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Study on Effects of Non-Ionizing Electromagnetic Radiation on Pollen Grains at Sub-THz Frequencies

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Abstract – **Theoretical investigations have been carried out on the effects of non-ionizing electromagnetic (EM) radiation on pollen grains at sub-THz frequencies. To carry out the investigation, a realistic three dimensional electrical model of pollen colony has been developed and placed between a pair of dipole antennas designed at sub-THz frequencies. The model is simulated using Finite Integral Time (FIT) based commercially available software CST Microwave Studio®. EM energy absorption in pollen grains increases significantly when applied frequency changes from quasi static to resonating modes. Initially, the resonance frequencies have been detected by changes in scattering parameters. Then phase distributions of *E* field and *H* field at the different planes inside the pollen grains have been investigated. Results obtained from the simulations show that significant EM energy is absorbed inside the pollen grains at frequencies close to their electrical resonance frequencies. Results obtained from the thermal simulations show that significant portion of the absorbed EM energy is converted into the thermal energy inside the pollen grains. Controlling the radiated EM energy, rise of temperature inside the pollen grains can be controlled**.

Keywords – **Dipole Antenna, Pollen Colony, Non-ionizing Radiation, Temperature Control.**

I. INTRODUCTION

Pollen grains are powder-like or granular substances that are produced on the anthers of the flower, the male part of the plant. Plants evolved pollen as a reproductive means more than 375 million years ago [1]. Pollination is the process by which pollen is transferred from stamens or male part to stigma or female part of the same flower or of another flower, thereby enabling fertilization and reproduction. Pollination is accompanied by different pollinating agents like wind, insects, birds etc. The genetic diversity of the plants depends on the number and types of pollen grains.

Some wind pollinated flowers are found to be responsible for different allergies and pollen allergy has a remarkable clinical impact all over the world. They produce enormous quantities of light weight pollen that is carried easily by the wind, for miles. The symptoms of pollen allergy are cordially related with the population of airborne pollen grains [2].

A number of studies are available in the literature on the effects of temperature on pollen grains and the pollination process. An accelerating effect of increasing temperature on pollen germination and pollen tube growth kinetics, as well as an increase in the number of pollen tubes that reach the style base is observed in some specific species [3]. Opposite effect of increasing temperature is also observed within some other type of species. At higher temperature, pollen grains may become abnormal and further increase of temperature over the specified range has an adverse effect on the pollination process for this type of species [4-5].

A number of studies are available in the literature on the influence of ionizing and non-ionizing radiation in various species of pollen grains [6-7]. A significant part of the absorbed energy in pollen is converted into the thermal energy and alters the pollination rate. The major drawback of this technique is that the sensitivity of pollen to higher irradiation doses results in abnormality like double fertilization process. The effect of EM fields on structure and pollen grains development shows the reduction of pollen grains number and male sterility [8]. It has been observed that in some anthers, pollen grains are attached together and deformed. It is also observed that prolonged exposures to EM fields of plants may cause different biological effects at the cellular tissue and organ levels. Abnormal meiotic products are observed in some specimens during study of genotoxic effects of EM fields on the plants [9]. Percentages of sterile pollen grains are also significantly higher in test plants. The abnormalities and pollen sterility show a direct correlation with the exposure.

The objective of this study is to investigate the effects of the high frequency EM energy on the pollen grains. Different numerical EM methods play significant role to calculate various radiofrequency (RF) characteristics inside living objects including tissues and cells, because it is not always possible to actually measure the parameters inside the living objects, especially inside micro-organisms. In this work, CST Microwave Studio® has been used to carry out the required numerical simulations for study the effects of non-ionizing EM radiation on pollen grains at sub-THz frequencies [10].

II. POLLEN CELL AND IT'S ELECTROMAGNETIC SIMULATION MODELS

Pollen grains of various species can vary in size in the order of 10 µm – 100 µm [11]. The natural colors of pollen grains are mostly white, cream, yellow or orange. The texture of the cell wall of pollen grain may be either smooth or spiky. Two useful features for identifying pollen are pores and furrows. Pores are holes in the surface of a pollen grain. Furrows are slits or elongated openings on the surface of a pollen grain.

Shapes of typical Grass, Ostrya, Dahlia, Indian plum and Marigold pollen grains are shown in Fig. 1. For this study, marigold pollen grains are considered for analysis. From biological point of view, pollen grains are micro structure of size and consisting of tapetum, cellulose, hemi-cellulose and

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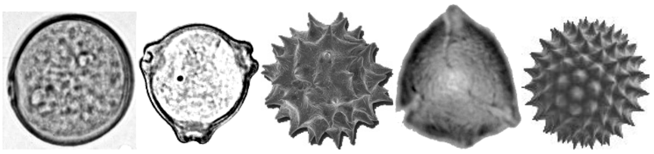
other complex compounds, having different chemical properties [12].



(a) (b) (c) (d) (e)

Fig. 1. Different pollen grain structures: (a) Grass, (b) Ostrya, (c) Dahlia, (d) Indian plum, and (e) Marigold

Shapes of typical Grass, Ostrya, Dahlia, Indian plum and Marigold pollen grains are shown in Fig. 1. For this study, marigold pollen grains are considered for analysis. From biological point of view, pollen grains are micro structure of size and consisting of tapetum, cellulose, hemi-cellulose and other complex compounds, having different chemical properties [12]. But instead of the chemical details of the compounds, the effective dielectric properties of those chemicals, characterized by their permittivity and conductivity values are required in EM modelling of a pollen cell.

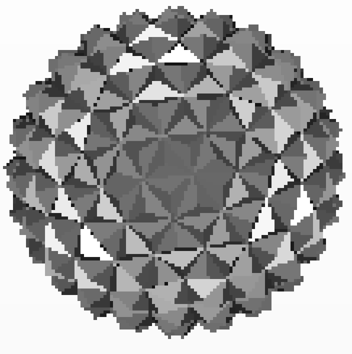


Fig. 2. Model of marigold pollen

A pollen cell like a bacterium cell is prokaryotic in nature and can be modelled as a single or multi-layered structure, where each layer has some specific electrical properties [13-15]. Here in this study, a single layered pollen cell is assumed to be filled with the water. Contribution due to the other cellular components in the value of equivalent dielectric constant is pretty small and has been neglected. The diameter of the core sphere normally varies from 10 µm - 100 µm and here core diameter of 100 µm is considered for analysis. A schematic diagram of the equivalent model of marigold pollen which has been used in the simulation is shown in Fig. 2.

A. Generation of Pollen Colony

Practically single pollen seldom exists in isolated fashion rather multiple numbers of similar type pollen exist together known as pollen colony. Normally in a pollen colony non isolated pollen grains are formed in a periodic fashion with some regular orientations. Here, for the EM simulation, one or two dimensional marigold pollen colony is modelled considering 220 µm distances between two consecutive pollen centres. A two dimensional colony model consists of 6×6 marigold pollen grains are shown in Fig. 3.

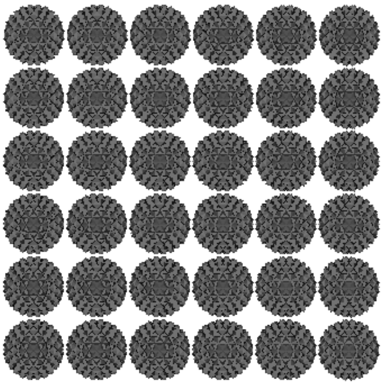


Fig. 3. Pollen colony of 6 × 6 marigold pollen models

B. Construction of Dipole Antenna System

For the investigation of EM energy absorption by a pollen colony, a pair of dipole antennas aligned along X-axis with 0.9 mm lengths (*L*) are placed 40 mm apart in the air media and pollen colony models are placed at the middle as shown in the Fig. 4. Wide band Gaussian pulse is applied in the feed gap of the T_x and the received voltage at R_x is measured to compute S_{11} and S_{21}. The choice of length is in fact an optimization problem. Initially, a pair of dipole antennas of any lengths can be varied to obtain the optimized resonance frequency where the S_{11} and S_{21} vary significantly due to the presence of the pollen grains. Here, for the 0.9 mm length of antenna, the fundamental resonant frequency is observed near 160 GHz where significant variation of S_{11} and S_{21} are obtained in the presence of the pollen grains.

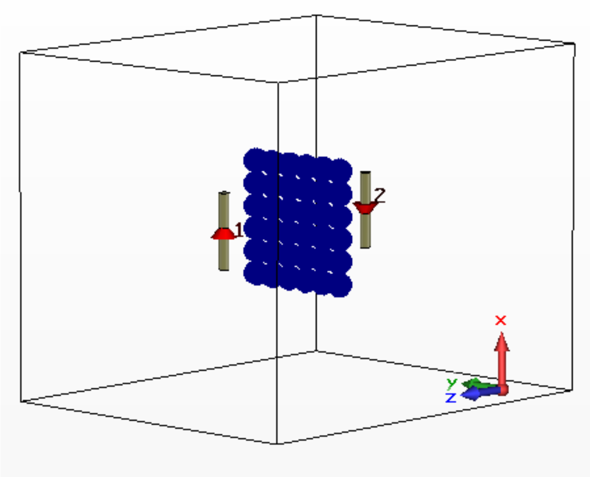


Fig. 4. Simulation Model of pollen grains placed between two dipole antennas

Finally, the effects and variation of EM fields and variation of temperature are observed inside single pollen, a linear array of six pollen grains and the two dimensional 6×6 pollen colony for a single antenna placed 20 mm away from the pollen colony. Usually the pollen grains are shed under dehydrated conditions and their metabolic rate is very low [16]. So, during thermal simulation in CST Microwave Studio®, effects of Basal metabolic rate and effects of fluid perfusion on temperature rise are not considered. All the thermal simulations in this study have been carried out assuming ambient back ground temperature of 30°C.

III. RESULT AND DISCUSSIONS

The variations of S_{11} and S_{21} with frequency for the cases without and with two dimensional 6×6 pollen colony are shown in Fig. 5.

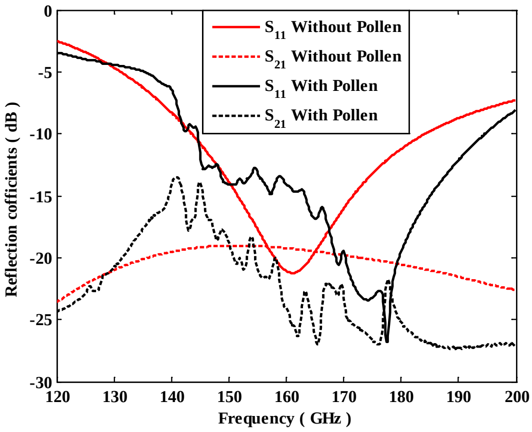
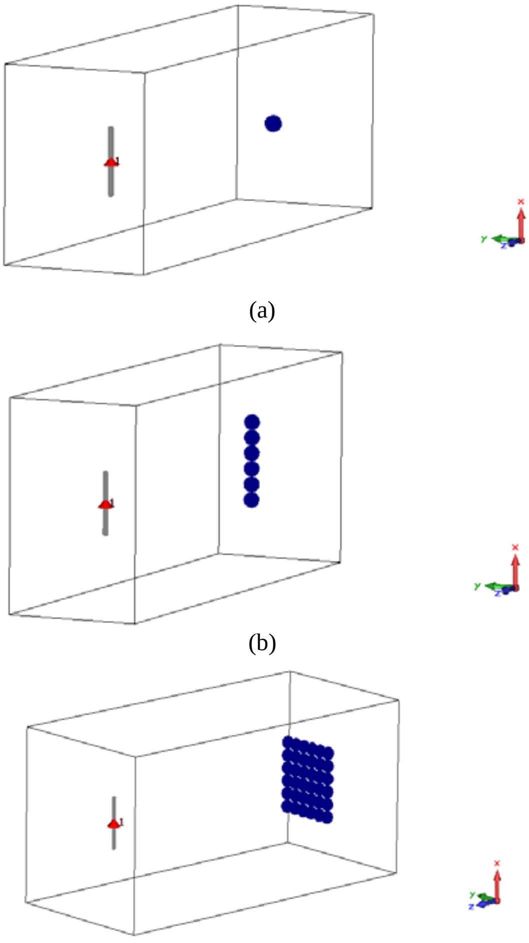


Fig. 5. S-parameters vs. frequency plot for dipole antennas



(a)

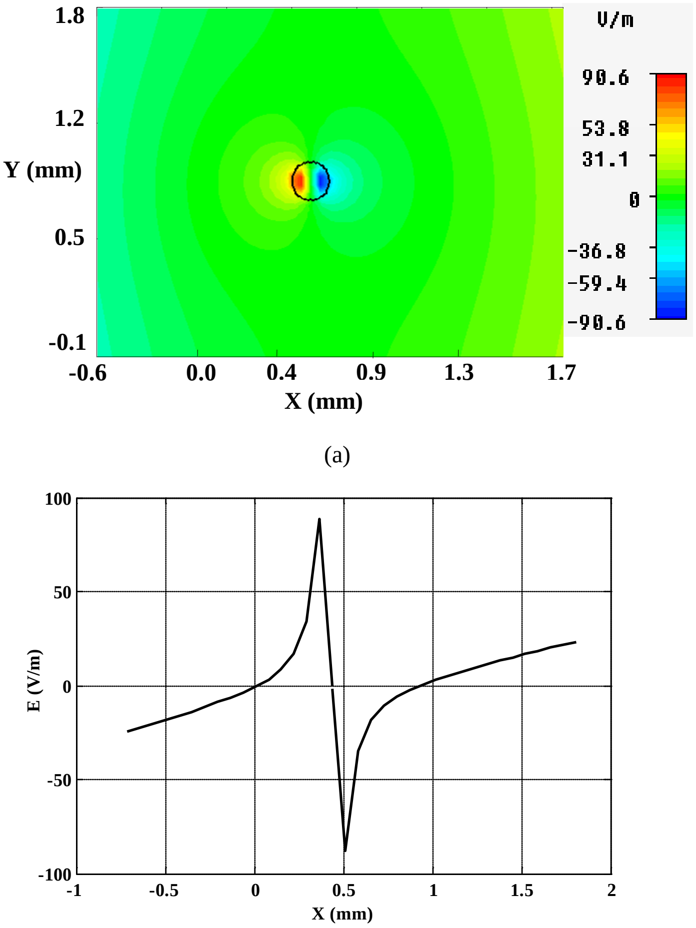
(b)

(c)

Fig. 6. Simulation Model of (a) single pollen, (b) a linear array of six pollen grains and (c) pollen grains (6×6) placed in front of a dipole antenna

From the curve it can be observed that for the cases without pollen grains, minimum S_{11} is at 160 GHz and remains below -10 dB at the frequencies from 143 GHz to 184 GHz. With pollen grains placed at the middle, some fluctuation can be observed in S_{11} and S_{21} plots, which are possibly due to the absorptions of EM energy at various electrical resonance modes for individual cells or their structural combinations in the pollen grains. It is observed that the value of S_{11} is changed from –13 dB to –24 dB at 175 GHz whereas S_{21} is changed from –20 dB to –26 dB. Decrease in both reflected and transmitted powers clearly indicates energy absorption in pollen grains.

To observe the field distribution inside single pollen, a linear array of six pollen grains and the two dimensional 6×6 pollen colony only one antenna is considered as EM source. The antenna is placed 20 mm away from the pollen colony as shown in the Figs. 6 (a-c).



(a)

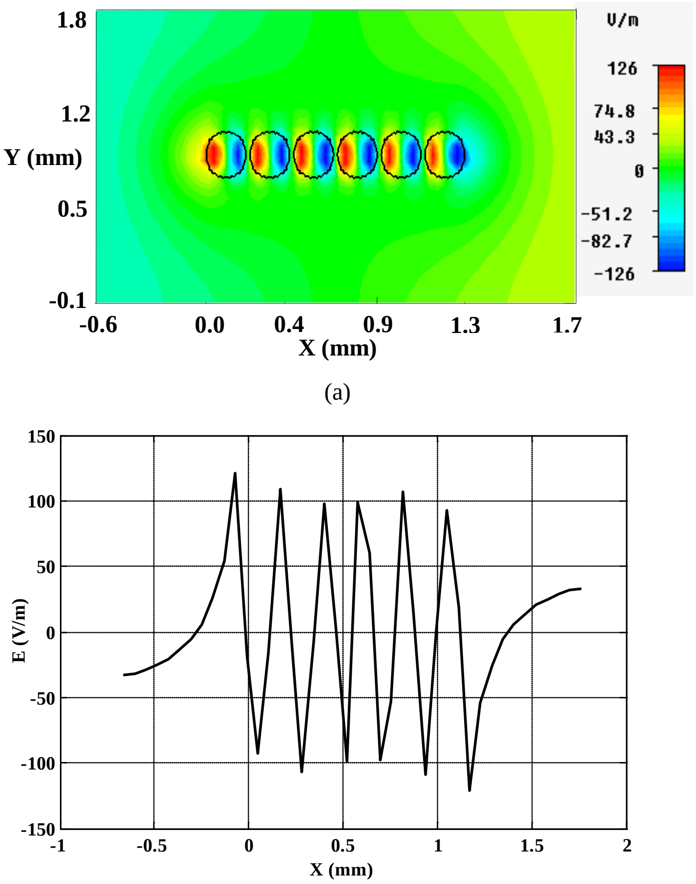
(b)

Fig. 7. *E* field distribution inside the single pollen (a) at XY plane for Z = 0 and (b) along the X-axis

The distributions of *E* field inside single pollen grain parallel to XY plane for Z = 0 at 175 GHz is shown in Fig. 7 (a). Two high concentrate *E* field zones of opposite polarity can be observed inside the pollen near the outer membrane. It is clear from the figure that each pollen individually resonates near this frequency band of study and behaves like electric dipoles. The variation of *E* field through the pollen parallel to

X-axis is shown in Fig. 7 (b). Electric field of ± 90 V/m can be observed at two poles inside the pollen for 1.0 W of radiating power.

The distributions of *E* field inside a linear array of six pollen grains parallel to XY plane and in the X direction for Z = 0 is shown in Fig. 8 (a). It can be observed that like before, two high concentrate spots corresponding to the *E* fields maxima are formed inside each pollen cell. The variation of *E* field through the pollen grains parallel to X-axis is shown in Fig. 8 (b). Higher peak values of *E* field are found inside the far end pollen grains.



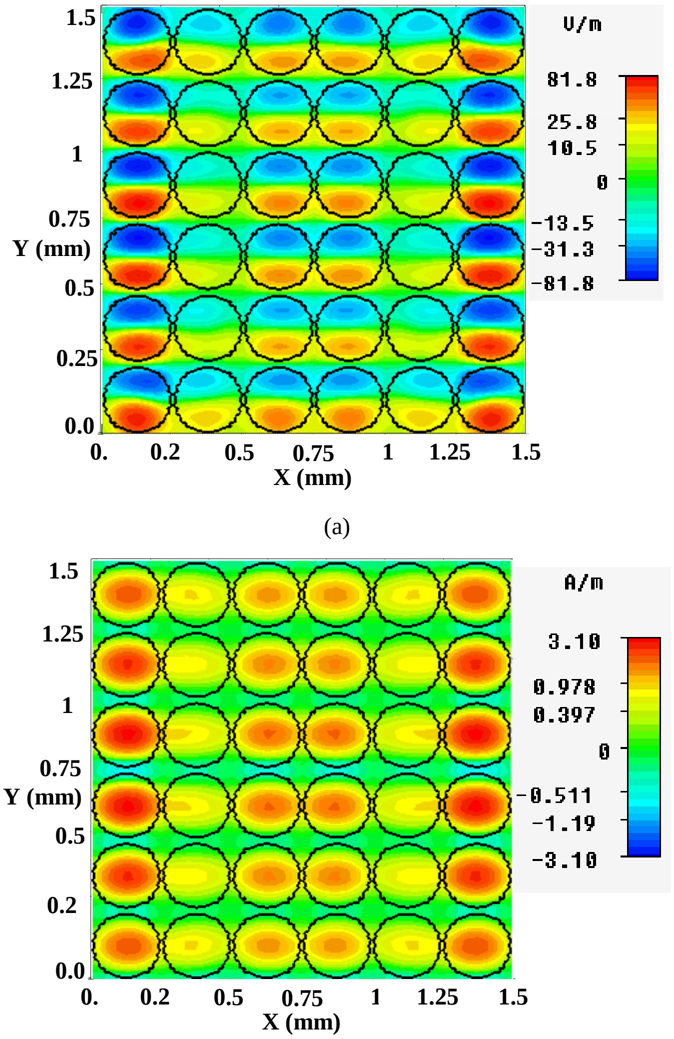
(a)

(b)

Fig. 8. *E* field distribution inside the array of six pollen grains (a) at XY plane for Z = 0 and (b) along the X-axis

The distributions of *E* field and *H* field at the central plane of the whole pollen colony are shown in Fig. 9 (a-b). In Fig. 9 (a), two high concentrate spots consisting of different phases can be observed inside each of the pollen grains. From Fig. 9 (b), it can be observed that a single high concentrate spot is formed inside each pollen which confirms maximum current at centre.

The distributions of *E* field at XZ plane for y = 0.85 mm is shown in Fig. 10. It is seen that the images of *E* field inside the central pollen grains are more prominent compare to others. Higher intensity of field in the central part is possibly due to the Fresnel planar lens effect [17].



(a)

(b)

Fig. 9. (a) *E* field and (b) *H* field distributions inside the pollen grains at XY plane for Z = 0.

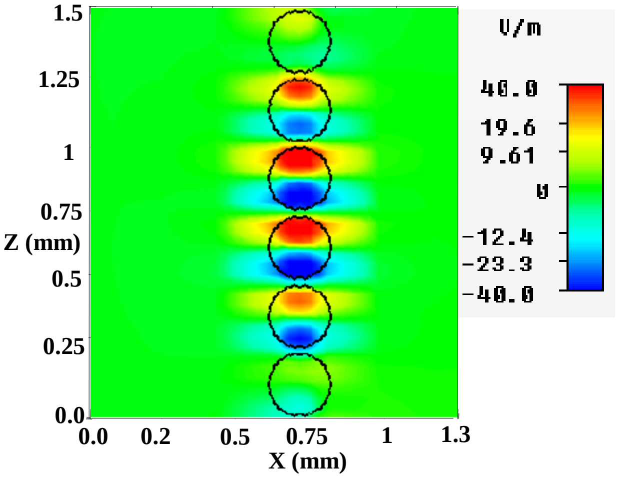


Fig. 10. Distribution of *E* field at XZ plane for y = 0.85 mm

Steady-state temperature distributions inside the pollen grains for 20.0 mm distance between the dipole antenna and the pollen grains with 10.0 W input power at the dipole antenna at 175 GHz is shown in Fig. 11. Planar lens like effects are also present here. It can be observed that higher value of temperature is induced inside the central pollen grains and decreases for those pollen grains which are in the outward direction.

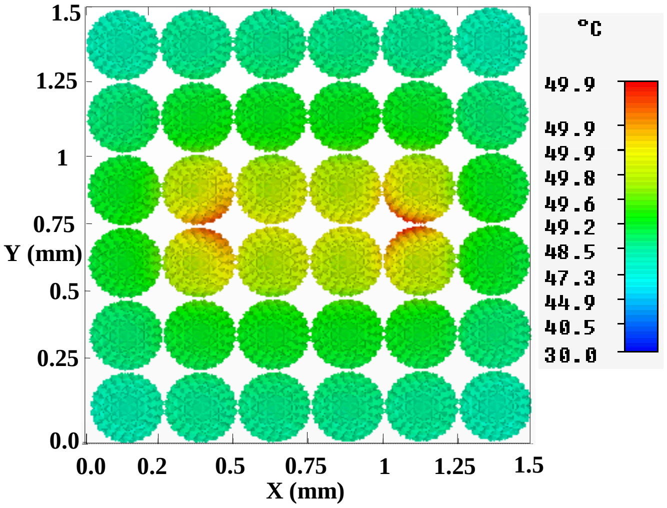


Fig. 11. Steady-state temperature distribution for 10.0 W input power with the dipole antenna distance of 20.0 mm at 175 GHz

Variations of maximum value of steady-state temperatures with different input power level at the dipole antenna for 20.0 mm distance between the dipole antenna and the pollen grains are shown in Fig. 12. With increase of input power level, peak value of steady-state temperature increases and vice versa.

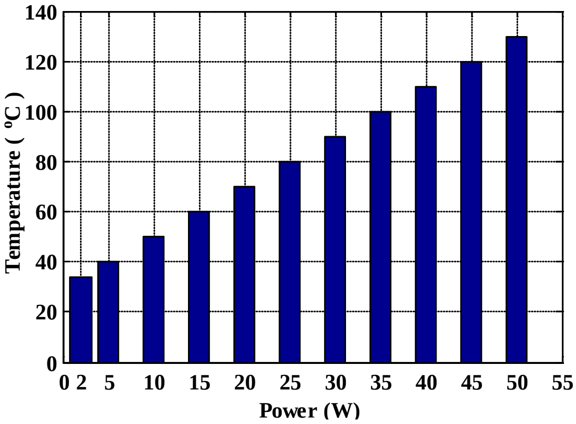


Fig. 12. Maximum value of steady-state temperature vs. input power level at the dipole antenna for distance of 20.0 mm at 175 GHz.

IV. CONCLUSION

In this work, non-ionizing EM energy absorption characteristics of pollen grains have been analyzed using FIT based commercially available software CST Microwave Studio®. The resonance frequencies of pollen grains have been obtained by observing the change in s-parameters of a trans-receiving antenna system. Due to the significant absorptions of EM energy in the pollen colony, abrupt changes are observed in the scattering parameters for a trans-receiving dipole antenna system operating at sub-THz frequencies. At some frequencies, decrease in both reflected and transmitted powers is observed which clearly indicates energy absorption in the pollen colony. The distributions of *E* field and *H* field at the different planes near the resonance frequency have been studied. Two *E* field spots of opposite polarity are observed inside the individual pollen grains which confirm electrical resonance. It has also been observed that a single spot is formed inside the pollen grains due to the maximum current at the central part of the pollen. Analysis of field distribution inside a planar colony indicates to possible planar lens effects. This study also includes the effects of variations of input power level of EM radiation source. It is observed that, with increase of input power level, peak value of steady-state temperature increases and vice versa. These results indicate that the temperature of a particular type of pollen can be changed selectively in order to change or control the pollination rate.

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