Modeling of an Electric-Based Defogging System for Laparoscopy

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Abstract: This paper addresses the common issue of laparoscopic lens fogging (LLF), which hampers the surgeon's visibility and prolongs procedures. The proposed solution involves an advanced electrical defogging system utilizing a thin, conductive transparent material in different configurations such as circular disk and concentric spiral models. These configurations generate consistent heat on the lens surface, minimizing the temperature difference between the lens and the inside of the body. The ideal results were achieved with a 14-circle ITO model, maintaining a constant 310 K (37°C) on the lens surface. Through detailed simulations and modeling, this research demonstrates the effectiveness of the proposed system in maintaining a fog-free lens, ultimately reducing operational delays and enhancing both surgical efficiency and patient safety in laparoscopic procedures.

1 INTRODUCTION

Laparoscopy is a minimally invasive surgical technique that relies heavily on the clarity of the laparoscopic lens to provide surgeons with a clear view of the operative field. It is conducted in response to view internal organs of the body clearly such as checking for polyps in stomach, bleeding, infections, and blockages. The main advantages of this surgery are faster recovery times and less bleeding compared to exploratory laparotomy leading to shorter stay at the hospital. Fogging of the laparoscope lens is a prevalent issue in laparoscopic surgery. It arises from the temperature disparity between the human body and the laparoscope lens, leading to the condensation of water vapor on the cold lens leading to obstructing the view. Multiple methods exist that solve this issue but none has the efficiency to provide both a totally clear image and full safety of the patients with zero side effects. Several anti-fogging approaches have been established and are used in the laparoscopic surgical field. Physical methods include preheating the endoscope camera with 60-80℃ sterile normal saline for 5-10 minutes before insertion. Chemical methods involve applying substances like iodine, anti-fog oil, and alcohol to the lens. Ventilation systems work by maintaining airflow to prevent fogging using CO2 (Calhoun & Redan, 2014). Each method has its advantages and drawbacks. Physical methods can be time-consuming and lack effectiveness but are the cheapest among all methods (Yasui & Kubo, 2022), while chemical methods may leave residues that harm the lens or cause irritation to the patient but can have a very clear image (World Laparoscopy Hospital, 2013). Ventilation systems can cause heart and other health issues to the patient but also provides a clear image (Jiang & Sun, 2019). The aim of this research is to investigate defogging using heating to provide a clearer and more visible image during laparoscopic surgeries with minimal side-effects.

2 METHODOLOGY

The proposed defogging system employs a thin conductive Indium Tin Oxide (ITO) layer to generate heat over the laparoscopic lens, maintaining a constant temperature of 310 K (37°C), which is safe for both human cells and the laparoscopic lens. This

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system prevents fogging by reducing the temperature difference between the body and the lens to near zero, effectively eliminating condensation. The research approach includes defining boundary conditions, implementing electrical and heat transfer models, and conducting simulations to optimize the ITO configuration. COMSOL Multiphysics software is used for modeling the electric-based defogging system. Detailed simulations are conducted to model the temperature distribution and effectiveness of the system, considering various parameters such as film thickness, electrical properties, and heating efficiency. The modeling starts with sketching a 10 mm diameter circle extruded by 1mm as thickness which will represent the lens. Followed by sketching another circle over the lens with approximately 10 mm diameter and later replaced by concentric spiral circles with 10 µm thickness for both which will be the ITO layer. The lens is made of silica glass which withstands up to 1100°C and has many other characteristics that make it suitable for this project. And as for the ITO it was chosen in this project due to its high transparency which peaks around 93% and always above 80% throughout all the visible spectrum as shown in figure 1. while having high electrical and thermal conductivity to be able to generate heat using current by utilizing joule's effect. After everything is in place we begin to assign the electrical properties initializing with having an electric potential of 5V as a constant input which is used in laparoscopy machines and assigning a ground. Each is assigned over 1 of the edges of the ITO circuit as shown in Figure 2 note that both edges indicated by the arrows should be connected to external pads using a wire bonding machine. Additionally, for the circular disk model, two pads should be placed directly on the opposite edges of the disk for voltage and ground interfacing and connections. DC current is used in this simulation which generates more heat than AC current. Heat transfer in solids is used to simulate the heat transfer between the ITO and the lens to finally

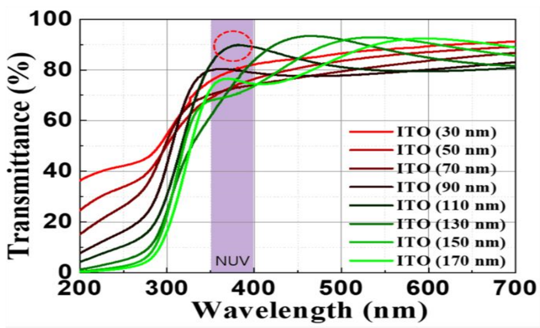

Figure 1: Transmission spectra of a typical ITO thin film (Kim, 2023).

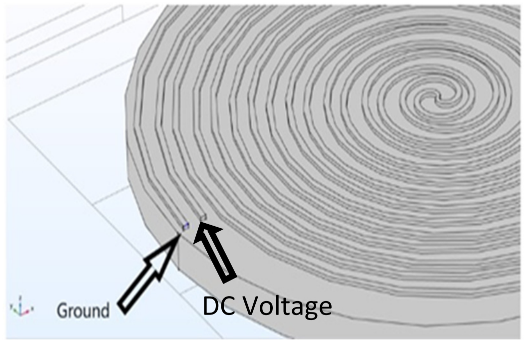

Figure 2: Assignment of electric potential and ground on ITO spiral.

get the results. Design optimization is applied to the concentric circles by increasing the number of circles placed on the lens to get the ideal result which is full distribution of 310K over all the lens which is the human body temperature.

3 RESULTS AND DISCUSSION

The simulations of the first circular configuration will be observed, then using the second spiral configuration numerous results have been derived while optimizing the size of ITO in order to detect variable results reaching the ideal outcome.

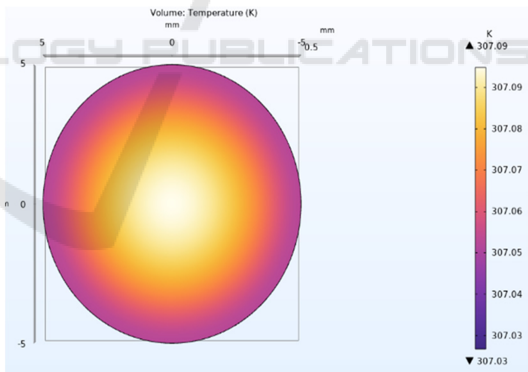

Figure 3: Temperature distribution on the ITO circular full disc.

After observing the above simulation in Figure 3, it is noticeable that the temperature is disturbed in a very inadequate and inefficient manner reaching a max temperature of 307 K only on the center of the lens. Thus, circular disc configuration that is used is no longer applicable to reach the most ideal and desired results needed for this research.

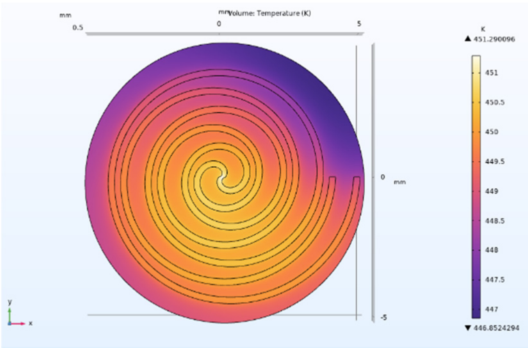

Figure 4: Temperature distribution on the 3 circles ITO spiral.

Figure 4 shows the temperature distribution on the three circle ITO spiral and on the laparoscopic lens respectively. It can be noticed that a high temperature of 451 K is reached only on the middle of the lens and gradually decreasing reaching a minimal value of 447 K on the edges.

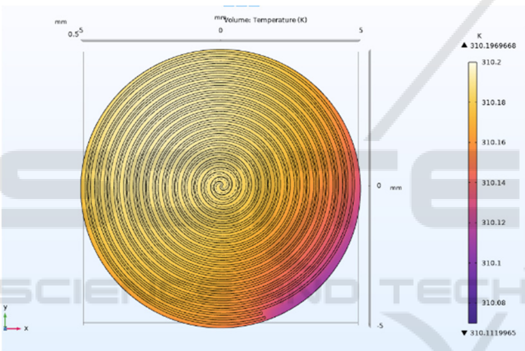

Figure 5: Temperature distribution on the 14 circles ITO spiral.

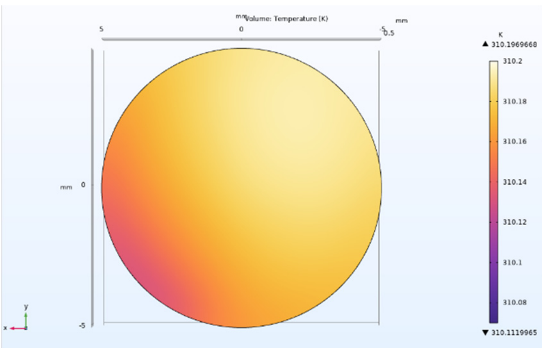

Figure 6: Temperature distribution on the lens of 14 circles ITO model.

Figures 5 and 6 show the ideal temperature distribution on the 14 circles ITO spiral and on the laparoscopic lens respectively. Observing that a desired maximal temperature of 310.2 K is distributed on the whole lens, bear in mind that there is a negligible difference of 0.08 K on the lower edge reaching a value of 310.14 K.

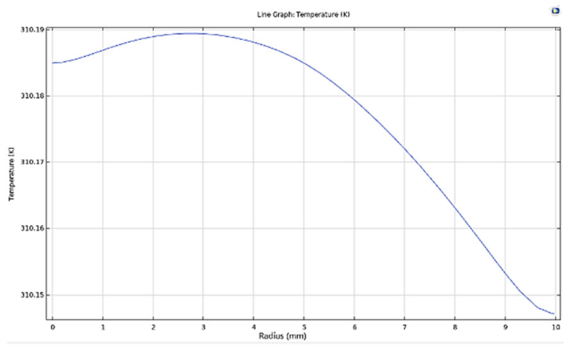

Figure 7: Line graph representing temperature distribution with respect to the radius of the lens.

Figure 7 shows the temperature distribution on the laparoscopic lens in Kelvin while using 14 circles ITO model with respect to the radius of the lens in mm. Noting that it reaches a peak of 310.19 K at a 3 mm radius near to the center of the lens.

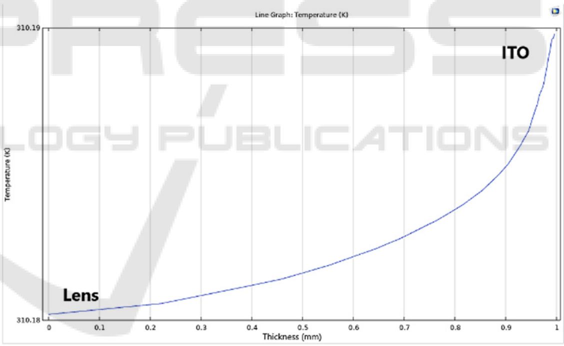

Figure 8: Line graph representing temperature distribution with respect to the thickness of the lens.

Figure 8 shows the temperature distribution on the laparoscopic lens in Kelvin while using 14 circles ITO model with respect to the thickness of the lens in mm. It demonstrates that the temperature is higher on the ITO side, as the heat generated by the ITO, which is embedded within the laparoscope, gradually transfers to the lens.

The first simulation with a circular ITO disc resulted a deficient and inadequate temperature distribution on the lens with a temperature of 307 K. The second configuration that have a spiral form, multiple simulations have been resulted initializing with 3 circles ITO then increasing the number of

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circles to attempt 5, 8, 10 and ending with 14 circles of ITO. At first, 3 circles ITO have shown an insufficient temperature distribution with an extremely high temperature of 451 K. As the number of circles increases, the temperature distribution becomes better and more intensified because less distance is found between turns. In addition, the temperature value is decreasing due to increasing the length of the wire. This can be noticed by comparing the 3-circle configuration with the 14 circles, where the distribution being uniform all over the surface and the temperature dropped from around 450K to 310K. The 14 circles ITO configuration has the ideal temperature reached with a value of 310.2 K representing body temperature that is perfectly and equally distributed on the whole lens where such result is emitted by applying an input voltage of 5 V only. Thus, the 14 circles configuration was the optimized result. In addition, it is important to mention that as the thickness of the laparoscopic lens increases moving toward the ITO, the temperature distribution increases as shown in figure 8 and vice versa moving away from the ITO spiral thus the temperature distribution will keep decreasing till reaching the lens. Finally, after the above analysis and interpretation of the whole results and after reaching our optimal distribution. It is essential to highlight on the main points that specializes our research from any other available techniques that improve vision during laparoscopic surgeries. This research will initially add a special advantage of keeping a clear and vivid image during the whole laparoscopic surgical procedure. Adding, it will maintain a safe and secured heating technique on the lens since it is found on the inside of the laparoscope keeping the patient well and protected without any side effects compared to any other technique.

4 CONCLUSIONS

The development of an electric-based defogging system for laparoscopy represents a significant advancement in surgical technology. This research demonstrates that the proposed system can effectively maintain a clear lens surface, addressing a common issue that hinders laparoscopic surgeries while not harming the patient with any side effects. Future work should focus on the testing of the system under real-life conditions to validate its performance and reliability. Further optimization and experimental validation are necessary to enhance system performance and ensure practical applicability.

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