A study of Some Inherent Causes for Non-Uniform Microwave Heating

Y. F. Tsai,[1] L. R. Barnett[2], H. H. Teng[2], C. C. Ko,[1] and K. R. Chu[2,3]

[1]Department of Entomology, National Taiwan University, Taipei 106

[2]Department of Physics, National Taiwan University, Taipei 106

[3]krchu@yahoo.com.tw

Radio frequency (RF) and microwave heating of dielectric objects is often susceptible to an excessive temperature spread due to uneven energy deposition. The exposure to a non-uniform field is a well-recognized and extensively-studied cause for this difficulty encountered in numerous applications. There are, however, some other causes, which are inherent in nature in that they persist even in a perfectly uniform field.

Of these causes, somewhat less obvious is the polarization-charge shielding effect. Exposed to the wave electric field **($\mathbf{E}_0$)**, molecular charges in a dielectric object are polarized along $\mathbf{E}_0$ to partially shield $\mathbf{E}_0$. As a result, the object's interior electric field can be much smaller than E_0. This is a well-known "plasma effect" in dielectrics. However, until recently, there has been little discussion in literature that such an effect can result in significant orientation- and shape-sensitive RF/microwave heating rates (Fig. 1), and hence a very large temperature spread after the heating[1,2].

On the other hand, in 1989, the Montreal Protocol stipulates a gradual phase-out of some of the most effective pesticides, such as methyl bromide. This has led to accelerated research on non-chemical insect and bacteria, control, including RF and microwave treatments of a great variety of farm products (stored grains, beans, nuts, fruits, etc.). Despite impressive progresses made so far, non-uniform heating and the resultant temperature spread remain a major hurdle. This suggests the need for a deeper physics understanding of these difficulties.

On such a background, here we present a theoretical and experimental investigation on how the heating rate can be affected by the polarization-charge shielding effect, as well as a quantitative demonstration of the temperature spread caused by it, with rice grains as samples.

Experiments are conducted in an applicator[3], in which samples are irradiated by a 24 GHz microwave. High radiation uniformity (~99%) and polarization control allow a quantitative examination of each inherent cause. Their individual and collective effects are found to be highly significant. In particular, polarization-charge shielding alone can result in a temperature spread of ~18.2% for the samples examined, which is far greater than other causes. Physical interpretations are given and an effective method for its mitigation is demonstrated.

In summary, this study provides an in-depth understanding of the most persistent difficulty encountered in RF and microwave insects control for farm products (rice in particular). Since the causes studied are of a common nature, the physics, methods, and results reported here can hopefully be a useful reference for a wide range of microwave heating applications.

References

1. M. S. Lin, S. M. Lin, W. Y. Chiang, L. R. Barnett, and K. R. Chu, Phys. Plasmas **22**, 083302 (2015).
2. Y. F. Tsai, L. R. Barnett, H. H. Teng, C. C. Ko, and K. R. Chu, Phys. Plasmas **24**, 103301 (2017).
3. W. Y. Chiang, M. H. Wu, K. L. Wu, M. H. Lin, H. H. Teng, Y. F. Tsai, C. C. Ko, E. C. Yang, J. A. Jiang, L. R. Barnett, and K. R. Chu, Rev. Sci. Instru. **85**, 084703 (2014).

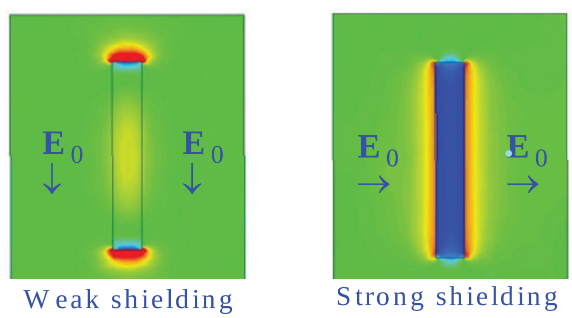

Figure 1. Polarization-charge shielding effects on an elongated dielectric object. Polarization charges are induced at the ends (left figure) and on the sides (right figure) of the object by an incident $\mathbf{E}_0$, thus producing much different shielding effects.