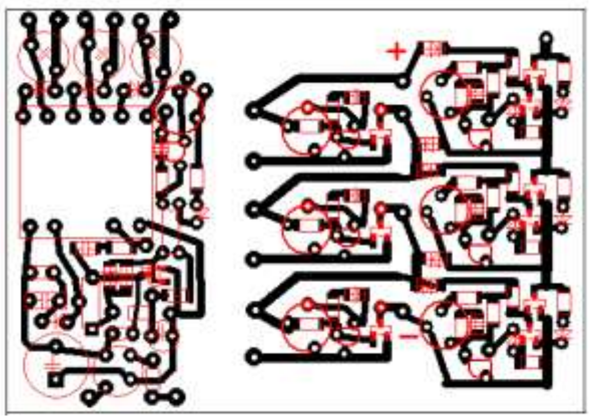

Fig. 4. Circuit plate of the rechargeable power block

With a parallel connection, they accept the same charge, and the discharge may not occur equally. Then, the “weakest” battery, having discharged, may draw energy from the neighboring one. With a serial connection, the charging current is the same, and the voltage accumulation does not grow evenly on the elements of the block. As a result, the battery voltage is different at the nominal total. With subsequent charge-discharge cycles, this difference increases, and the battery quickly goes out due to one unsuitable bank.

It is most advisable to use one mono battery for such devices for most durable operation. In our case, the most cost-effective case is to use a battery of three consecutive elements. In order to minimize risks, we used a complicated charge and discharge scheme – a parallel independent charge of each element and a sequential discharge with control of the potential of each element. If the voltage drops below the critical value in any element, the battery discharge is interrupted and a battery discharge signal is displayed. This protects this element from failure due to over discharge.

The charge cycle allows charging each element independently with full control over overcharge without removing the elements from the case. After the charge cycle is complete, the full charge indicator is displayed. A charger circuit is installed inside the autonomous power supply unit. Such a unit has sockets for power cord and for a cable for link with the device.

The circuit contains a module for charging batteries with three disconnected outputs at the input, simultaneous synchronous charging of three batteries at once. The power of the charging module is 15 W.

When the autonomous power supply unit is operating on the load, a different battery discharge monitoring scheme operates.

To exclude elements of extreme discharge, below 3.2 V, the voltage of each element is monitored. As soon as a situation arises on any of them, it is triggered and the electronic key is broken. Since they are connected in series, the power is broken and the battery discharge indicator is lit, and then the charging cycle must be started again.

3. PIC-MICROCONTROLLER SOFTWARE

Many different development tools have been released for PIC microcontrollers. Microchip Technology has introduced a number of tools that are very effective and widely used in practice.

The developed application software (software) is designed to control and ensure the functioning of a portable device for wound treatment in field conditions. The device controller is implemented taking into account the microprocessor controller and includes software control. The microcontroller was selected as a microcircuit manufactured by Microchip Technology PIC18F2550.

When the device is turned on, the dynamic indication program of a two-digit seven-segment indicator is started, and the previous value is displayed. If it is necessary to change the value, pressing the (+/-) button and holding it for more than 200 ms causes the value to be incremented by one, and if held for more than 1 s, the increment occurs automatically every 0.5 s until the button is released. And if the holding time is less than 200 ms, the value is decremented by one. The software includes application packages for various purposes and user work programs. The software executive modules are embedded in the microcontroller's Flash memory. The program parameters are set by the operator before the therapy cycle begins.

Microchip Technology offers a range of debugging devices for debugging newly developed PIC microcontroller software. Below is a Table with the list of such devices for debugging PIC microcontrollers in the MPLAB X integrated development environment (IDE).

Debug Devices for MPLAB X IDE

Support for Programmers and Debuggers in the MPLAB® Development Ecosystem

Product	New Device Support	MPLAB Debugger/ Programmer Support	SAR Support
PICkit™ 3 In-Circuit Debugger	No	Yes*	No
MPLAB® ICD 3 In-Circuit Debugger	No	Yes*	No
MPLAB REAL ICE™ In-Circuit Emulator	No	Yes	No
MPLAB PM3 Universal Device Programmer	No	Yes	Yes
MPLAB Snap In-Circuit Debugger	Yes	Yes	No
MPLAB PICkit 4 In-Circuit Debugger	Yes	Yes	Yes
MPLAB ICD 4 In-Circuit Debugger	Yes	Yes	Yes**
MPLAB ICE 4 In-Circuit Emulator	Yes	Yes	Yes
MPLAB PICkit 5 In-Circuit Debugger	Yes	Yes	Yes
MPLAB ICD 5 In-Circuit Debugger	Yes	Yes	Yes

*Requires download of patch plug-ins for version 6.10.
**Supported in SAR until replacement inventory runs out.

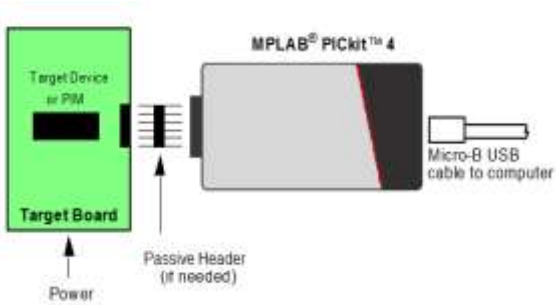

Fig. 5. Functional diagram of connecting a programmable device with an in-circuit programming node (Target Device) to a standard programmer/debugger

In the process of software development, it is convenient to use layouts of electronic components designed for device to check the operation of individual software modules. The use of various demonstration debugging boards greatly facilitates this work (Fig. 5).

The authors had one of such boards at their disposal – PICDEM™ 2 Plus. The using of it for layout and software debugging of the corresponding (supported) microcontrollers is very useful.

Fig. 6. PICDEM™ 2 Plus demo board with mock-ups of used components

A microcontroller of the PIC18F2550 type is used, which is successfully supported by the available demonstration board (Fig. 6).

CONCLUSIONS

A portable easy-to-use device based on cold atmospheric plasma (CAP) for skin disinfection and chronic wound treatment has been developed. Ozone, hydrogen peroxide, and UV radiation are sterilizing factors, and the discharge itself promotes blood clotting. The device uses a microprocessor that stabilizes the plasma generating modes and provides timing of the operating mode.

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РОЗРОБКА ПОРТАТИВНОГО ПРИЛАДУ НА ОСНОВІ ХОЛОДНОЇ АТМОСФЕРНОЇ ПЛАЗМИ ДЛЯ ДЕЗІНФЕКЦІЇ ШКІРИ ТА ЛІКУВАННЯ ХРОНІЧНИХ РАН

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На основі холодної атмосферної плазми (ХАП) розроблено простий у використанні портативний пристрій для дезінфекції шкіри та лікування хронічних ран. Такий альтернативний метод лікування поверхневих ран використовує заряджені частинки плазми та реактивні сполуки, що утворюються в діелектричному бар'єрному розряді (ДБР). Завдяки технологічним інноваціям, які забезпечують більш ефективну генерацію ХАП та її численні корисні властивості, існує великий інтерес до розробки портативних плазмових систем для лікування ран. Озон, перекис водню та УФ-випромінювання є стерилізуючими факторами, а мікророзряди сприяють згортанню крові. У пристрої використовується мікропроцесор, який стабілізує режими генерації плазми та керує процесом.