Electrical Modeling of Microelectrode for Deep Brain Stimulation

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Abstract: This study involves the electrical modeling of metal microelectrode, which is used for Deep Brain Stimulation (DBS). DBS involves the implantation of microelectrode inside the brain to target brain tissue. The brain is a delicate portion of our body, it is utmost important that the technique be well tested and accurate. As microelectrode is the main component; its electrical properties are investigated under various conditions. In this paper, metal microelectrode is assumed to be coated with PEDOT material and the property of the whole microelectrode is investigated. The spice electrical model is simulated using SPICE simulator and results are presented. The impedance of microelectrode is calculated with respect to frequency of operation.

***Index Terms* – Microelectrode, Deep Brain Stimulation, SPICE, Electrical modelling. Warburg.**

I. Introduction

The bran is amazing part of our body and it controls the overall functionality of different organs. The brain is made of neurons and there are billions of neurons inside the human brain. It is known that the neurons form a complex structure inside our brain which can be termed as electrical in nature to analyze the functionality of our brain. Normally, Parkinson disease (PD) is associated with movement disorder and affects the quality of life of a person. At some stage, it becomes impossible to treat PD with medication and the health of the patient deteriorates rapidly. It is suggested that PD can be managed by stimulating deep part of the brain (Sub thalamic nucleus/ STN). The idea is to implant a microneedle inside the brain and target STN tissues. The electricity is passed through this microelectrode and stimulates the surrounding tissue. Thus, microelectrode acts as a transducer between the external world and the internal tissue. Not to mention the role of microelectrode is crucial for the successful treatment of the PD. This process is also called as deep brain stimulation (DBS)**[1].**

A deep brain stimulation procedure needs a microelectrode, implantable batteries, programmer and leads. The external power supply provides control electricity through the battery and that passes through the metal microelectrode. Although, the scheme looks simple to implement but the interface between the microelectrode and the brain tissue is non-linear in nature. When the microelectrode is implanted, brain material begins to deposit around the microelectrode. This interface is highly directional and non-linear. It is difficult to accurately predict its properties **[2].**

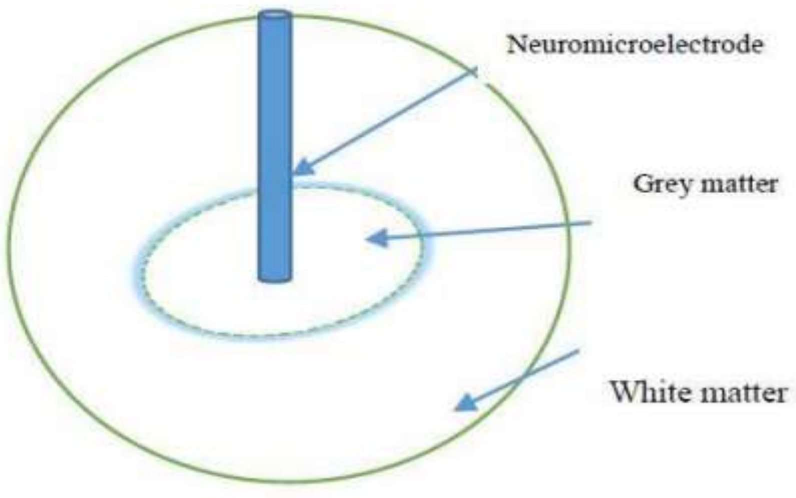

Figure 1. The microelectrode brain tissue interface model

The other trouble is the continuous changing electrical behavior of the interface. A major factor is the variation of the impedance of the interface. The value of interface impedance is crucial, because once the impedance is changed it would change the electrical potential, current also. Again, the initial electrical parameters need to be changed **[3].**

In this paper, we have presented a simplified electrical model of the microelectrode. The model is simulated using SPICE simulator, and our main focus is on the impedance versus frequency behavior. Although, metal electrode is the basis of our research but it suffers from some drawbacks. To overcome those drawbacks, we have assumed a thin coating of biocompatible material on the metal electrode. The choice of material is a separate research area but we have assumed PEDOT as the possible coating material. Once, we have coated material microelectrode, the model of the metal microelectrode should be modified. We have done the same thing and again simulated the microelectrode model for coated materials **[4].**

II. Mode of Microelectrode

In this section we present the methodology and development of modelling for microelectrode. The microelectrode is considered to be cylindrical in shape. A basic assumption is made that the microelectrode exhibits resistive and capacitive properties when implanted inside the brain. The metal of interest is Platinum.

II.I MODELING OF METALLIC MICROEELCTRODE

A basic equivalent model for metallic microelectrode is as shown in the Figure 2**.** It consists of **a** resistor and a capacitor in parallel. The capacitor will allow ac component to pass while resistor component will allow direct current to pass. The behavior of electrode is neither ac nor dc but both due to the interface. The value of the resistor and the capacitor will change according to the material and environment. The resistance is not linear resistance and follows the Ohm's law in conventional term. The expression for Rct is quite complex and depends on many factors such as type of interface and size.

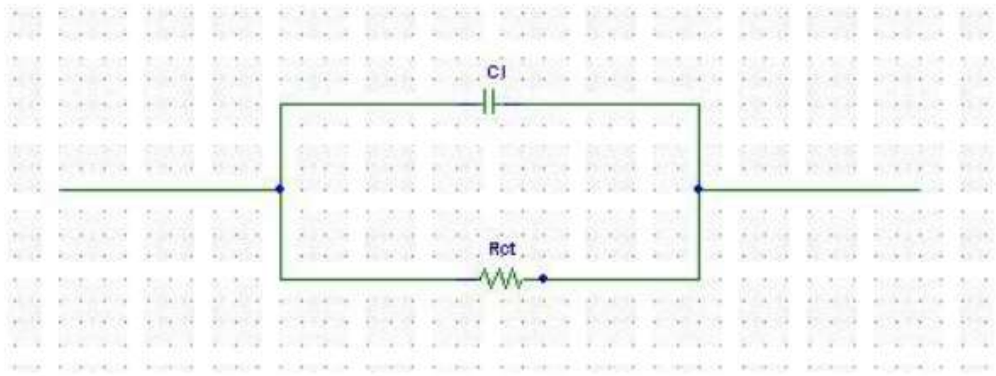

Figure 2. The microelectrode brain tissue interface model

II.1I MODELLING OF METALLIC MICROEELCTRODE (Warburg Element)

In this section the model includes Warburg components also. The major Warburg components included are Rw and Cw . The Warburg model included a parallel RC circuit as shown in the Figure 3. The effective impedance of this combination is inversely proportional to the square root of the frequency. The geometrical area of the microelectrode affects the resistance of the microelectrode. The other parameters of interests are specific density of the microelectrode material, length of the microelectrode, radius of the microelectrode and the type of coating on the microelectrode.

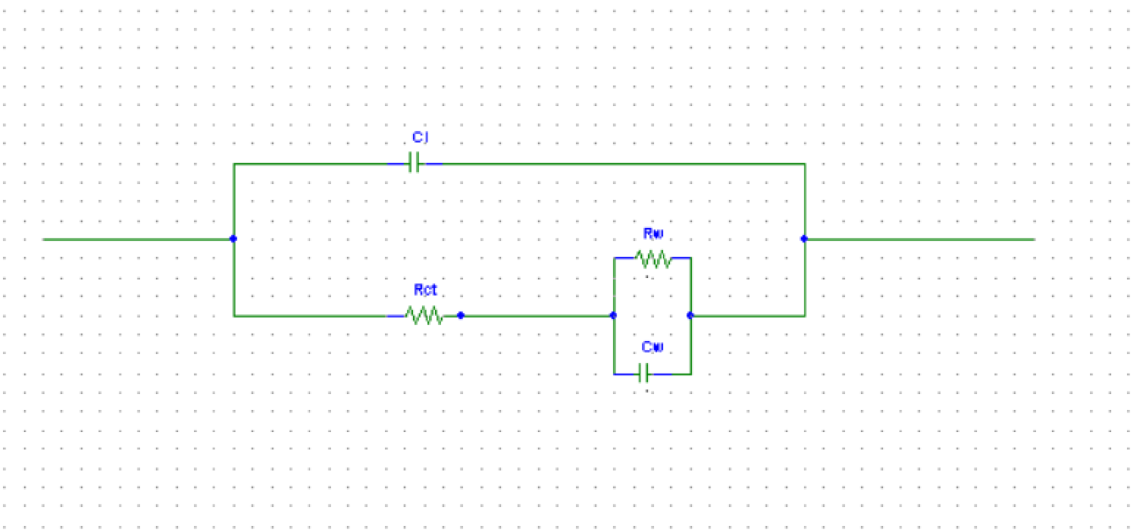

Figure 3. The microelectrode brain tissue interface model (Warburg)

II.1II MODELLING OF METALLIC MICROEELCTRODE (COATING)

As discussed previously, the microelectrode has coating of biocompatible material. The purpose of this coating material is to improve the bio compatibility and transfer of charge to the surrounding brain tissue. There are many materials which are used for this purpose but the equivalent model can be expressed by the model as shown in Figure 4. The coating layer acts a capacitor as shown in the figure. However, the behavior of this capacitor is highly non-linear. The capacitance of this capacitor depends on the type of the material and the surface size.

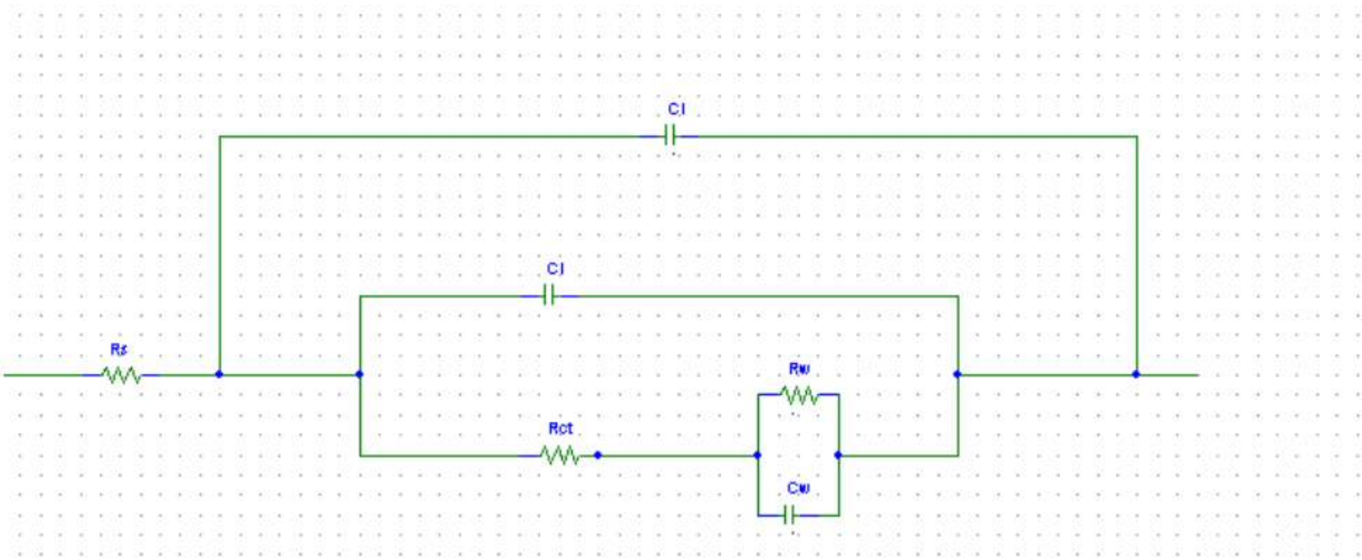

Figure 4. The microelectrode brain tissue interface model (Coating)

III. Results

In this section results are presented and discussed. As described earlier, the impedance of the microelectrode does not remain constant but varies over a period of time. Once, this impedance varies, the resulting current, power dissipation, electric field intensity also varies. It may fail the overall procedure. Apart from others, impedance also depends on the frequency **[7].** We have plotted impedance vs frequency behavior for this paper and presented in figures 5 and 6. We have taken two ranges of frequencies one upto 30kHz and the other beyond that up to 100 kHz. The simulated parameters for the metal microelectrode is as follows

. Rs =5.3kOhms, Cl=322.5pf, Ci= 0.43GOhms, Rct = 51.8kOhms, Cw = 0.9uf and Rw = 23.6kOhms

These simulation model parameters are very close to reality and suitable for modeling. There are different kind of microelectrodes fabricated by various companies and vast parameters are available for simulation

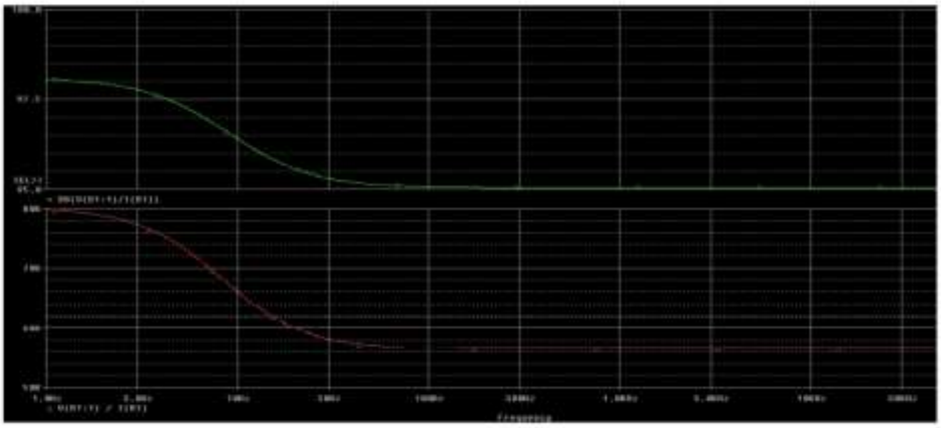

Figure 5. Impedance variation (30 kHz and PEDOT coating microelectrode)

The doctor has availability of a range of frequency to be implemented. Here we take slightly larger frequency range for simulation and can see that the variation of impedance is faster than the earlier low frequency application **[8][9] [10]..**

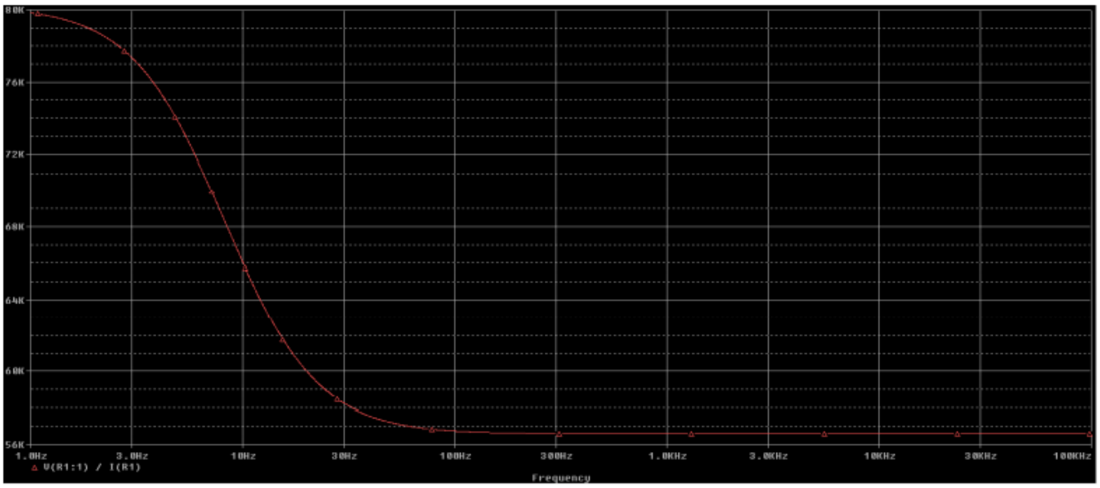

Figure 5. Impedance variation (100 kHz and PEDOT coating microelectrode)

It is clear from the above results that impedance falls as the frequency rises and achieves a standard level after sometime.

IV. Conclusion

In this paper simplified microelectrode model is presented. The metal electrode model is simulated for a practical microelectrode. Since, metal microelectrode has coating of conducting polymer, we have presented a model having conducting polymer. The impedance versus frequency is plotted to demonstrate the behavior of the impedance. The results follow the expected behavior. In future work, more models can be presented for more realistic microelectrodes.

V. Reference

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