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Accurate Detection of Small Shapes Using Total Field/Scattering Field Approach: A Radar Cross Section Based Study of Zno Dust

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Taking cue from the Radar Cross Section based detection schemes in large dimensions; this simulation based study applies the total field/scattering field formulation to a small dimensional system. Using a Finite Difference Time Domain based Electromagnetic solver, a shape detection scheme is presented that answers the accuracy question that are often raised for the non-standard shapes. A previously known shape of Zinc Oxide based powdered particle is tested using this methodology. The 2-dimensional projection of a hexahedral volume is "caged" in the virtual test bed. Data obtained from detectors located in the encompassing positions is then normalized and plotted over 360°. For a minimum of two separate orientations of the obstacle, no changes in the location of the "far-field pattern" in the resulting polar plots, is observed, allowing us to present our "coincidence paradigm". In a post -trapping scenario, a fundamental question "How accurately has the shape been detected?" remains. This letter attempts to answer such an accuracy problem by presenting a self-correcting detection technique.

Keywords : Radar Cross Section, Material Science ,Thin Films, Semiconductors, Meteorology, Absorption

INTRODUCTION:

Three dimensional analysis of field distribution inside an array of uniform geometrical shape is difficult due to the lack of accurate optoelectronic control at the experimental stage. Major reasons to run computer based simulation for such analysis are a) Stringent precision and control in fabrication scheme of such an array, b) Limitations of production of materials with uniform shape and size. At the same time computer based solvers have their own algorithmic and hardware limitations. Such a paradox presents an ideal scenario to research and analyze the behavior of very small scale geometries of rare shapes under electromagnetic excitation.

In here, we present the results of applying the theoretical formulation[1] of Radar Cross Section (RCS) based study on a very small sized object of regular shape. A computer simulation of such a detection methodology is inspired by the idea of increased optical absorption as a means to add to the overall device efficiency[2] of the constituting device. Rough surfaces fabricated out of odd geometries are expected to enhance the light-matter interaction in Silicon as well as novel semiconductor material [3].

For such absorption (event) to happen, each constituting small particle of the thin film, should participate in a light matter interaction scheme. Since we safely assume the thin film to be made up of very small symmetric particles, it would be nice to study the behavior of this (individual) shape under electromagnetic excitation. Additionally, in order to validate the scheme, it would be favorable confine the individual constituent particle in a predefined space and observe the resulting conditions existing in the vicinity. A hexahedral geometry of Zinc Oxide (ZnO) dust [Fig.1] like particle was, first processed, chemically. ZnO is a known optically active, direct gap wide band semiconducting material[4]. The 2 dimensional (2-d) projection of the ZnO shape thus obtained is simulated using a Finite Difference Time Domain

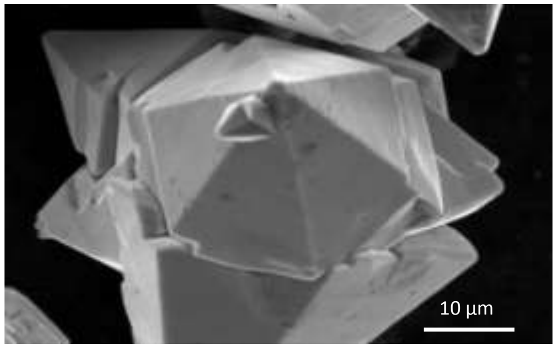

Fig.1 Scanning Electron Micrograph (SEM) of Zinc Oxide (ZnO) particles, processed via a wet chemical processing route.

(FDTD)[5] based electromagnetic solver[6].The choice of ZnO based material is motivated by an experimental work in progress[7] and its wide applicability in diverse areas such as cosmetics industry (sun screen), solar cells (transparent conducting oxide) and electronics (gate materials in transistors). Based upon the processing route and controlling parameters, ZnO has been known to exist in several forms and shapes [8]. However, Figure 1 like geometries find, rare mention in literature.

SIMULATION OF EXPERIMENT:

As a first step, towards setting up of a FDTD based simulation, an enclosed 2-d projection of a scaled down particle volume is excited by an arbitrary tilting plane wave. Eight tilting planes form the boundary of two "cages", encapsulating the fields. Total field scattering field (TF/SF) generated thus, divided the computational space into two separate rectangular regions

Outside of the inner rectangular region, it is pure scattering field (SF), while the inner rectangular region is rich with the total field (TF) consisting of the incident as well as the scattered field. A TF/SF formulation of this type serves the basis of our RCS analysis. We present and compare the precision with which this setup helps in shape-boundary detection of geometrical shapes. Electromagnetic analysis of 3-dimensional (3-d) structures of various shapes and cross sections have appeared in standard text [9] .Under these conditions, we place, a normally incident projection of the hexahedral shape inside of the exciting "cage". The accuracy of the detection of such a shape, depends upon the concurrence of figure forms that that appear in RCS based polar plots (such as the ones that are reported in the later part of this communication).The plots were obtained from the four identically spaced and placed detector positions in the computer simulation. The RCS based polar plots maintained, concurrence for two separate orientations (90° apart) of the ZnO based shape.

Chance natural appearance[10] and the analysis of biologically complex, yet geometrically symmetric shapes [11] add relevance to our study. Depending upon the fundamental properties (such as refractive index, dielectric constant, pH factor etc.,) accurate, 2-d shape detection of an electromagnetically irradiated, 3-d volume depends upon several critical factors of the "test-bed" setup. Experimental evaluation, of the time lapsed distribution of electromagnetic field inside a layered semiconductor design, under an accelerated aging test setup, may not be practical in rapid product development life cycles. However, at the device design stage a need to conduct a layer by layer analysis, for a photon based, light guidance [12] system, remains. Common solid state light emitting diode or a solar cell, are examples of such multilayered devices. Prudent parameter selection in OptiFDTD, allowed us to mimic, diverse test conditions. Since the rough compounds have a distinct 3-d shapes [13], an estimate of the conditions existing at interface of the thin films is important. This also depends on chemical composition of the 3-d shaped compound .This leads to our problem of accurate

shape detection of small sized scattering shapes. Note should be taken that our study is not much different from large dimension systems (such as drone based radars for shape estimates of ground objects).
In such a case, the RCS data [14] (normalized with the exciting wavelength) plotted over 360°, provides a self-correcting mechanism. Our interpretation of this scenario is as follows: For standard shapes a rough idea of the smallest imaginable obstruction and its projection on a 2-d plane, is known beforehand (See Table I). In case of non-standard shapes, detection may be inaccurate. In the absence of reference data such inaccuracies persist leading to larger design based problems.

A. SOFTWARE BASED DEFINITION OF THE DATASET:
To check this anomaly, objectivity has to be incorporated in the accuracy related data. We introduce a "coincidence paradigm" to overcome this paradox. Using the far-field RCS based datasets for accuracy-check, co-incidence of a far-field patterns (over and extended range) of the polar plots for a minimum of two separate orientations (90°apart), for all the four detector positions, of the obstructing non-standard shape is considered as an instance of accurate detection. In the post simulation analysis using this hypothesis one can incorporate objectivity to the "exactness of fit"-problem.

Table I. Standard volume based shapes and there 2-d projections inside the Total Field/Scattering Field "cage".

#	Volume based shape	Possible number of lines in 2-D projection *	
		TOP	SIDE
1.	Simple Rod	None (Circle)	4
2.	Parallelepiped Rod	------------------------	
	Rectangular CS[&]	4	4
	Hexahedral CS	6	4
	Square CS	4	4
3.	Conical Rod	None(Dot or Circle)	3

*based on the projection inside the cage

We set a computational space occupied by air, hypothecating a space of length 2μm and a width of 2μm.Physically this should be assumed to provide a background wafer space. The refractive index of such a space is assumed to be that of air (n=1).Next a 2-dimensional structure of known refractive index [15] (ZnO =1.92) and geometry (hexagon) is constructed. The center of this geometry is matched with the computational (wafer) space. The input wave is assumed to be parallel to this shape. This fundamental formulation of the FDTD based computational algorithm relies on the contrasting waveguide principle [16].
Two linear "cage's" (as mentioned previously) are constructed next within the limits of the computational wafer space. In doing this a 2μm by 2μm free space domain is defined (thin red lined boundary in Fig. 2). Such a small area is considered because of the time related convergence issues. A center space cut section, consisting of 0.9 μm by 0.9μm area (thick red boundary in Fig. 2), defining the Total Field (TF) inside this domain is created next. To detect and contrast ,the unmixed scattering field (SF), four observation line detector adjoining this TF/SF generated region are placed 0.15 μm apart from the center of inner cut section (thick green line in Fig. 2).Individual "caging" depicting two orientations of the hexagonal shape are shown in Figure 2. Notice that the same shape is oriented, 90° apart for separate simulation runs, apart.

B. RESULTS & DISCUSSION:

To present the results, precisely and comprehensively, the best way in our knowledge is to use polar plots. Since, presentation for each orientation, would involve four detector positions, at each orientation, it is beyond the scope of the current version (OptiFDTD, 32-bit version 12.1) to present, the entire result in one instance. As the size of the shape defines the size of the "cage" TF/SF formulation of this type is independent of these constraints, as long as the electromagnetic excitation, meets the required specification. The size of the "cage" can be changed by changing the detector positions by moving them closer or farther to each other. or instance, the set up presented by us here, would not be the best choice for a large dimensions like that of aircraft shape detection. One would need a setup which along with having a different wavelength and amplitude setting should also be flexible ,to provide the contrasting echo .

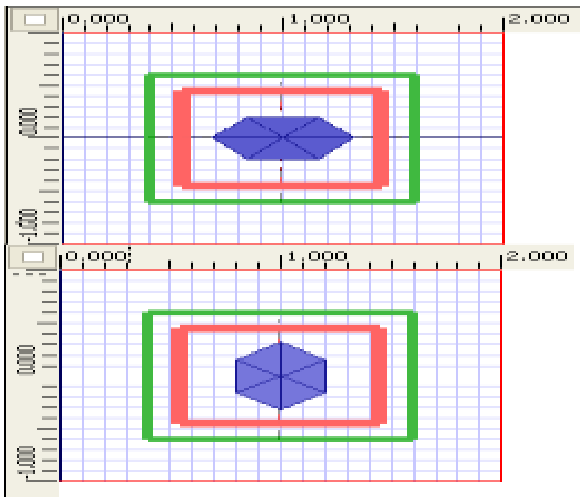

Fig.2. Two dimensional normal projection of the shape presented in Fig.1inside the TF/SF boundary. The two orientations are 90° apart inside the same TF/SF boundary.

The common point between the two setups is that both work on the contrasting principle. This provides the necessary capacity to define the space inside which the necessary resolution (for accurate shape detection) can be achieved. In our case, the far-field pattern of the RCS based polar plots (Fig. 3), serve the same purpose. It is important to understand the "far-field" concept in low dimensional RCS analysis. In the post simulation analysis we have accommodated tens to ten thousands of the exciting wavelengths of the electromagnetic excitation centered around 1.55 µm. This yields a realistic figure of 1.55 cm for the "far field". Notice that the order change from micrometer to centimeter involves an order of difference even in the low dimensional analysis. This large range provides sufficient space to accommodate a big window for shape/size detection, to design a practical device in application. Further to this the cross sectional analysis of the electromagnetic field, as it develops across a contrasting, continuously graded waveguide boundary (consisting of ZnO/Air interface in the computational space) was attempted using the same setup. Figure 4 depicts the cross sectional spread of the field, along with the refractive index of the ZnO based hexagonal projection. This, part of the result analysis is presented to prove that the continuity boundary conditions set by Maxwell's equation are satisfied.

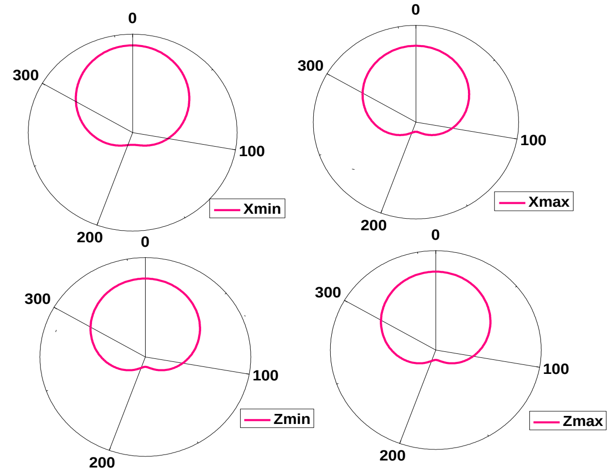

Fig.2. Polar plots of the far-field pattern on the RCS dataset from the four detector postions (X_{min}, X_{max}, Z_{min} & Z_{max}). Similar curves were obtained for the 90° oriented position.

Poynting vector showing the Power distribution across the hexagonal obstacle in the computational space is shown in Figure 5.

CONCLUSION:

In summary, we applied the TF/SF based formulation on a much small scale for a ZnO based small sized particle. The resulting far field (100,000 times the exciting continuous wavelength centered around 1.55 µm) RCS data is normalized with the exciting wavelength. The polar plots of this data appear, identical for the different orientation of the shape at all the predefined detecting positions .This concurrence of the data/plots yields statistical confidence in the detection scheme. In the absence of such a concurrence, any detection cannot be termed as shape-accurate. Additional confidence in our fitment is provided by the secondary results that appear as a continuous distribution of power across the optically abrupt (refractive index changes) shape boundaries. In a more evolved version of the computer based Electromagnetic solver one, should

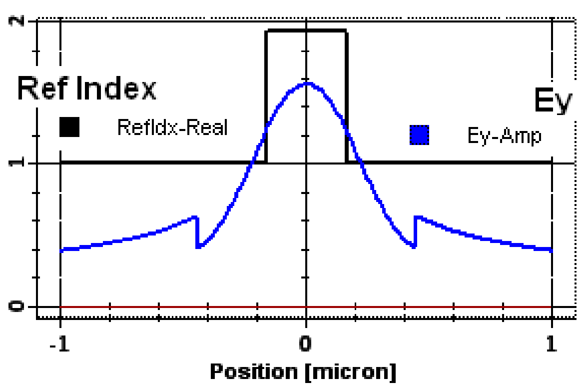

Fig. 4. Cross cut view of Refractive Index (in black) and Discretized Fourier Transform value of TE field (in blue) at 1.2 µm position in z-direction. Notice the lateral spread (from -1 µm to 1 µm, a total of 2 µm, which is also the limit of the computational space) is in the x-direction.

Expect a complete 3-d treatment of the fields with the options of selecting /deselecting, the total field and/or scattering field, inside the obstructive shape. The capacity to visualize thermal hotspots as the electromagnetic excitation builds up should also help in deciding the terminal (port) position selection in a thin film array configuration. A periodic arrangement of such symmetric obstacles can be of use in the layered design of thin films made out of such wide band gap materials.

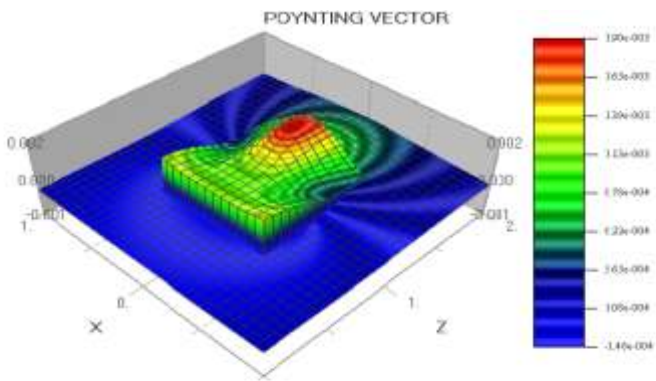

Fig. 5. Pointing Vector depicting the power spread across the computational space.

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