8th Asia-Pacific Conference on Plasma Physics, 3-8 Nov, 2024 at Malacca

Polarization Charge Effects in Microwave Heating

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Polarization charges play a vital role, but are commonly overlooked in microwave heating. In this talk, we illustrate the fundamental nature of this effect via two practical examples.

First, non-uniform heating very often results in an excessive temperature spread. Exposure to a nonuniform field is a well-known and extensively-studied cause for non-uniform heating. Polarization charge effects constitute another important cause, which are inherent in nature in that it persists even in a perfectly uniform field. In a uniform wave electric field (E_0), molecular charges in a dielectric object are polarized along the direction of E_0 to partially shield E_0. As a result, the object's interior E-field can be much smaller than E_0. The shielding effect, hence the heating rate, is sensitive to the object's shape and orientation. The difference in heating rate can lead to an unexpectedly large temperature spread. Its effect to microwave chemical synthesis will be discussed in detail.

Second, in the case of two dielectric spheres in a wave electric field, polarization charges form independently on each sphere when the two spheres are far separated. However, when separated by a narrow gap, polarization charges on opposite sides of the gap enhance each other. The enhanced electric field in a microwave oven is sufficient to cause air sparks. This explains a long-standing puzzle of public interest; namely, the gap region between two closely-spaced grapes in a 2.45 GHz household microwave oven is widely observed to spark curiously.

In microwave heating., electromagnetic resonances are also inescapable. Polarization-charge shielding produces an internal electric field sensitive to the sample size, shape, and orientation. Internal electromagnetic resonances result in a widely varying electric field, while also allowing much deeper field penetration than the attenuation length to allow large-scale treatment. The key to temperature uniformity, thus, lies in an optimized thermal flow to balance the non-uniform energy deposition. These complicated processes are examined in simulation and interpreted physically. It is shown that a spherical sample is most favorable for obtaining a high temperature uniformity mainly because of its rotational symmetry. This conclusion is significant in that prevailing sample vessels are mostly non-spherical.

References

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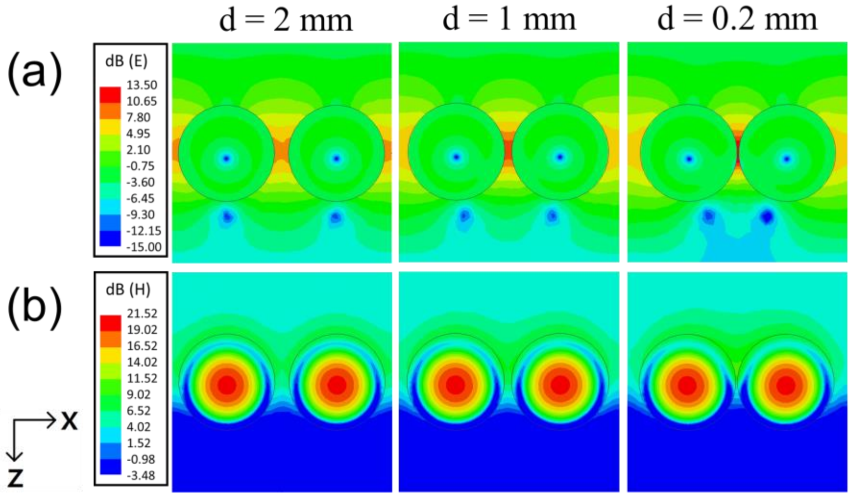

Figure 1. Simulation and experiment results at 2.45 GHz for a dimer ($\varepsilon = 77.5 + 10i$) with its axis aligned along E_0 ($400\,\mathrm{V/cm}$). (a) The *x-z* plane electric field amplitude pattern. (b) Corresponding *x-z* plane magnetic field amplitude pattern. The resonant field pattern inside the dimer is unchanged, while the gap E-field is strengthened by the mutual enhanced polarization charges. (c) QR code of our experiment video. Under 2.45-GHz radiation, the dimer moves close due to the attractive force caused by the opposite polarization charges, and then sparks.