IJSART – volume 1 Issue 7 –JULY 2015 ISSN [ONLINE]: 2395-1052

Electromagnetic & Microwave Absorption Properties of Carbon Black/PU Di-electric Nano-Composite Absorber

K.C. Tripathi[1], S.M. Abbas[2], R.B. Sharma[3], P.S. Alegaonkar[4], Manish Verma[5]

[1, 4]Defense Institute of Advance Technology, DIAT, Giri nagar, Pune-411 025, India
[1,2,5]Defense Materials and Stores Research and Development Establishment, Kanpur-208 013, India
[3]240, DRDO Bhawan, Rajaji Marg, New Delhi-110 011, India

Abstract- *Carbon black powder (CBP) / poly-urethane nano-composites in toroidal shaped sample have been prepared and electromagnetic (EM) and microwave absorbing properties at different thicknesses have been studied using simulation code for metal backed single layer absorber. The vector network analyzer (Model PNA E8364B, Software module 85071E) attached with coaxial measurement set up has been utilized to investigate the EM and microwave absorbing properties of the samples in the frequency range of 2–18 GHz. SEM & TGA have also been carried out to study the micro-structure and thermal stability respectively. The spectra shows that PU offers a low dielectric constant (ε' ~ 2.5) and an almost negligible dielectric loss (ε” ~ 0) in 2-18 GHz frequency range. The Reflection loss (R_L) vs. frequency spectra of PU shows negligible reflection loss (R_L) throughout the frequency range of 2-18 GHz. However, on dispersion of carbon black powder in PU in different proportions, more than 95% (17.07 dB) of microwave absorption is achieved for sample thickness of 2.0 mm at matching frequency of 10.64 GHz and more than 99% (24.60 dB) absorption is achieved for sample thickness of 4.0 mm at matching frequency of 5.1 GHz for optimum wt % 23.07 (300mg) of carbon black filler in 1.0 ml PU. Thus these carbon black powder/PU nano-composite materials can be potential light weight (density ≈ 1.08 g/cc) candidate for EMI shielding, EMC applications and Radar cross section (RCS) reduction purpose.*

Keywords- *Carbon black, Nano-composite, EM properties, Reflection loss, microwave absorber*

I. INTRODUCTION

With the advancement in electronics industries, there is a fast development in the area of ultra high speed switching components, smart mobile phones, high speed Wi-Fi, WLAN, bank ATM, mobile communication, radar communications, microwave oven etc. The number of users of these devices and services are increasing across the world with tremendous speed [1]. All of these devices & services use electromagnetic wave in different microwave frequency region to operate and communicate with associated devices. With the advancement in technologies, high level of integration became possible for miniaturization of electronic circuits. This has generated enormous electromagnetic interference (EMI) and electromagnetic compatibility (EMC) problems at microwave frequencies, which has drastically increased the demand of effective, light weight and efficient microwave absorbers in civil as well as defence sectors [2-4]. These microwave absorbers have the noble property to eliminate or mitigate electromagnetic wave pollution by converting the energy of microwave radiations into heat [1-2, 5]. In defence sector, these microwave absorbers are strategically utilized to reduce the radar signatures by reducing radar cross section (RCS) of the target by applying the coating of these materials on the target e.g. fighter aircraft, ships, tanks etc. These coatings soak the most of the energy of incident microwave from radar and thus there is either no reflected wave from the target or very weak reflected wave and hence producing no image or false echo of the target to the radar system [6-7]. These materials are also named as lossy materials, radar absorbing materials (RAM) or radar absorbing structures. Radar absorbing materials (RAM) have been identified as important class of materials in the scientific community since World War II, parallel to the first introduction of RADAR detection, as counter measure to RADAR detection by virtue of its strong absorbency. EMI/ EMC are also an area where RAM founds its wide applicability to improve the performance of the system under noisy EM environment [6-8]. Recent advents in material science and engineering have evolved several novel materials whose electromagnetic (EM) properties make them ideal candidates for use as radar absorbing materials (RAM). Depending upon their application and ease of implementations, RAM are been engineered to get the desired level of absorption. Recently, several attempts have been made to develop various types of RAM such as pyramid type, cutting cone shaped, bird eye shaped, frequency selective surfaces (FSS), meta-materials (negative refractive index materials), radar absorbing structures (RAS) etc [7-10] These new types of RAM materials can be applied as very thin layers and still maintain their absorption effectiveness making them ideal for radar cross section (RCS) reduction on aircraft, bridges, ships, and other structures [11-12]. Currently, conducting polymer based composites are gaining importance as EMI shielding materials, because of easy synthesis, light weight, low cost, easy to process as well as tunable dielectric and magnetic attributes. Polyurethane (PU) polymers are remarkable host matrices for the assimilation of conductive carbon black (CB) particles. The two-phase character of the PU systems provides an opportunity for the CB particles to distribute non-homogeneously within the phases, owing to their different characteristics [13-14]. It has been seen that carbon black powder (CBP) has shown fabulous microwave absorption properties. There are numerous electric and magnetic properties exhibited by carbon black powder (CBP) and among those, the permittivity (ε, also represented as e) and permeability (μ, also represented as u) are key factors for the RAM designing [15-17]. Additionally, studies have also been conducted to engineer these parameters towards the development of carbon black powder (CBP) based RAMs with significantly bandwidth. The most of the polymeric matrices are transparent to microwaves, and absorption in these materials occurs mainly due to interactive loss processes of dielectric and magnetic dipoles of the particulates suspended in these matrices. Taking optimized wt % of CBP as filler in PU matrix, we have reported potential microwave absorption properties of nano-composite in 2-18 GHz frequency range at different thickness.

II. MATERIALS AND METHODS

A. Nano-Composite Preparation

The nano-composite preparation has been carried out by thoroughly mixing conducting carbon black powder (CBP) (Senka Carbon, India) in acetone medium in mortar and pestle in two pack polyurethane matrix consisting of polyol-8 (Ciba-Geigy, Switzerland) and hexa-methylene di-iso-cynate (E-Merck, Germany) mixed in the ratio of 50:50. Materials used and their sources are given in table 1. The mixture was homogenized in mortar and pestle and then poured in the mould followed by curing it under pre-determined heating rate, constant temperature and pressure in a hydraulic press.

Materials	**Sources**
Polyol-8	Ciba-Geigy, Switzerland
Hexa-methylene di- isocynate	E-Merck, Germany
Carbon black powder (CBP)	Senka Carbon, India

Table 1

B. Microwave Measurements

Microwave absorbing properties have been measured using coaxial line method. Electromagnetic parameters (complex permittivity and Complex permeability) of CBP/PU nano-composites were determined using AGILENT vector network analyzer (Model PNA E8364B, Software module 85071E) in the frequency range of 2–18 GHz.

Further the reflectivities (RL) with different thicknesses (t) have been calculated by using the following equations (1) & (2):

$$Z_{in} = \left(\frac{\mu_r}{\varepsilon_r}\right)^{\frac{1}{2}} \tanh\left[j\left(\frac{2\pi f d}{c}\right)\left(\mu_r \varepsilon_r\right)^{\frac{1}{2}}\right] \quad (1)$$

$$\mathrm{R(dB)} = 20\log_{10}\left|\frac{Z_{in}-1}{Z_{in}+1}\right| \quad (2)$$

where Z_{in} is the normalized input impedance at the interface of the material and free space. $\varepsilon_r = \varepsilon' - j\varepsilon''$ and $\mu_r = \mu' - j\mu''$ are respectively the complex permittivity and complex permeability of the material. The real part of the permittivity/permeability is a measure of the extent to which the material will be polarized or magnetized by the application of electric or magnetic field respectively, whereas the imaginary part is a measure of the energy loss incurred in re-arranging the alignment of the electric or magnetic dipoles according to applied ac fields, d is the thickness of the absorber, c is the velocity of light and f is the frequency of microwave in free space.

III. RESULTS AND DISCUSSIONS

A. Morphological Properties

Morphological properties of polyurethane (PU), Carbon black powder (CBP) and prepared CBP/PU nano-composites have been analyzed by scanning electron microscopy (SEM) (Carl Zeiss EVO-50). The SEM micrographs in fig. 1 (a) & (b) show the morphology of virgin PU at low (1KX) and high (5KX) magnifications, while in fig. 1 (c) & 1 (d) shows that of CBP & CBP dispersed in PU matrix respectively. Fig. 1 (a) & 1(b) show freeze chain like structure on fractured surface. Fig 1 (c) shows coiled spring like structures. Fig. 1 (d) shows freeze impregnated CBP nano-particulate in fractured PU matrix.

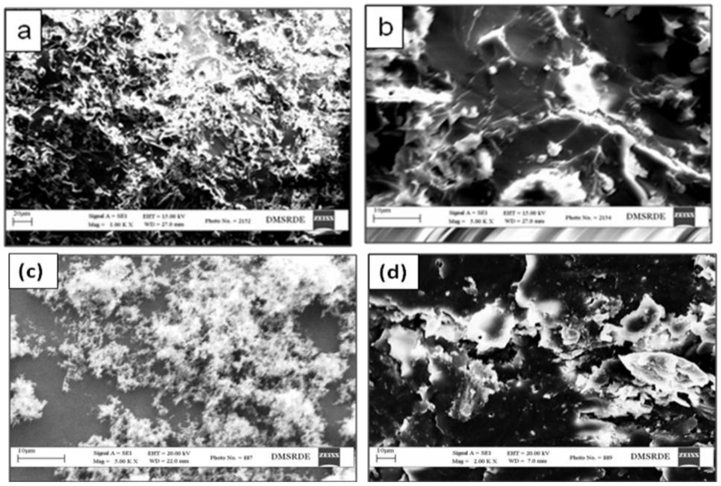


Figure 1: SEM micrographs of (a) virgin PU at low magnification (1K), (b) PU at high magnification (5K), (c) Carbon black powder

at magnification (5K) and (d) Carbon black powder/PU nano-composite.

B. Thermal Properties

Thermo gravimetric analysis (TGA) has been carried out to study the thermal stability of the prepared nano-composite sample. Figure 2 shows the TGA plot of prepared nano-composite which exhibits weight loss in several steps. But the prepared nano-composite is found to have a thermal stability at least up to 301 ^{0}C.

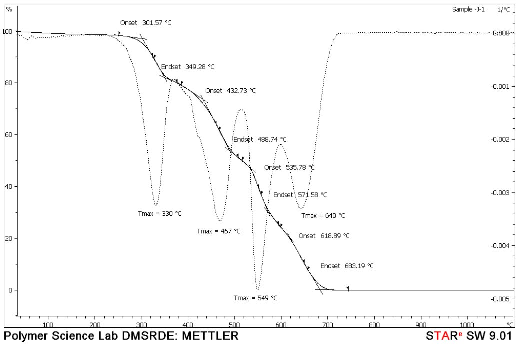
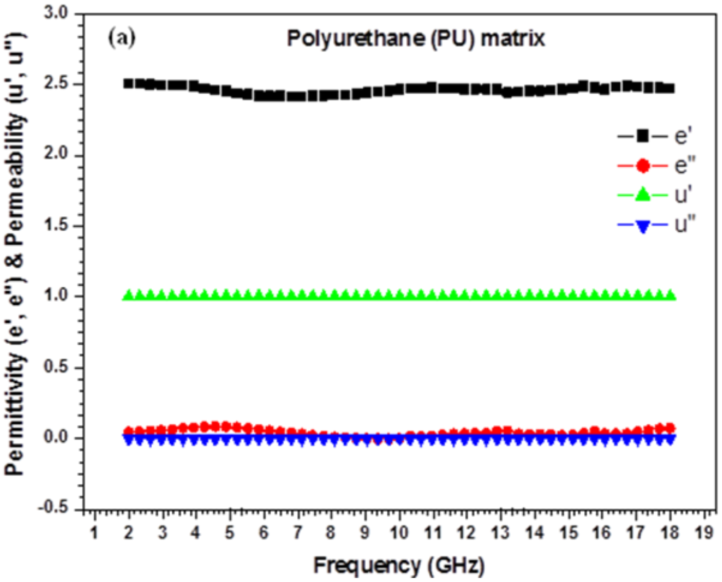


Figure 2: TGA Plot of CBP/PU nano-composite

C. Electromagnetic properties

Fig. 3 (a) shows the variations of complex permittivity (e’& e”) and complex permeability (u’ & u”) of virgin PU matrix with frequency (2-18 GHz) of incident electromagnetic wave. These spectra shows that PU offers a low dielectric constant (e’~2.5) and an almost negligible dielectric loss (e”~0) in 2-18 GHz frequency range. The spectra also shows that PU offers constant complex magnetic permeability (real permeability u’=1, imaginary permeability u”=0) with frequency. This infers that the electromagnetic properties of PU are almost independent of frequency (2-18 GHz) of incident electromagnetic wave.



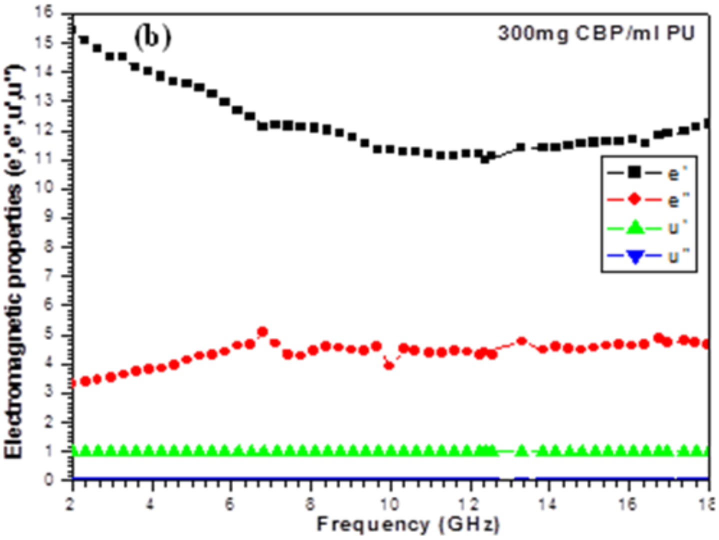


Figure 3: Electromagnetic properties of (a) virgin PU, (b) 300 mg CBP/ml PU

For CBP/PU RAM, the ε_r is varying with the frequency while μ_r is constant throughout the frequency range 2-18 GHz as is depicted from fig. 3 (b). This shows on adding the conducting filler CBP in PU, the electric properties have been modified with frequency of EM wave while magnetic response remains unaffected.

D. Microwave Absorbing Properties

Measured values of e’, e”, u’ & u” are used to determine the reflection loss in PU using equations (1) & (2). Fig. 4 (a) shows the reflection loss (R_L) vs frequency (f, GHz) response for different sample thickness (t = 1.0 mm to 4.0 mm) of virgin PU. Reflection loss varies marginally with frequency. The reason for very small value of R_L is due to negligible dc conductivity of PU & almost zero value of the ac loss contribution (ε''_{ac} ~ 0) because of the absence of conducting filler. Though the fig 3 (a) shows that the electromagnetic parameters (e’, u’) of PU are almost independent of frequency but fig 4 (a) shows the negligible reflection loss ($R_{L,}$ max) of less than 1 dB at higher frequency (10 to 18 GHz).

The reflection loss (dB) of the prepared CBP/PU composite sample having 300 mg carbon black in one ml polyurethane for various sample thickness has been calculated using experimentally obtained values of ε_r and μ_r.

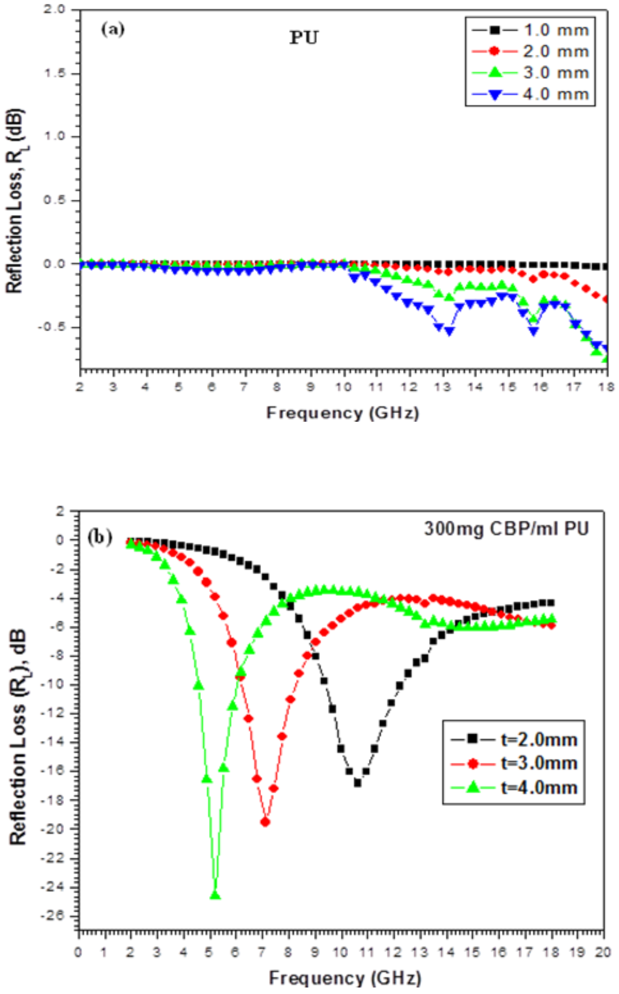
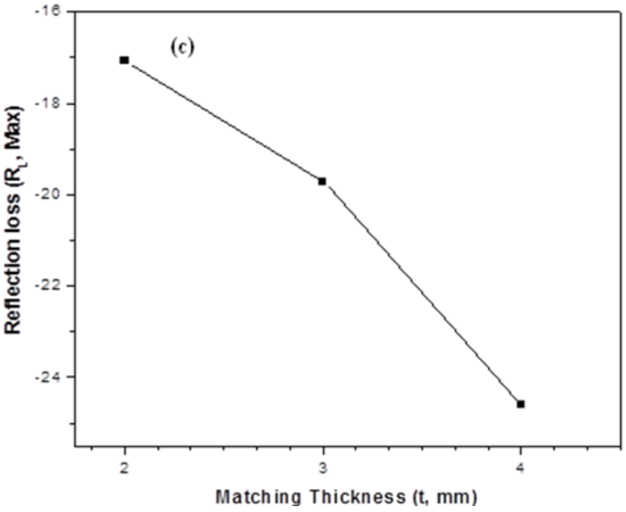


Figure 4: Reflection loss vs. frequency spectra of (a) PU and (b) CBP/PU nano-composite



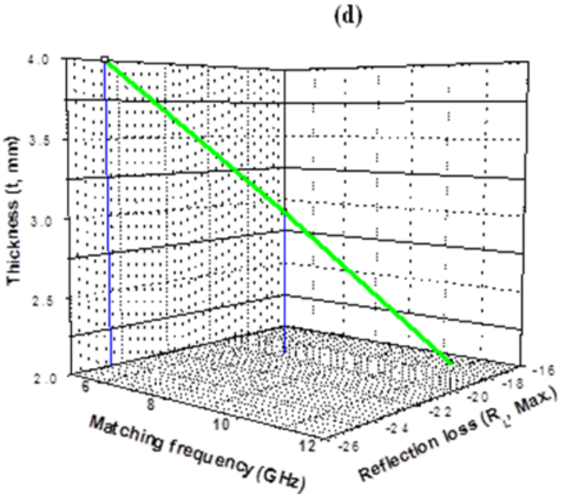


Figure 4 (c) and 4 (d)

Figure 4 (b) depicts the variation of the reflection loss (R_L, dB) with frequency band in 2- 18 GHz for CBP/PU composite. Fig 3 (b) shows that the ε_r is varying with the frequency while μ_r is constant throughout the frequency range 2-18 GHz, hence the reflection loss varies with frequency as shown in fig. 4(b). The reflection loss (dB) maximum is shifted towards lower frequency with increasing thickness. It can be seen from fig. 4 (b) that R_L, max for thickness t=4.0 mm is (-) 24.60 dB at 5.091 GHz, is the maximum observed reflection loss (dB) among all the sample thicknesses. As the thickness increases from t=2.0 mm to t=4.0 mm, reflection loss (dB) R_L, max increases as evident from fig. 4 (c). The probable reason for this behavior can be explained with the help of equation (1) & (2). The fig. 4 (d) shows the 3D plot of the variation of maximum reflection loss with matching frequency for thickness t=2, 3 & 4mm. The observed reflection loss spectra for CBP/PU RAM shows that reflection loss R_L, max is dependent on thickness of PU RAM and there exists a matching thickness for a definite matching frequency at which maximum reflection loss occurs.

IV. CONCLUSION

We have successfully prepared the Carbon black /PU based torroidal shaped nano-composite. CBP/PU composite has a definite matching frequency for a particular thickness. Hence the radar absorbing material can be tuned for a particular frequency (matching frequency) at a fixed thickness. Thus the prepared carbon black /PU based composite may be utilized in stealth technology as well as EMI shielding for particular band of microwave frequencies.

ACKNOWLEDGEMENT

Authors are grateful to Director, AK Saxena, DMSRDE, Kanpur for permitting this work. Authors also thank to Dr. T.C. Shami, Mr. Alok Dixit of DMSRDE, Kanpur for their support in microwave measurements and Ms. Kavita Agarwal for recording SEM images. Thanks also due to Dr. Sangeeta Kale, Professor and Head Department of Applied Physics, DIAT, Pune, for the support.

REFERENCES

[1] S.M. Abbas, Mahesh Chandra, A. Verma, R. Chatterjee a, T.C. Goel, Complex permittivity and microwave absorption properties of a composite dielectric absorber, Composites: Part A 37 (2006) 2148–2154

[2] Devender, Ramasamy SR, Review of EMI shielding and suppression materials. In: Proceedings of INCEMIC – 97: 7B-7, IEEE conference.New Jersey; 1997. p. 459–466.

[3] Emerson W.H., Electro-magnetic wave absorber and anechoic chambers through the years, IEEE Trans Antenna Propag 1973; 21(4):484–490.

[4] Parveen Saini, Veena Choudhary, B.P. Singh R.B., Mathur, S.K. Dhawan, Enhanced microwave absorption behavior of polyaniline-CNT/polystyrene blend in 12.4–18.0 GHz range, Synthetic Metals 161 (2011) 1522– 1526

[5] Ott H. *et al.* Noise reduction techniques in electronic systems. (Wiley, New York, 1988).

[6] John D, Washington M. USAF unveils stealth fighter. Aviat Week Space Technol 1988; 129(Nov14): 28–29.

[7] YC Chung, BW Kim, DC Park, Range of validity of transmission line approximations for design of electromagnetic absorbers, IEEE trans on Magnetics, vol 36, No. 4, pp 1188-1192, July 2000

[8] Nader Engheta, Invited metamaterials with negative permittivity and permeability: Background, Sailent features, and New Trends, IEEE MTT-S Digest, pp. 187-190, 2003

[9] HJ Yoon, Dong II Kim, Two-Dimensional Simulation of Broad-band ferrite electromagnetic wave absorbers by using the FDTD method, J. of the Korean Physical Society, vol. 45, No. 4, pp. 1025-1031, Oct 2004

[10] C Morales et al., Tunable Magneto-Dielectric Polymer Nanocomposites for E. Segal, R. Tchoudakov, M. Narkis and A. Siegmann , Thermoplastic polyurethane–carbon black compounds: Structure, electrical conductivity and sensing of liquids, Polym Eng Sci, 42: 2430–2439. doi: 10.1002/pen.11129 (2004)

[11] Courric S, Tran VH. The electromagnetic properties of poly (pphenylene-vinylene) derivatives. Polymer 1998; 39(12): 2399–2408.

[12] Chung DDL. Review of Electromagnetic interference shielding effectiveness of carbon materials. Carbon 2001; 39:279–285.

[13] Das NC, Khastgir D, Chaki TK, Chakraborty A. Electromagnetic interference shielding effectiveness of carbon black and carbon fibre filled EVA and NR based composites. Compos Part A 2000;31: 1069–1081.

[14] Microwave applications, IEEE Trans on Microwave theory and Techniques, vol. 59, No. 2, Feb 2011

[15] Stonier RA. Stealth aircraft and Technology from World War II – the Gulf. SAMPE 1991; 27(4):9–17.

[16] Abbas SM, Aiyar R, Prakash O. Synthesis and microwave absorption studies of ferrite paint. Bull Mater Sci 1998; 21(4):279–282.

[17] Peng CH, Hwang CC, Wan J, Tsai JS, Chen SY. Microwave absorbing characteristics for the composites of thermal-plastic polyurethane (TPU)-bonded NiZn-ferrites prepared by combustion synthesis method. Mater Sci Eng B 2005; 117:27–36.

Author’s Profile

Dr. S.M. Abbas is presently Scientist ‘F’, Joint Director and head of Central Analytical Facilities in Defence Materials and Stores Research and Development Establishment (DMSRDE), Kanpur, India. He did his M. Tech. in Metallurgical Engg. and Materials Science from IIT Bombay in 1997 and Ph.D. in Physics (Solid state materials) from IIT Delhi in 2007. His area of interest is characterization of materials, development of camouflage materials/ products, Radar and multispectral Camouflage Net, Mobile Camouflage System, and Radar absorbing Materials Composites. He has published 09 papers in reputed journals and presented 10 papers in International conferences. He received two best paper awards: one in International conference on Advanced Materials (ICAM 2007) at IISc., Bangalore, and another in MRSI conference 1997 at BARC Mumbai,. He has also received DRDO cash 1999 for development of thermal Pads.

Dr. R.B. Sharma obtained M.Sc. (Physics) from Agra University (1979), M. Phil. (Physics) from Rajasthan University (1986) and PhD from Pune University (1997). He has taught Physics courses at undergraduate/ Post graduate/ doctoral level for more than 30 years. He has supervised 3 Ph.D. and 8 M. Tech. / MS theses. Presently, he is working as Scientist ‘G’ at DRDO headquarters, New Delhi and also as an adjunct faculty at the Department of Applied Physics, DIAT Pune, India. He has published more than 32 research papers in International journals.

Dr. P.S. Alegaonkar received the M.Sc. degree in Physics (specialization in nuclear techniques) from University of Pune, Pune, Maharashtra (India) in 1999 and Ph.D. degree in Physics from same department in 2004. From Mar 2010, he has joined Defence Institute of Advance Technology, Pune. Presently, he is working in as Assistant Professor in Applied Physics Department.

Mr. Manish Verma received his M.Sc. degree in Physics (specialization in electronics) from University of Lucknow, U.P. (India) in 2005. From 2008, he has joined Defence Research & Development Organisation as Scientist ‘B’. Presently, he is working in as Scientist ‘C’ in DMSRDE, Kanpur. His areas of interests are materials science & electronics.

Mr. K.C. Tripathi received the M.Sc. degree in Physics (specialization in electronics) from CSJM University, Kanpur. U.P. (India) in 1997, AMIETE (CS) from IETE, New Delhi and M. Tech. degree in Computer Science and Engineering from Allahabad Agricultural Institute, Deemed University, Allahabad in 2007. From July 2008, he has joined Ph.D. (Applied Physics) program from Defence Institute of Advance Technology, Pune.