ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 2, Issue 2, August 2012

A Novel Method for RCS Reduction of a Complex Shaped Aircraft Using Partial RAM Coating

A. Upendra Raju, Jyothi Balakrishnan

Abstract* - *In this paper, a novel method of partial coating to reduce the Radar Cross Section (RCS) of a complex shaped perfectly electrically conducting (PEC) aircraft, of electrically large size, is proposed. The physical optics (PO) method is used to identify the hot spots of the PEC aircraft. An empirical procedure is then proposed to coat partial contiguous areas with Radar Absorbent Material (RAM). The PO is then modified to compute the RCS reduction of the partially coated aircraft. The level of coating can be adjusted so as to obtain the required reduction in RCS. It is shown that, with an appropriate choice of the partial coating level, the RCS can be reduced to the same level as that of a fully coated aircraft, over a wide frequency range. The weight, volume and thus cost reduction through the proposed partial coating techniques are also quantified.

Index Terms **- RCS (Radar Cross Section), PO (Physical Optics), RAM (Radar Absorbing Material), PEC (Perfectly Electrically Conducting), Partial Coating.**

I. INTRODUCTION

RCS reduction has been an important topic amongst researchers because of its importance in military applications for increasing survivability by reducing the detectability of bodies. Techniques such as shaping, active loading, passive loading, and RAM coating are used to reduce detectability. These methods are normally employed in stealth technology for RCS reduction [1, 2], and among them RAM coating is the most widely used method [1]. RCS may be determined by experimental measurement, but such a procedure may not be practical and applicable for all angles of observation and object dimensions [3]. Therefore, numerical electromagnetic techniques are required for the computation of RCS. The electrical size of a practical aircraft is large and hence the use of low frequency techniques such as Method of Moments (MoM) and Finite Element Method (FEM) are infeasible. Despite a dramatic improvement in the speed and storage capacity of computers in recent years, the practical size of the object that can be handled *via* the MoM approach is still of the order of about 25λ or less. Even methods such as the Fast Multipole Method (FMM) are computationally inefficient [4]. The high frequency techniques, though computationally simpler, offer the desired accuracy in RCS prediction. They can also be modified to handle both metallic and coated surfaces in the same complex shaped body [5,6]. There are many high frequency RCS prediction techniques available in literature [7]. The simplicity of high-frequency prediction methods is due to the assumption that each part of the body essentially scatters energy independent of all other parts. Therefore, the fields induced on a portion of the target are due only to the incident wave and not the energy scattered by other parts. This makes it relatively simple to estimate the induced fields and to integrate them over the body surface to obtain the far scattered field and, therefore, the RCS. This paper deals with the RCS analysis where it is implicitly assumed that the radar frequency is high enough such that the corresponding wavelength is small compared to the physical dimensions of the scattering body. Selecting an appropriate method for RCS computation depends on the main objective behind the scattering calculations, the computing equipment, and the geometry of the target, its electrical length and its conductivity [4]. High frequency asymptotic methods are widely used to compute the RCS of three-dimensional complex targets at high frequencies, because of their ability to provide considerable physical insight into the diffraction mechanism and predict the RCS at a reasonable computational cost. Physical optics (PO) is one such high frequency method and is suitable to compute the field scattered by complex objects, since it yields bounded results at any point in space, including those points where boundary layers overlap [8, 12]. PO has been used in this paper.

II. PHYSICAL OPTICS (PO) METHOD

The physical optics (PO) method is a high-frequency technique where the target is replaced by induced surface currents that serve as the source of scattered fields. The basic assumptions in PO are (i) the radii of curvature of the surface are large compared to wavelength, (ii) currents exist only in the area that is directly illuminated by the incident wave, and (iii) currents on the illuminated surface have the same characteristics as those on an infinite plane tangential to the surface at the point of incidence. PO is essentially based upon Huygens's principle, which states that each point on the primary wave front gives rise to secondary wave fronts. Hence, a spherical wave front, as it propagates, gives rise to secondary spherical wavelets. This provides a mechanism for the bending of waves and accounts for the diffraction phenomenon in the shadow region. In PO, the target is replaced by induced currents. The field due to the radiating source is assumed to exist independent of the scattered. Thus, finite fields exist in both the illuminated and shadow regions and obviously must also be continuous at the shadow boundary. The effect of the scattered manifests as a field due to the source induced current on the scatterer, known as the PO current.

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 2, Issue 2, August 2012

A. PO for A Conducting Body

The PO current for a conducting body is given by,

$$\vec{J}_S = \begin{cases} 2\hat{n}\times\vec{H}^i, & \text{illuminated region} \\ 0, & \text{shadow region} \end{cases} \quad (1)$$

Where $\hat{n}$ is the unit normal vector of the surface positioned outward and $\vec{H}^i$ is the incident magnetic field vector? In the presence of a perfectly conducting surface, the total electromagnetic field of a source may be expressed as a superposition of the incident fields and scattered fields by the surface of the body. The scattered fields can be expressed in terms of the radiation integrals over actual currents induced on the surface of the scattered as [9],

$$\vec{E}^s = \frac{e^{-jkr_s}}{r_s}(\vec{E}^i_\phi\hat{\theta}^i - \vec{E}^i_\theta\hat{\phi}^i)\times(\frac{j}{\lambda})\iint_S \hat{n}e^{jk(\hat{r}_i+\hat{r}_s).\vec{r}}ds. \quad (2)$$

B. Po for a Radar Absorbing Material Coated Body

Radiation from a body coated with a thin layer of absorbing material has been studied by [6]. For an incident plane wave, the total scattered field from a coated body is given as,

$$\vec{E}^S = \vec{E}^S_J + \vec{E}^S_M \quad , \quad (3)$$

Where $\vec{E}^S_J$ and $\vec{E}^S_M$ are the scattered fields due to the electric ($\vec{J}$) and the magnetic current ($\vec{M}$), respectively. The expressions for $\vec{J}$, $\vec{M}$, $\vec{E}^S_J$ and $\vec{E}^S_M$ are given detail in [6].

The RCS is then can be computed using the well known formula,

$$\sigma = \lim_{r\to\infty} 4\pi r^2 \frac{|\vec{E}^s|^2}{|\vec{E}^i|^2} \quad , \quad (4)$$

Where $\vec{E}^i$ and $\vec{E}^s$ are the incident and scattered electric fields respectively.

III. RADAR ABSORBING MATERIAL (RAM)

RAM coating is the most widely used method for RCS reduction [1]. Radar absorbing materials (RAM) reduce the energy reflected back to the radar by means of absorption. Radar energy is absorbed through one or more of several loss mechanisms, which may involve the dielectric or magnetic properties of the material. Dielectric RAM uses carbon as the basic material because of its poor conductivity, but these materials are not easily applied to operational weapons platforms and they are usually too bulky and fragile in operational environments. Hence, magnetic absorbers are used widely for operational systems [7]. Also, magnetic materials offer the advantage of compactness as they are typically around one-tenth of the thickness of dielectric absorbers and they can be effective over a wide range of frequencies. The loss mechanism in magnetic absorbers is primarily due to a magnetic dipole moment. Compounds of iron are the basic ingredients in these absorbers. Carbonyl iron, made of oxides of iron (ferrites) has been used extensively as radar absorbing material. Permittivity (ε) and permeability (μ) are two properties that are closely associated with the effectiveness of these absorbers. They both vary considerably with frequency in different ways for different materials. For a coating to be effective, it should have a thickness that is close to a quarter wavelengths at the frequency of interest [14]. The ferrite layer of approximately quarter wavelength thickness over a conducting surface acts as an impedance matching layer as well as absorber. RCS reduction using a magnetic RAM of Sintered Nickel Zinc Ferrite [7] is studied in this paper.

IV. SCATTERER MODELING

For illustrative purpose an aircraft of length 4m, wing span 7m and height of 1m is used, to represent a scale model of typical fighter aircraft Me 163B-1. There has been no intention to reproduce exactly the design of any particular fighter aircraft. The aircraft is modeled using 29 surfaces. The fuselage and nose of the aircraft is modeled using 8 curved surfaces and the wings and tail are modeled using 21 flat surfaces. For PO application purposes, the surface of the aircraft is discritized into triangular elements with 10 elements per wavelength. The aircraft is placed with the nose along the X-axis and wings along the Y-axis, as shown in Fig. 1. The simulation was done at frequencies of 1, 3, and 10 GHz, representing the L, S, and X wave bands respectively. The largest dimension of the aircraft, i.e., the wing span, is 23λ, 70λ, and 233λ at 1, 3, and 10 GHZ, respectively. A plane electromagnetic wave, of unit amplitude and given frequency, is incident on the nose of the aircraft and the bistatic-RCS is observed in the azimuthal plane. The number of unknowns, memory , CPU time, and the characteristics of the RAM at the above said frequencies are listed in Table 1. The simulation was done on a Tyrone 8 processor parallel machine with 32 GB memory. FEKO [10] with physical optics (PO) is used for the simulation.

V. RCS REDUCTION USING PARTIAL RAM COATING

Though magnetic RAMs are advantageous compared to their dielectric counterparts, the presence of iron make

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 2, Issue 2, August 2012

them heavy and also requires skilled personal for coating them uniformly on the surface [7]. To make the scatterrer not too heavy due to coating, one should reduce the amount of coating material to a minimum, without compromsing on the RCS reduction. This also reduces the cost. From the scattering center approach of a target, it can be concluded that, it may not be necessary to coat a target fully. Instead, it is enough to coat only the major scattering centers called hot-spots [13]. In this paper, the hot-spots are first identified and a novel method of only coating the hot-spots on the surface of a complex shaped aircraft with RAM is proposed, instead of coating the entire surface of the aircraft. A similar method of RAM saving by coating only the edges of a flat plate has been discussed in [13]. There are also recently, methods of RCS reduction using meta materials [15-17] for partial concealment of objects [18] are available in the literature. In Fig. 2, the normalized value of reduction in bistatic RCS is shown with varying RAM coating thickness, expressed in terms of wavelength λ. It is evident from Fig. 2, that maximum reduction in RCS can be achieved when the coating thickness is of the order of λ/4. Also it can be seen that the RCS reduction is substantial for thickness values ranging from 0.18λ to 0.4λ. A coating of thickness 3.7mm is in the range of 0.18λ to 0.4λ at all the three frequencies of 1 GHz, 3 GHz and 10 GHz. Hence, a 3.7mm coating thickness is used in the present study.

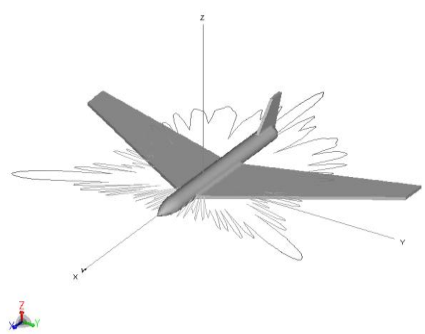

Fig. 1. Plane Wave Incidence at the Nose of an Aircraft and RCS Pattern In the ϕ - Plane.

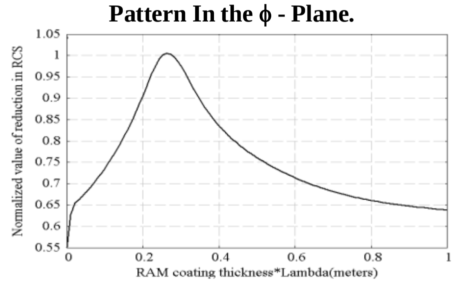

Fig. 2. Normalized value of reduction in Bistatic RCS of aircraft with RAM thickness (expressed in terms of wavelength) at 1GHz.

A. Monostatic RCS of aircraft

The monostatic RCS of an aircraft is anlyzed at 1GHz using physical optics (PO) method. The discretization of the body of the aircraft resulted in 95,175 unknowns, as shown in Table 1. Fig.3 shows the monostatic RCS of a PEC and RAM coated aircraft at 1 GHz. Analysis of the RCS shows that the nose cone of the aircraft is a major contributor to the backscatter cross section, having an RCS of -15 dBm^2 at 0^o. As the viewing angle increases, the broadside of the aircraft contributes to the RCS, and the RCS increases. Two RCS peaks of 10.26 dBm^2 at 31^o and 8.44 dBm^2 at 162^o are due to the cylindrical sections of the aircraft facing the radar. A minimum RCS of -17 dBm^2 at 42^o is due to the obtuse angled corner between the cylindrical body and wing of the aircraft. The maximum RCS peak of 16 dBm^2 at 90^o is due to the edge of the wing. There is a decrease in RCS to -12.8 dBm^2 at 148^o, due to acute angled corner between the wing and cylinder. So the major contributors to the RCS are the cylindrical section of the aircraft and the edges of the wings. Only these parts are coated with RAM. A maximum reduction in RCS of about 4 dBm^2 is obtained at 90^o with partial coating. Since the aircraft is symmetric with respect to the XZ-plane, the same results will be obtained for ϕ = 180^o to 360^o.

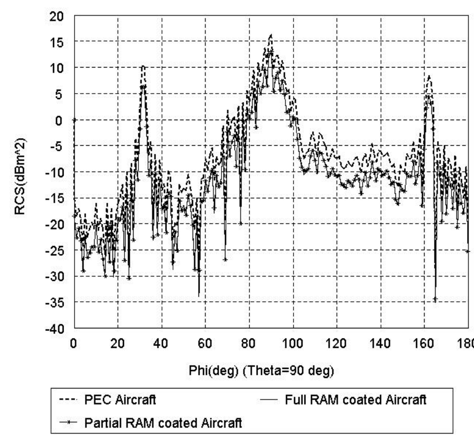

Fig. 3. Monostatic RCS of aircraft at 1 GHz.

B. Bistatic RCS of aircraft

Analysis of the bistatic RCS at 1GHz, given in Fig. 4, shows that for an incident plane wave, peaks are observed at 63°, 137°, and 180° and a minimum at 0°. For an incident EM plane wave, the nose of the aircraft appears like a point source, hence, minimum RCS of -15 dBm^2 is observed at 0°. As the viewing angle increases, the broadside of the aircraft contributes to the RCS, and the RCS increases. The peak RCS of 9.3 dBm^2 at 63° is due to the edge of wing and the increase in RCS after 100° is due to the cylindrical section of the aircraft and the peak RCS of -3.2 dBm^2 at 137° is due to the corner between cylindrical body and wing. Maximum RCS of 17.72 dBm^2 is observed at 180^o due to the curved surface of the tail section and also due to forward scattering. Hence, it may be concluded that the major contributors to the RCS are the cylindrical section of the aircraft, the corners between wings and cylinder and edges of the wings. The bistatic

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 2, Issue 2, August 2012

RCS of the aircraft at 3 GHz and 10 GHz are presented in Fig. 5 and 6, respectively. The RAM coating is applied to the entire aircraft and the RCS is calculated at all three frequencies. Sintered Nickel Zinc Ferrite [7] is used as RAM, with the properties given in Table1. The RCS at 1 GHz, 3 GHz and 10 GHz are plotted in Figures 4, 5 and 6, respectively. It can be seen from Fig. 4, that RCS has reduced by 3.23 dBm^2, 18.22 dBm^2, 0.34 dBm^2, and 1.55 dBm^2 at 63°, 80°, 137°, and 180°, respectively. In order to determine the surfaces for coating, for efficient RCS reduction, the average current density of all the cells of each of 21 flat and 8 curved surfaces is calculated. The surfaces with an average current density greater than -48 dBA/m have been chosen for the RAM coating. Based on this method, 5 surfaces out of 29 were chosen for RAM coating. The savings in surface area due to selective coating has been computed to be about 80% of the total aircraft area. The RCS for this partially coated case is given in Figures 4, 5, and 6. It can be seen that with this partial coating the RCS reduction is comparable to the fully coated case. The surface current distribution on the PEC and RAM coated aircraft is given in Fig. 7.

VI. CONCLUSION

In this paper, a novel method of partially coating the aircraft to obtain reduction in RCS comparable to that obtained by a fully coated aircraft is presented. The RCS of a complex shaped aircraft of size 23λ, 70λ and 233λ at 1, 3, and 10GHz frequencies respectively is determined. In order to effectively reduce the RCS with minimum amount of RAM coating, a method to identify the hot-spots for RAM coating has been proposed. Physical optics (PO) technique has been used first to identify the hotspots on the aircraft and only these hot-spots are coated with RAM instead of coating the entire aircraft. To study the effectiveness of the proposed technique, the monostatic and bistatic RCS of aircraft are analyzed. It has been found that the partial (i.e., hot-spot) RAM coating reduces the RCS, and this reduction in RCS is comparable to that of a fully coated body. This gives a significant saving of nearly 80% in weight and volume of RAM, and thus cost of the RAM coating. This reduction in volume of RAM coating is valuable with respect to complexity of applying RAM coating.

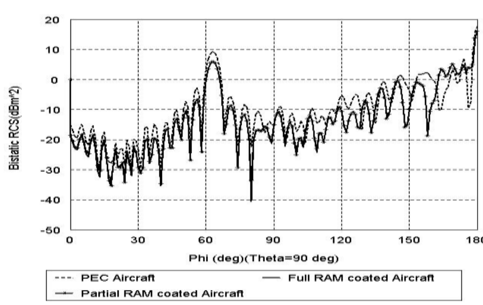

Fig. 4. Bistatic RCS of aircraft at 1 GHz.

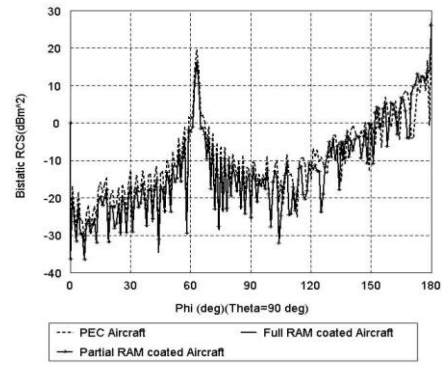

Fig. 5. Bistatic RCS of aircraft at 3 GHz.

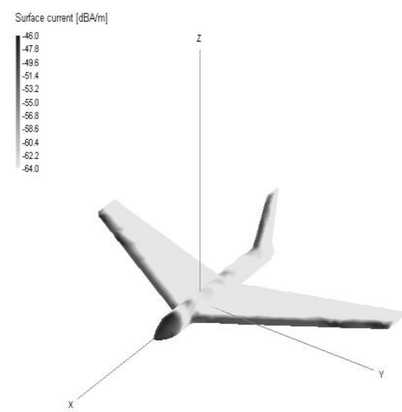

Fig. 6. Bistatic RCS of aircraft at 10 GHz.

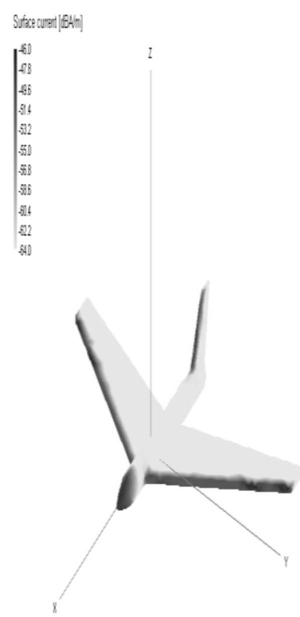

Fig. 7(A). Current Density on A PEC Aircraft & Fig.7 (B). Current Density On A RAM Coated Aircraft.

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 2, Issue 2, August 2012

Table 1: Memory and CPU Time Requirements for PEC and RAM Coated Aircraft

Frequency GHz	Aircraft	No. of unknowns	Peak memory used (MB)	Total time taken for simulation (S)	RAM properties [7]
1	PEC	95,175	57.76	6.73	ε = 20.0 + j 9.0 µ =1.2 +j 12.0
	Fully RAM coated	190,350	60.96	8.36	
	Selectively RAM coated	116,722	58.50	7.20	
3	PEC	857,739	298.14	42.88	ε = 18.0 + j 6.3 µ =0.9 +j 6.3
	Fully RAM coated	1,715,478	431.64	54.66	
	Selectively RAM coated	1,051,991	409.41	47.03	
10	PEC	4,622,085	1568	228.56	ε = 15.0 + j 6.3 µ =0.1 +j 0.32
	Fully RAM coated	9,244,170	2258	290.27	
	Selectively RAM coated	5,646,962	2038	251.42	

REFERENCES

[1] K. J. Vinoy and R. M. Jha, Radar Absorbing Materials from Theory to Design and Characterization, Kluwer Academic Publishers, Boston/London, 1996.

[2] Mauro A. Alves, Rafael J. Port and Mirabel C. Rezende, “Simulations of the radar cross section of a stealth aircraft,” SBMO/IEEE MTT-S International Microwave & Optoelectronics Conference (IMOC 2007), pp. 409-412, 2007.

[3] H. Oraizi and A. Abdolali, “Ultra wide band RCS optimization of multilayered cylindrical structures for arbitrarily polarized incident plane waves”, Progress In Electromagnetic Research, PIER 78, 129–157, 2008.

[4] A. Upendra Raju, and Jyothi Balakrishnan, “Performance analysis of CEM techniques for prediction of RCS of a complex shaped body”, International Journal of Applied Engineering Research (IJAER), ISSN 0973-4562, Volume 7, Number 4, pp. 411-420, 2012.

[5] Andrey S. Andrenko and Makoto Ando, “Analysis of line current wave diffraction from Metal backed dielectric strip by extended PO method”, MSMW'98 Symposium Proceedings. Kharkov, Ukraine, pp. 387-389, September 15-17, 1998.

[6] F S Adana, I G Diego, O G Blanco, P Lozano and M F Catedra, “Method based on physical optics for the computation of radar cross section including diffraction and double effects of metallic and absorbing bodies modeled with parametric surfaces”, IEEE Trans. on Antennas and Propagation, Vol. 52, No.12, pp. 3295-3303, December 2004.

[7] E.F Knott, J.F. Schaeffer and M.T. Tuley, Radar Cross Section, 2nd Edition, SciTech Publishing, Inc. 2004.

[8] Daniel Bouche, Fredric Molinet, and Raj Mittra, Asymptotic Methods in Electromagnetics, Springer-Verlag, Berlin-Heidelberg-New York, 1997, Chapter 7.

[9] N. A. Albayrak, “RCS Computation with PO/PTD for conducting and impedance object modeled as large flat plates,” M.Sc. Thesis, Bilkent University, July 2005.

[10] http://www.feko.info

[11] A.A.Abdelaziz, “Improving the performance of an antenna array by using radar absorbing cover”, Progress In Electromagnetics Research Letters, Vol. 1, pp.129–138, 2008.

[12] D. Klement, J. Preissner and V. Stein, “Special problems in applying the physical optics method for backscatter computations of complicated objects”, IEEE Trans. on Antennas and Propagation, Vol. AP-36, No.2, pp. 228-237, February 1988.

[13] A. K. Bhattacharyya, “Electromagnetic scattering from a flat plate with rim loading and RAM saving”, IEEE Trans. on Antennas and Propagation, Vol. 37, No.5, pp. 659-663, February 1989.

[14] Paul Saville, “Review of Radar Absorbing Materials”, A Technical Report, Defence R&D Canada, January 2005.

[15] M. E. de Cos, Y. Alvarez, and F. Las-Heras, “A novel approach for RCS reduction using a combination of artificial magnetic conductors”, Progress In Electromagnetics Research, Vol. 107, pp.147-159, 2010.

[16] L. Varga, “Radar Signature Control Using Metamaterials”, A Technical Report, Defence R&D Canada, November 2004.

[17] H. Oraizi, A. Abdolali, and N. Vaseghi, “Application of double zero metamaterials as radar absorbing materials for the reduction of radar cross section”, Progress In Electromagnetics Research, PIER 101, pp.323-337, 2010.

[18] A M Lebedev, A I Fedorenko, “Efficient partial concealment of convex conductive body”, PIER Symposium, Suzhou, China, Sept. 12-16, pp175-178, 2011.

AUTHOR’S PROFILE

A. Upendra Raju received his M.Sc. in Electronic Science from Bangalore University in 2000. He is currently a research student in the Department of Electronic Science, Bangalore University, Bangalore, India. His current fields of interests are in computational electromagnetic and radar cross section control.

Jyothi Balakrishnan received her M.Sc. in Physics from Pune University in 1976 and Ph.D in Physics from Indian Institute of Science, Bangalore in 1981. She is currently with the Department of Electronic Science Bangalore University. Her interests are in material characterization, power electronics, device physics and microwaves.