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A Microelectrode Array for the Micro Dynamic Ion Flow Detection of Plants

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Abstract: In order to meet the demand for detecting different ions of one plant material at the same time in the future, it's of great significance to design a microelectrode array for the micro dynamic ion flow detection of plant. This paper introduces a microelectrode array for the ion flow detection based on Fick's law. The microelectrode array is composed of microelectrode, electrode holder, fixed link of array, array framework, silver thread, wire, signal amplifier, etc. Compared with the previous ion flow signal detection electrode, the microelectrode array is characterized by detecting different ions at the same time with diversified forms and high efficiency. It's found through the detection experiment of nine ions like K^+ and NH_4^+ in the maize root tip that: the microelectrode array can meet the demand fordetecting different ions at the same time. In addition, with the characteristics of high efficiency and small error, it can describe the growth of plants more accurately.

Key words: Ion flow, signal detection, microelectrode array

INTRODUCTION

China is a large agricultural country in which agriculture is the foundation of the national economy. With huge population and relatively small amount of arable land, grain production especially plays a dominant role. However, planting is affected by many factors, so with the rapid development of modern agriculture, it's of profound significance to exploring the dynamic growth laws of plants and thus promoting the development of planting (Wang *et al*., 2011). As a basic unit of organic structure and life activity, cells play a key role in delivering the metabolism information of the organism. The research and analysis with the cell as the object include the physical and chemical means but these means can not obtain the dynamic growth law of plants accurately as they damage the tissue cells and fail to do the long-term monitoring (Mcfadden, 2002). Non-invasive micro measurement technology, which obtains the flow information of ions or molecules inside and outside the membrane of the test samples on the premise of not damaging the test samples, is applied by many experts and scholars at home and abroad in the research experiment. With the microelectrode as the carrier, it gets the molecule/ion concentration and flow velocity of the samples (Kunkel *et al*., 2005; Xu *et al*., 2006). The existing detection methods mostly use single or double electrodes for detection and some use multiple electrodes, which can realize the single electrode ion which can realize the single electrode ion signal detection or the detection of limited electrodes at the same time to some extent but can not meet the demand for detecting multiple ions of one biological material at the same time in the future. In this paper, a microelectrode array device is introduced to detect the ion flow through arranging the micro electrodes into an array. The experiment has high efficiency and can make up for the defect of producing errors due to the repeated replacement of electrodes in the experiment.

DEVICE DESIGN

Composed of glass microelectrode, silver chloride, irrigation fluid, ion exchanger and signal amplifier, as shown in Fig. 1, the existing ion flow signal detection devices can detect the ions of limited amount and categories. However, without the support structure, it can not detect different ions at the same time.

As different ions need to be detected in the actual experiment and the frequent replacement of

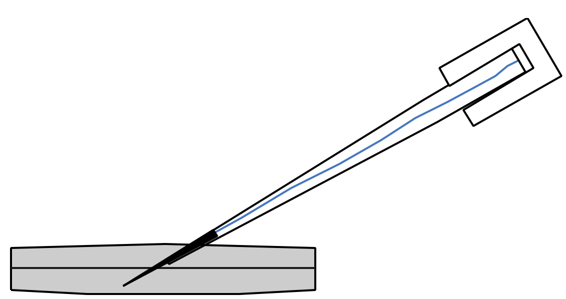

Fig. 1: Diagram of the existing ion flow signal detection device

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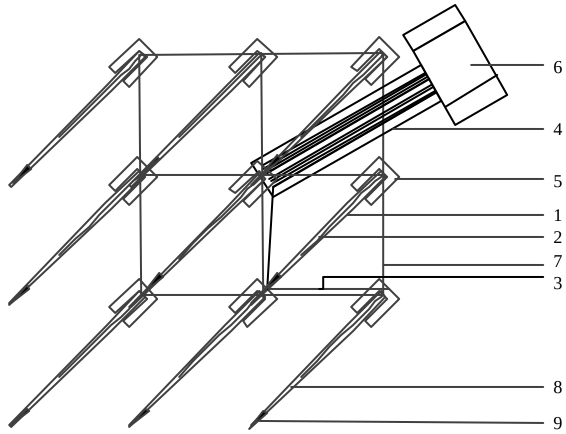

Fig. 2: Diagram of the microelectrode array structure

microelectrodes will cause the low efficiency of the experiment and the instability of the text solution environment, thus affecting the accuracy of the experiment results, how to design a microelectrode array device has profound practical significance. Taking the 3*3 microelectrode array as an example, the array form can be selected according to the specific experimental requirements. Figure 2 shows the ion flow signal detection device designed in the form of the microelectrode array, including Microelectrode 1, Reference Electrode 2 in the Electrode, Wire 3, Fixed Link of Array 4, Electrode Holder5, Signal Amplifier 6 and Array Framework 7. In this device, a lot of microelectrodes can be installed on the array framework at the same time. Through adding different liquid ion exchangers in the microelectrodes, it can detect a variety of ions. Based on the theory of Fick's law, it can obtain the potential difference generated by the ion/molecular motion and thus calculate the ion/molecular concentration and flow velocity of the test solution in the space.

Common microelectrodes contain glass microelectrode, metal microelectrode, carbon microelectrode, optical fiber microelectrode, etc. Glass microelectrode is an electrochemical sensor which measures the activity or concentration of ions in the solution with the membrane potential. In the noninvasive micro measurement technology, when the glass microelectrode contacts with the test solution with the ions to be tested, the membrane potential directly related to the activity of the ion will be generated on the interface between its sensitive membrane and the solution. Therefore, glass microelectrode filling with irrigation fluid and liquid ion exchanger is applied in the design (Ma, 1991). There are many different kinds of reference electrodes in the electrodes, like silver chloride electrode, hydrogen electrode, calomel electrode, mercuric oxide electrode, mercury sulfate electrode, etc. Among them, silver chloride electrode has table potential and good reproducibility, so it's used in the design (He and Wang, 1989). Silver chloride electrode is inserted into the microelectrodes to connect the signal amplifier through the wire. There should be the insulating layer on the wire surface. The microelectrodes are fixed on the array framework by the electrode holder in the holding form. One side of the array holder is connected to the array framework and the other side to the signal amplifier. When detecting the dynamic ion flow signal, multiplexed signals will be delivered to the signal amplifier, so the multiplexed signal amplifier should be selected. In addition, there are several microelectrodes and electrode holders and the array form of the array framework can the changed according to the requirements of the experiment.

Eight and nine in Fig. 2 are irrigation fluid and ion exchanger, respectively. Both of them are selected according to the type of the target ion. Irrigation fluid contains the positive and negative ions ready to be exchanged. Different ions under test should contain the corresponding compounds to be irrigation fluid (Sun *et al.*, 2010). Liquid ion exchanger is a kind of organic liquid with the function of ion exchange.

MICROELECTRODE ARRAY DEVICE TEST

After completing the design of the microelectrode array device, in order to verify whether this design can achieve the desired effect, the ion flow signal collection experiment is done to calculate the absorption of the maize root tip for 9 ions, including K^+, Na^+, Ca^{2+}, NH_4^+, Cl^-, $NO3^-$, H^+, Mg^{2+} and Cd^{2+}. In other words, the 3*3 microelectrode array is adopted to number the glass microelectrodes from 1 to 9 and correspond them to the above ions, respectively. Then, the software developed by LabView to do the human-computer interaction and signal acquisition control with the maize root tip as the target material. KC1 is selected to be the irrigation fluid of $K^+$and Potassium ionophore I-cocktail A as its liquid ion exchanger; NaCl is selected to be the irrigation fluid of $Na^+$and XY-SJ-Na as its liquid ion exchanger; $CaCl_2$ is selected to be the irrigation fluid of $Ca^{2+}$and Potassium ionophore I-cocktail A as its liquid ion exchanger; NH_4Cl is selected to be the irrigation fluid of $NH4^+$and Ammonium ionophore I-cocktail A as its liquid ion exchanger; the irrigation fluids and ion exchangers are not repeated here. Before the dynamic ion signal collection

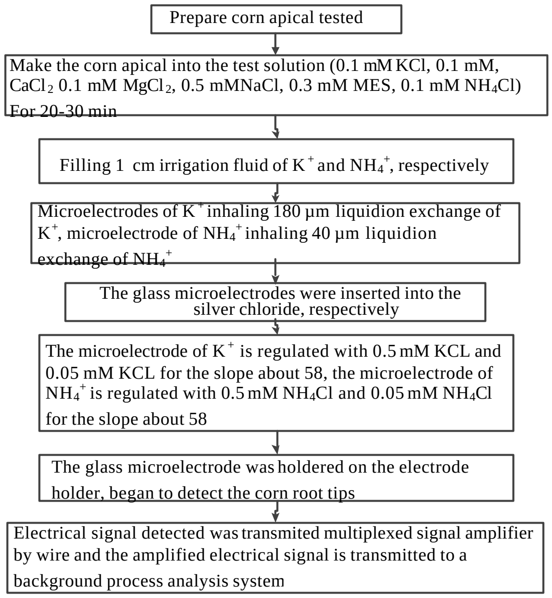

Fig. 3: Dlow chart of the ion flow signal collection experiment

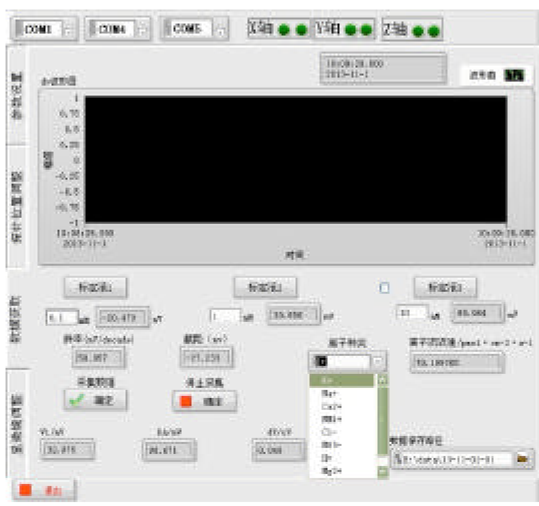

Fig. 4: Ion flow signal collection interaction interface

experiment, the grass microelectrode filled with irrigation fluid and liquid ion exchanger is corrected (Sun *et al*., 2012). The experiment flow chart is shown in Fig. 3 (taking K^+ and $NH4^+$ as the examples).

The ion flow signal collection experiment begins after the correction of all glass microelectrodes. In order to ensure the orderly experimental process and obtain more accurate test data, in the microelectrode array device test, the independently developing portable ion flow signal collection device is taken as the hardware device and the self-designed LabView control software as the human-computer interaction interface. The ion flow signal detection interface is shown in Fig. 4. When the collection begins, 9 ions and the corresponding ion flow velocities can be clearly seen from the drop-down box in the interface. The experimental results show that the electrical signals produced by the ion movement are transformed to the ion flow velocity through the processing of the background analysis system after enlargement, so as to be used for judging the state of the target material. The experiment realizes the demand for detecting a large number of ions of one biological material at the same time.

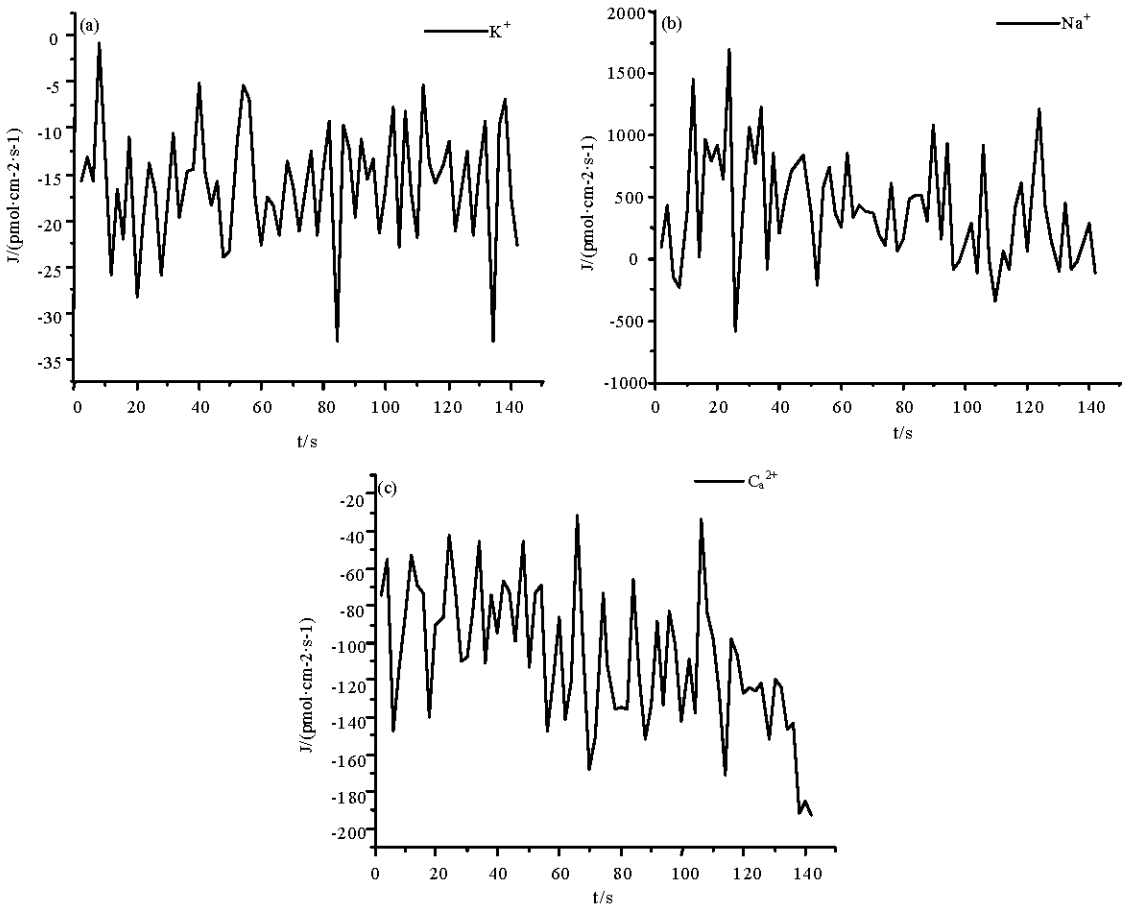

Fig. 5(a-c): Ion flow velocity curve, (a) K^+, (b) Na^+ and (c) Ca^{2+}

According to the requirement of the user, the ion flow velocity data will be stored in Excel for the further research.

To see velocity change of the ion flow collected in the design more intuitively, the ion flow velocities of K^+, Na^+ and $Ca^{2+}$are drawn in curves, as shown in Fig.5. The horizontal axis refers to the time and the vertical axis refers to the ion flow velocity.

CONCLUSION

The microelectrode array designed in this study realizes the demand for detecting the absorption of different ions of one plant through the ion flow velocity detection experiment of 9 ions, so as to accurately reflect the ion activity information in the detection period ion. With this method, it avoids the change of the detection environment and time caused by the replacement of electrodes, saves the time of the experimenter and improves the efficiency. The detection of different ions at the same time can more accurately describe the growth of plants, provide the most intuitive and accurate data for the study of the adverse stress resistance mechanism of plants and help botanists and biologists explore the ion absorption mechanism and life activity law of plants (Lv *et al*., 2013), so it has profound significance in the study of the micro ion.

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