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ISM Bandı Mikrodalga Ablasyon Sistemi için Mikrodalga Prop Tasarımı

Microwave Probe Design for ISM Band Microwave Ablation Systems

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***Özetçe*— Bu çalışmada mikrodalga ablasyon sisteminin (MDA) bir parçası olup, ISM bandında tümör hücrelerini yüksek güçte ve bölgesel olarak ortadan kaldırılabilecek mikrodalga prop tasarımı önerilmiştir. Aplikatör tasarımı, kompakt ergonomik prob boyutunda RF sistem performans parametrelerini optimize etmek için sayısal olarak çalışılmıştır. MDA sisteminin aplikatör bölümü olan RF probu temel olarak klinik kullanım için tasarlandığından, RF probunun RF performans parametreleri, tümörlü hücre taklit modelleri için incelenmiştir.**

Anahtar Kelimeler—mikrodalga ablasyon, mikrodalga prop, ex vivo ablasyon, koaksiyel anten.

***Abstract*—In this paper, a microwave probe design as a part of microwave ablation (MWA) system is proposed to operate in ISM band for the local annihilation of tumor cells with high microwave power. The applicator design has been numerically studied in order to optimize the RF system performance parameters in compact ergonomic probe size. Because RF probe is to be basically designed for the clinical utilization as an applicator section of MWA system, RF performance parameters of RF probe have been examined for the tumorous cell mimicking models.**

Keywords—microwave ablation, microwave probe, ex vivo ablation, coaxial antenna.

I. INTRODUCTION

Microwave ablation system is a promising technology for cancer treatment [1-3]. Microwave ablation is typically based on the principle that a microwave radiating power through tumor cells at a frequency of 2.45GHz causes the tumorous cells to die with a temperature above 60°C [4-7]. Conventional heating systems are fundamentally based on the heat radiation from an external heat source to the region to be heat treated with the result of the heat penetration not only into the cellular sections but also a whole volume due to unwanted heat spreading [8] as shown in Fig. 1.

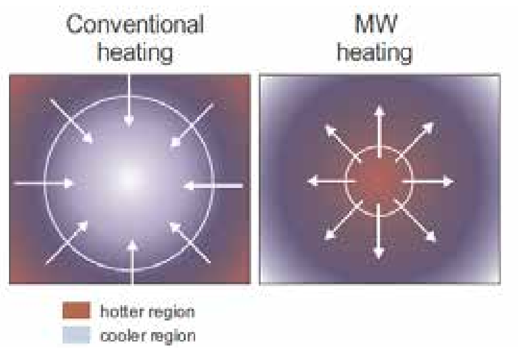

Figure 1: Temperature distribution and direction of heat transfer between conventional and MW heating. In MW heating, energy is uniformly dissipated throughout the material [8].

The penetrating microwave power could damage healthy cells due to the RF ablated cellular portions' being in a form of a non-spherical shape. This is an undesirable situation. These undesired features can be typically eliminated by a high power operated highly directed RF probe design to suppress the unwanted currents in the healthy cells and produce the localized specific absorption rate (SAR) and heating patterns in the tumorous region [7].

In this paper, a microwave probe design to be utilized as an applicator section of a whole MWA system is proposed for the medical applications in ISM band. The proposed microwave probe geometric model and design principle are explained in Section 2. The numerical computation results are presented in Section 3.

II. MICROWAVE PROBE DESIGN

In MWA systems, the tumor cells are destroyed with a highly localized microwave power, which has been generated

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and transmitted by a high power microwave system operating in ISM band. Therefore, the RF probe to be designed has to include specific parts which are not influenced by high temperature which is to be generated by the transmitting high power. In order to design the microwave probe, the numerical calculations are done by CST Microwave Studio. RF performance parameters have been optimized to a reasonable range for the prototype fabrication.

The microwave probe consists of four main parts. These fundamental parts can be termed as field concentrating cone section, dielectric section, transmitting metal shaft and feeding sections as shown in Fig. 2. Concentrating cone, metal shaft and feeding sections are made up of aluminum material whereas the dielectric section is made up of high-temperature endurable castermid material. The electromagnetic (EM) material properties of each section are shown in table1.

In addition to the main parts of the microwave probe, there are some important parameters to design prototype (Figure 2). Screws of each module are respectively; 10mm, 20mm and 7mm for cone, dielectric and feeding.

Table1: EM properties of materials used in the microwave probe sections

Materials	Relative dielectric parameter(ε)	Relative magnetic parameter(µ)
Teflon	2.1	1
Castermid	3.7	1

Because the relative dielectric constant of the tumorous cell is large in the range of 43.3 which is comparatively larger than the materials used in RF probe model, the tumorous cell to be located near the radiating cone section potentially chances the input impedance due to near field coupling in the operation band. Therefore, the numerical computations of the RF probe with /without tumor cells are done in Section 3.

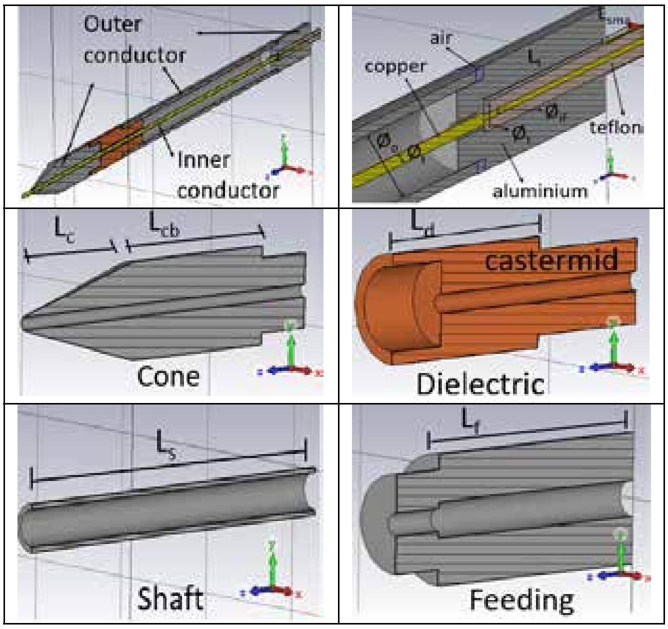

Figure 2: Microwave probe sections

III. NUMERICAL COMPUTATION RESULTS

A dielectric loaded coaxial feeding based RF probe structure is numerically computed in CST Microwave Studio with/without tumor cells. The optimized geometric model parameters providing minimal return loss are determined as a result of numerical computations as shown in figure 3 and figure 4 under the assumption of spherical and homogeneous tumorous cells.

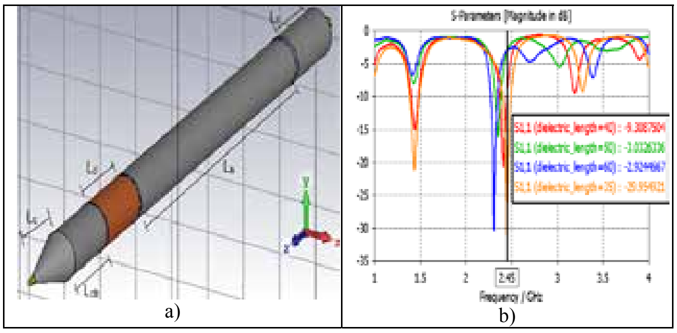

Figure 3: a) Probe without tumor b) S11 results probe without tumor

The length of dielectric section (L_d) is selected to be 35mm to obtain the minimal return loss at 2.45GHz(figure3) However, the return loss value is totally different when the tumorous cells are located near the radiated cone section due to the near field coupling at 2.45 GHz.

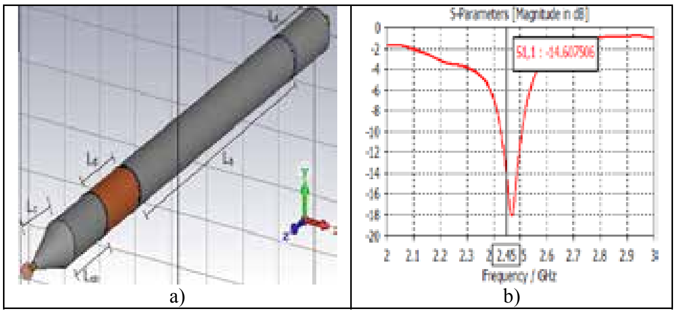

Figure 4: a) Probe with tumor b) S11 result of the probe with tumor

As a result of numerical computations shown in figure 4 dielectric length(L_d) is determined to be 30 mm to get minimal return loss at 2.45GHz for RF probe with tumor cells. The L_d is therefore adjusted by changing the dielectric section with a numerically computed length of 30mm to prevent the whole system from the reflected signal. In addition to the dielectric length arrangements, tumorous cell dimensions are also examined. To observe the effect of tumor cell size on S11 parameter results, four tumor samples with different dimensions up to 10 mm are located near the radiating cone section of the RF probe. However, there is no significant change in the S_{11} parameter as a result of numerical computations (figure5).

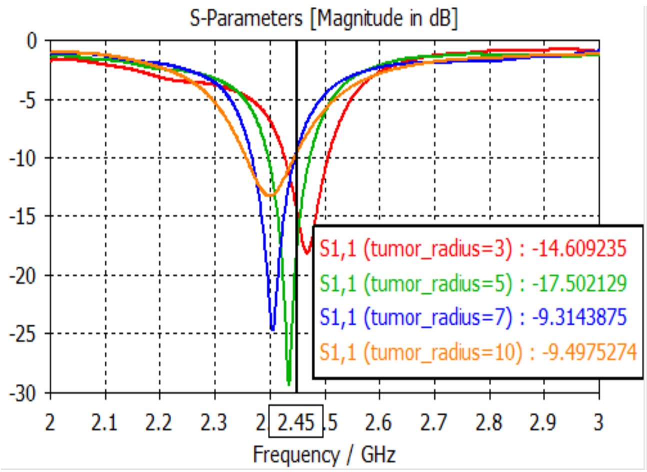

Figure 5: S_{11} parameters of microwave probe dependent on tumor dimensions

As a result of numerical computations shown in figure4 and figure5, the optimized dimensions of RF probe are determined to obtain a minimum return loss (table2).

Table2: Probe dimensions

Parameter	Probe without tumor(mm)	Probe with tumor(mm)
L_c	25	25
L_{cb}	30	30
L_d	35	30
L_s	148	148
$L_f = L_t$	32	32
L_{sma}	10	10
$Ø_o$	13	13
$Ø_i$	2	2
$Ø_{if}$	1	1

After comparing the geometric parameters for the optimal results of both numerical simulations, it has been observed that the only difference in parameters is L_d. Therefore, in order to obtain the minimal return loss of microwave probe, L_d should be respectively 30 mm and 35mm in the numerical computations with and without tumor cells, respectively. Thus, the change in return loss due to the tumor cells can be compensated by adjusting the dielectric length. It is important to bring out an adjustable device in literature.

In addition to the return loss values of microwave probe, it is also important to examine the field pattern. It can be observed that the coaxial line based probe sections guide the microwave power without any kind of field radiation from the outer conductor surfaces (Figure 6). Radiation mechanism starts from the cone section which is quite close to the tumor cells. The microwave power is hence focused on the tumor cells by absorbing the RF power because of high dielectric constant of tumor cells.

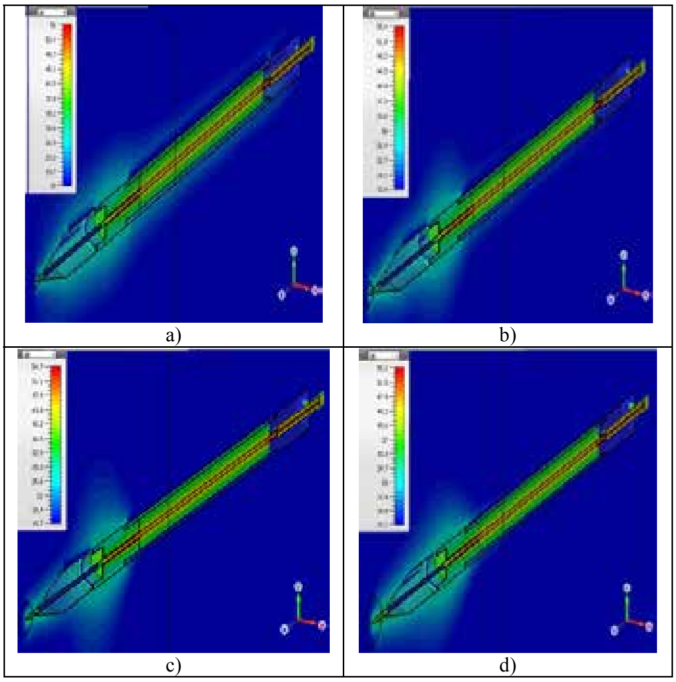

Figure 6: Radiation pattern of microwave probe dependent on tumor dimension a) Radius of tumor=3mm b) Radius of tumor=5mm c) Radius of tumor=7mm d) Radius of tumor=10mm

SAR values on tumor cells which have the radius of 3mm, 5mm, 7mm and10mm are shown in figure7. It is observed that high SAR values have been achieved especially in large tumor dimensions, which results into the localized ablation of even larger tumor cells.

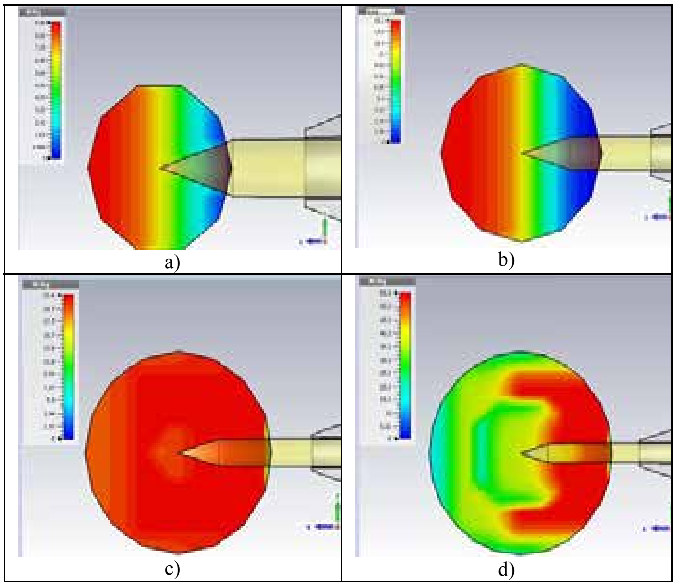

Figure 7: SAR value inside of tumor dependent on tumor dimensions a) Radius of tumor=3mm b) Radius of tumor=5mm c) Radius of tumor=7mm d) Radius of tumor=10mm

IV. CONCLUSION

In this paper, a microwave probe is designed to operate in ISM band for the highly directive localised ablation of tumor cells in high power medical applications. Through the numerical computations on the microwave performance of RF probe with tumor cells, the effectiveness of the afferent system has been examined. Because the RF probe may be affected by the tumorous cells during the surgical operation, the numerical computations with/without tumor cells have been done in addition to the studies in the literature to determine the optimum probe dimension. As a result of numerical computation results, the proposed probe design is also expected to provide significant technological advances in terms of medical engineering applications. On the basis of this study, the RF probe can be conveniently fabricated to bring out an improved medical device in the cancer therapy due to the commercially available materials.

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