Recent Developments in Metallized Films for Microwave Heating and Computer Simulation of the Same

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ABSTRACT

This paper describes new microwave food packaging materials - heavily metallized plastic films, their method of development and the reason why these materials survive the hostile microwave oven electromagnetic (EM) environment. Improved microwave heating of pizza, pastry, bread, oil-less popcorn, chicken nuggets, and many other two part food systems has been demonstrated using a new metallized film/paper substrate introduced last year called ACCU-CRISP 2000. Two other new patent pending, non-susceptor materials, ACCU-WAVE and BARRIER-WAVE, will be described which can be used in microwave heating applications where shelf stability is required combined with microwave heating of the food product. Aseptic packaging and lidding stock replacements for foil and film are some of the possible end uses. A computer modelling/simulation program has been developed which facilitates the engineering of these new materials and is compared to actual results.

INTRODUCTION

The penetration of the microwave oven into the American home has saturated at over 90%. While the “microwave” has provided convenience to the end user, with the convenience comes a lingering feeling of unfulfilled promises. Susceptor films and metallized barrier films are used extensively in the food packaging industry. However, susceptor films frequently do not adequately provide uniform browning and crisping, while metallized barrier films will not survive when exposed to normal microwave oven electro-magnetic energy. However, by using different patterns of metallized films, focussing of susceptor energy can eliminate cold centers of pizza, a metallized barrier film can be made to survive microwave cooking environments and metallized films can provide some shielding attributes.

There are opportunities for growth in these immense markets - all one has to do is satisfy the North American consumer.

ACTIVE PACKAGING

The ‘active’ microwave packaging market exists because there is a perceived need for improved heating of microwaveable foods. Frozen dinners and entrées in particular, require improved heating uniformity as the periphery of these foods invariably over-heats before the centre is warm. The great majority of the ‘active’ microwave packaging market is susceptor packaging for pizza, popcorn, meat pies, breaded fish etc. Other than susceptors there have been only a few active microwave packages - none very successful. Recently however, a new construction has entered the active packaging market, two new products employ a thick metallized layer, that is, a metallized layer thicker than the common susceptor have become commercial.

“ACCU-CRISP 2000”

As figure one shows, this substrate is a multiple layered metallized polyester film in which at least one metal layer is used for creating browning and crisping temperatures while at least one other metal layer is used to focus or shield energy. The black and white infrared photograph in figure two shows the bottom of a pizza using a standard susceptor paperboard platform. The cold center and non-uniformity of temperature is apparent.

In contrast, viewing figure three, we see an IR photo of the same pizza product cooked under equivalent conditions, but which demonstrates better uniformity of temperatures resulting in improved browning and crisping of the center. (refer to temperature statistics of figures two and three)

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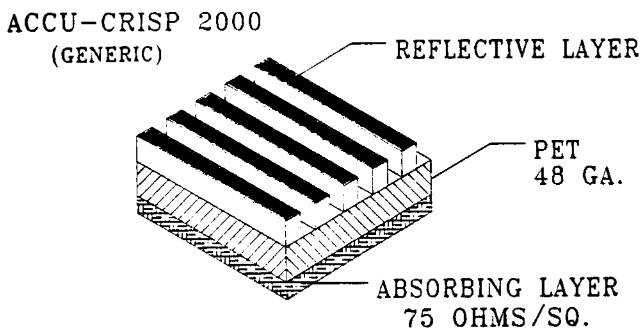

FIGURE ONE

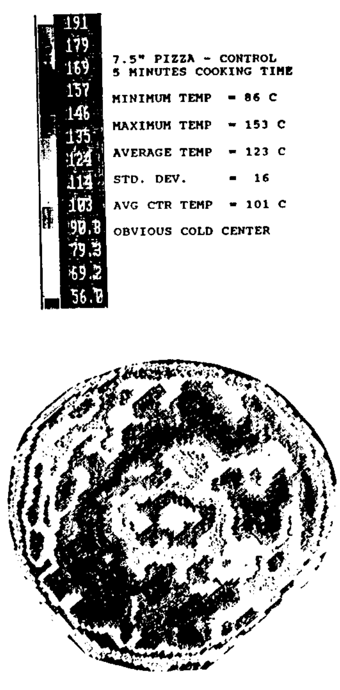

FIGURE TWO = STANDARD SUSCEPTOR

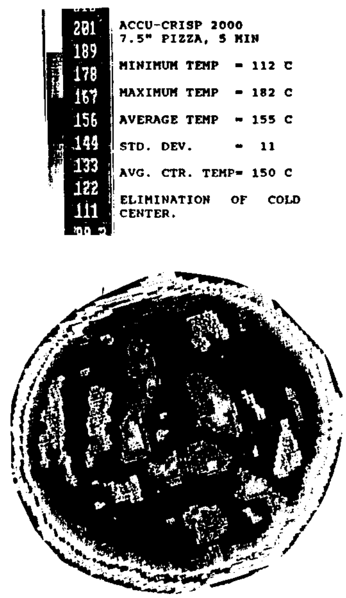

FIGURE THREE = ACCU-CRISP 2000 SUSCEPTOR

USE OF COMPUTER SIMULATION IN THE DESIGN OF ACTIVE MICROWAVE PACKAGING

For years product development methodology has followed the classical steps of requirements generation, design, sample fabrication, testing - iterating on the design, sample fabrication, testing steps as required - then if and when successful, product specification, manufacturing specification and finally manufacturing . Recently many organizations have inserted a new step into this classical process. The step which fits between the design and sample fabrication steps is computer simulation or modelling.

Our computer simulation models the illumination of the pattern of metallization with a single source of electro-magnetic energy at the microwave oven frequency of 2450 MegaHertz. The original program upon which the ADTech's EM simulation package is based, is publicly available. This general program is used extensively in the broadcast industry to model radiation patterns of radio and television antenna in large cities in order to show non-interference with other communication and to obtain a broadcast license.

The program, originally designed by J Richmond at Ohio State University was modified by G Morin and M Tilston at the University of Toronto and further modified by J McCormick to facilitate modelling active packaging structures. By using and modifying this wire grid structure computer modeling program using the moment method to calculate currents in wire grids, we can calculate the anticipated theoretical electric energy field for a particular metallized pattern at a given distance from the metallized pattern. Figure four shows a pattern of metal islands and one quadrant of the corresponding resultant field 5mm from this pattern. Note: there has been very little influence by the pattern on the field.

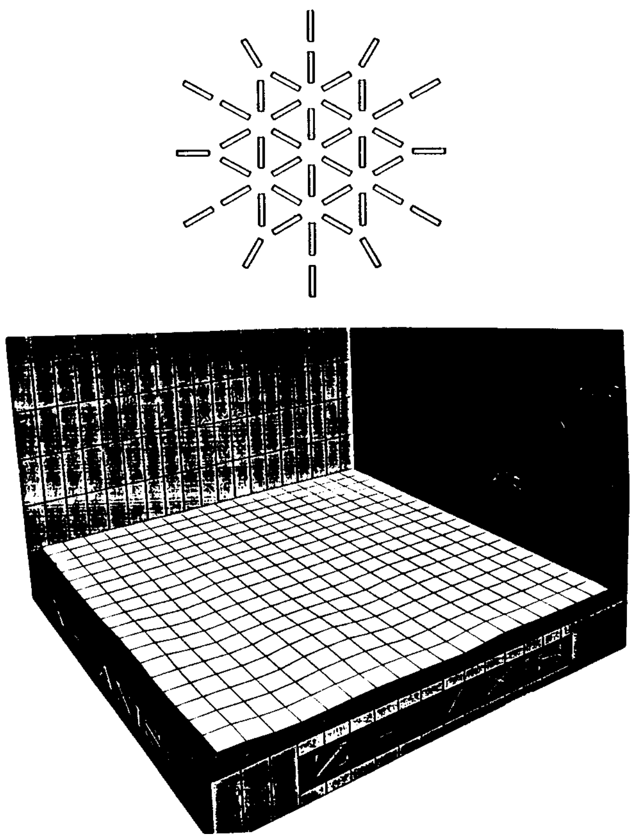

FIGURE FOUR

Figure five shows another pattern of metal islands and the resultant theoretical field 5mm away from this pattern. Finally, figure six shows the pattern used in the IR photographs where the center was noticeably hotter than the control. Figure seven shows all four quadrants of this field and it is quite similar to the pattern in the IR photo.

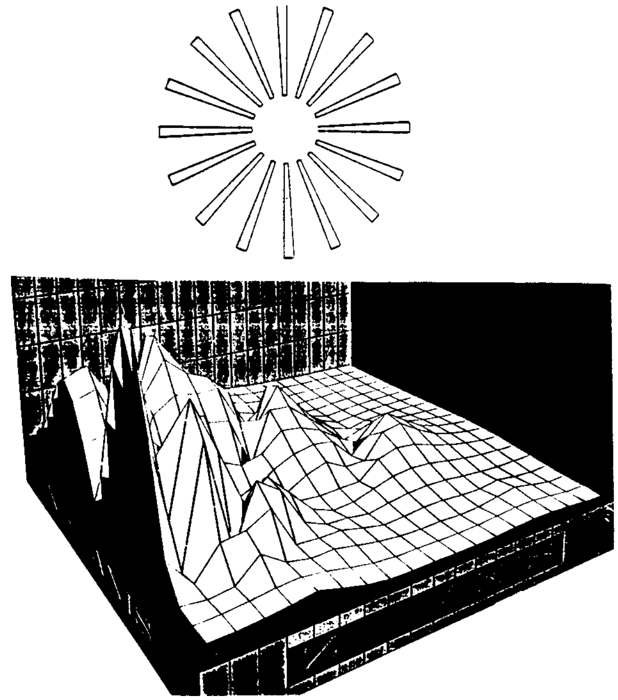

FIGURE FIVE

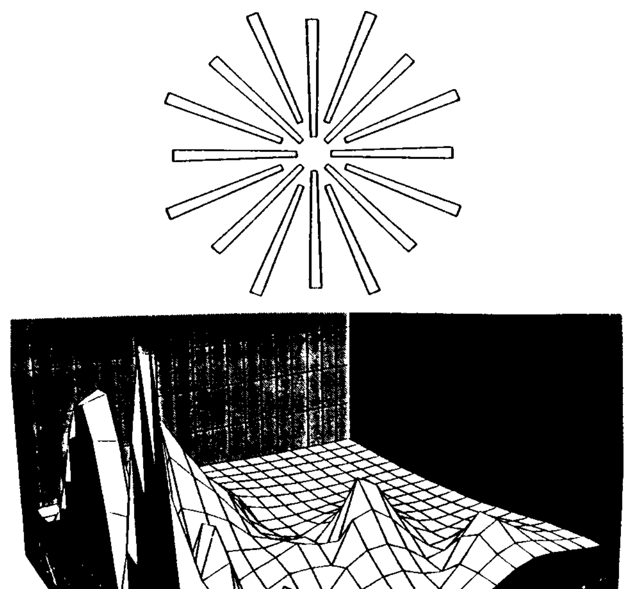

FIGURE SIX

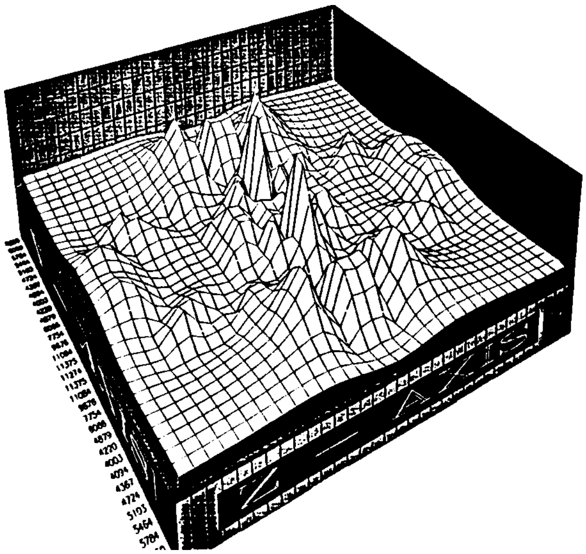

FIGURE SEVEN

By using this computer simulation, we can evaluate other metallized patterns when looking for specific performances. We have also used this program to effectively predict structures which can reduce the transmitted energy to the food product. Consequently, we have been able to create new substrates for two part foods where you want to brown and crisp the exterior at a similar rate as you heat the interior. This can be done more effectively by using patterned metallized substrates to reduce the transmitted energy which otherwise would overcook and boil out the food fillings in many applications.

Specifically, what the simulation does is illuminate a wire grid structure with a single source and calculate the EM field at a user specified but limited set of points in the vicinity of a wire grid structure. Most simulations involved symmetrical patterns producing symmetrical results, therefore normally only one quadrant of data except for figure seven which shows all four quadrants.

In the complex environment of the microwave oven there are multiple reflections from oven walls, mode stirrers, turntables, food containers and the food. This is a desired feature of microwave oven, but it makes it nearly impossible to model.

Consequently in order to use the simulation to reliably predict performance of the metallized structure in the oven several results of controlled simulations must be analyzed.

Normally several simulations of one structure are performed, the position of the source is changed to examine the response of the modelled structure from EM energy impinging at various angles.

SURVIVABILITY OF METALLIZED FILM IN THE MICROWAVE OVEN

In addition to these enhanced susceptors there is a role for heavily metallized films in active microwave packaging in their own right. These applications differ from the enhanced susceptor in that 1) there is no susceptor and 2) there is a higher percentage coverage of metallized material. This latter difference introduces a major problem for metallized films destined for the microwave oven. Continuous heavily metallized films do not survive the microwave oven. In order to use these films in active microwaveable packaging one must first make the material survive the microwave oven.

"BARRIER-WAVE"

Some of you may have wondered why you can "see" into a microwave oven door, but why microwave energy does not "see" you.

Without going into the physics of cut-off frequencies, electromagnetic energy reflection theory, or Babinet's principles, it suffices to say that it works. Our BARRIER-WAVE films work on a variety of similar principles. In other words, we have created a metallized patterned structure which permits microwave energy to pass through, without destroying the substrate, and yet the patterned structure is highly impermeable to oxygen and moisture. Figure eight shows a cross sectional view of this structure.

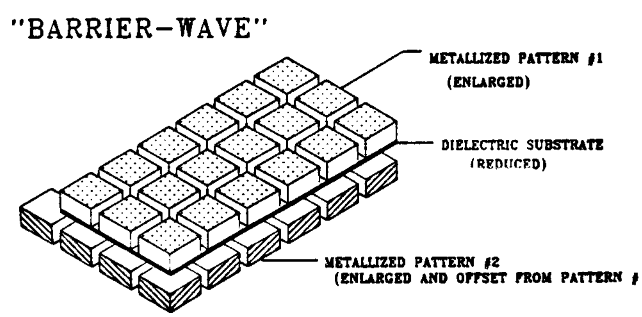

FIGURE EIGHT

If you attempted to use a normal metallized barrier film in a microwave packaging application, you would find that the metallized substrate would self-destruct in the microwave oven in part because the microwave energy cannot pass through the fully metallized film and thus causes arcing on the metal which destroys the package. However, by using a double metallized patterned film in place of foil you can create packages which:

1) Have excellent barrier properties, not as good as foil, but better than standard metallized films.

2) Can be more easily recycled unlike foil/film structures.

3) The final package will survive microwave heating.

4) Microwave energy will "pass" through metal coating and heat food inside the package without destroying the package.

Given these characteristics, this new substrate is an excellent candidate for replacement of foil in aseptic packages or lidding stock where good shelf life and microwave heating of the food product are required.

To modify the levels of transmission or reflectivity one need only de-tune the "transparent" pattern to cause more energy to be reflected bearing in mind that it is possible to "de-tune" the structure too much causing the material to breakdown in the microwave oven. As the transparent structure is de-tuned it reflects more energy.

Four parameters are varied to tune or control the degree of transparency of a pattern of conductive metallic islands to electro-magnetic energy: size and shape of the metallic islands, width of the slot, conductivity of the material forming the metallic island, and thickness of the metallic layer. For a given material and layer thickness decreasing the width of the non-metallic slots from the "cut-off frequency dimension" de-tunes the "transparent" pattern and increases the current within the metallic island and the reflected energy. If the length of all sides of the rectangular metallic island are kept much less than one half the wave length of the EM energy in a vacuum, the larger the metallic islands, the greater the electric currents and the greater the reflected EM energy becomes.

Of course the "transparent pattern" can be de-tuned too much, causing the metallic islands to attempt to reflect more of the impinging EM energy than the metallic islands are capable. The electric currents within the metallic islands, concomitant with reflected EM energy, increase and can cause the thin metallic layers of the islands to breakdown. The greater the conductivity of the material and the thicker the metallic layer, the greater the electric currents which the material can sustain without the metallic layer breaking down.

ACCU-WAVE

Using the theory of the previous section one can construct a microwave food packaging material which controllably reflects (or equivalently transmits) a desired fraction of the microwave energy. This metallized film substrate is derivation of both BARRIER-WAVE and ACCU-CRISP 2000. It is not a susceptor. Figure nine shows a cross section of such a substrate.

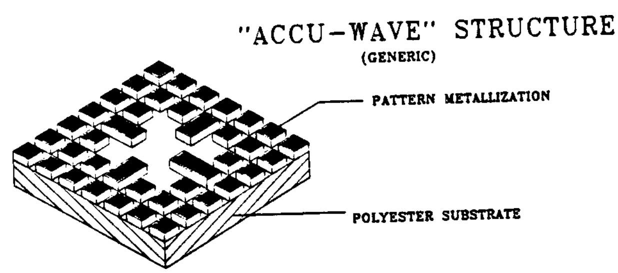

FIGURE NINE

Essentially, we are taking the principles of patterned metallized films for focussing or shielding microwave energy as discussed for ACCU-CRISP 2000, combined with the microwave survivability aspects of BARRIER-WAVE. The net result is a packaging material which does not directly heat the food, but which modifies the electro-magnetic energy in the oven to partially block or intensify the field in a particular location.

This film substrate when laminated to paper, paperboard, or CPET can change temperature uniformity by either reducing energy at hot spot locations in the food or by increasing energy at cold spots. This metallized film can also be used as lidding stock. Its barrier properties to oxygen and moisture are primarily limited to the characteristics found with the base film sheet.

As ACCU-WAVE's pattern is characterized by continuous non-metallic slots, a perfect EM shielding structure can not be made from the invented material. However a structure can be designed which reduces the amount of microwave energy passing through the material or an area of the material.

CONCLUSIONS

New metallized patterned films can be used to enhance and create unique microwave heating characteristics. When laminated to other films, paper, paperboard, and plastics such as CPET, a cost effective package is created which can be engineered to the particular geometry and formulation of a specific food product. A computer simulation modeling program has been developed to reduce the trial and error process frequently relied upon in the past.

CREDITS, REFERENCES & ACKNOWLEDGEMENTS

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