The Optical Society of India
NEWSLETTER

April 2007

Designing 'Superlenses' with Metamaterials

K N CHOPRA, JOBY JOSEPH, AND KEHAR SINGH

The discovery of isotropic, homogeneous, dielectric-magnetic materials that bend light the "wrong way" created a stir in the year 2001. A range of exotic and potentially useful phenomena such as negative refraction, negative Doppler shift, and inverse Cerenkov radiation, have been predicted for this type of man made materials (metamaterials) called left–handed materials (LHM) or negative–index materials or even negative–phase–velocity materials. The most useful application of such materials, perhaps, is for designing the so-called perfect lenses. Although scientists have sought to minimize the lens distortion for centuries, it is only during last 5 years or so that the production of the near-perfect lens has become a realistic possibility. A lot of progress has been made with the creation of the negatively refracting materials which enable rays of light, passing from one material to another to bend in the direction opposite to that described in the conventional optics text books. A negative refractive index wedge deflects an electromagnetic beam incident at an angle to the interface by a negative angle so that it emerges on the same side of the surface-normal as the incident beam. Another distinction between the positive and negative refractive index materials is that whereas a material with $n = +1$, does not refract electromagnetic waves, the one with $n = -1$ can do so. This leads to their being more compact than conventional lenses. Once satisfactorily designed and fabricated, such lenses could find use in modern optics, for communication, entertainment, and data storage and retrieval. Many researchers have devised methods of producing such metamaterials. This is really a significant development as lenses with minimum distortion can be made from flat slabs of these materials, These lenses can be the key components in technological fields such as telecommunications, microwave engineering, and optical engineering where they are expected to have wide ranging applications.

It is well understood that to make a conventional lens with best possible resolution, a wide aperture is required, and that the limit to the resolution is caused by the wavelength of the light. This restriction is huge as it limits the feature size achieved in computer chips and the storage capacity of DVDs. In contrast, there is no limit to the electromagnetic detail contained in an object. However, not all of it makes it across the lens to the image as the longitudinal component of the wave vector becomes imaginary (as value of wave vector perpendicular to the axis becomes large). The wave then acquires an evanescent character and hence has negligible amplitude by the time it reaches the image (this is the reason that they are called "near field" and the propagating waves "far field"). It is found that the negative refraction amplifies the evanescent waves by just the right amount, so that they contribute to the resolution in the image. This makes it possible to fabricate lenses with enhanced resolution.

As a result of the advantages described above, negative refraction in left–handed materials has triggered intense interest in designing microwave and optical lens elements, a flat lens being one of them [1]. In the case of the flat lens, the waves entering from the source refract negatively on both surfaces and meet constructively on the far side of it. Thus a flat lens applies phase correction to the propagating wave similar to a conventional lens made of a naturally available material and having a positive refractive index. However, it operates only when the source is close to the lens. For most applications, far field imaging is required. Negative refraction allows focusing of a far–field radiation by a concave vector from the convex surfaces [1,2], with the advantage of reduced aberrations for the same radius of curvature. Vodo *et al.* [3] have demonstrated that the real image of a far-field radiation can be produced by using left–handed photonic crystal (PhC) lens. This lens apart from giving reduced aberration is lighter and so is suitable for space applications. The tailor made refractive index available in PhC materials allows further control on the focal length and thereby helps reduce the length of the optical system.

In view of the various advantages and the tremendous application potential of such lenses, much interest has been shown by many researchers in studying various aspects of such lenses. Pendry [4], Garcia and Nieto-Vesperinas [5] and Lakhtakia [6] have studied the 'perfect lens' designing aspects using the LHM. Due to the importance of the evanescent waves in the image resolution, considerable interest has been shown in studying the imaging properties and the universal features of the time evolution of the evanescent modes in the left-handed perfect lens by Fang and Zhang [7], Fang *et al.* [8], Gomez–Santos [9] and Grbic and Eleftheriades [10]. Interest has also been shown in using the PhCs for making such lenses. In their investigations on the

President's Message

Let me thank you all for re-electing me as the President of the Optical Society of India (OSI) during the recent XXXII Symposium held at MS University, Vadodara. I feel privileged to have been so honoured and wish to take the opportunity to acknowledge the valuable contributions of all my distinguished predecessors and highly committed members of the earlier Executive Committees. With help from all of you, I look forward to steering the affairs of the Society to achieve the goals we have set for ourselves.

Optics and photonics are the emerging technologies worldwide and it will be our endeavor to propagate these exciting fields in various academic institutes, R & D institutes and industry.

While there is no doubt that OSI faces significant challenges, as do all scientific societies in the current environment, our society has a talent and expertise to flourish. The success of OSI will depend on the interest of its members to get involved in all the activities of the society. On this occasion, I extend my best wishes to all the members of OSI and look forward to their active participation in the affairs of the society.

- J.A.R. KRISHNA MOORTY

OSI NEWSLETTER

The issues of OSI NEWSLETTER is available at the OSI website. PDF copies can be obtained from the Editor (*asharma@physics.iitd.ac.in*).

imaging properties of a metamaterial superlens, Fang and Zang [7] have presented the full-wave numerical results and explained the effect of the loss and the electric mismatch on the image quality, magnification, and the depth of focus in the super-lens. Their simulation results revealed that the power flux is not a good measure to determine the focal plane of the superlens due to the elevated field strength at the exit side of the metamaterial slab. Fang *et al.* [8] have investigated the regenerating evanescent waves from a silver superlens. They have experimentally validated the foundation of the superlens theory, which states that the evanescent waves are regenerated by means of a metal film, thus opening the gateway to accessing the subwavelength features of a near-field object by synthesizing the enhanced evanescent components with the help of surface plasmon excitation. Gomez-Santos [9] has analyzed the time evolution of the evanescent modes in Pendry's 'perfect lens' for ideally lossless and homogeneous LHMs. It has been shown that the time development of subwavelength resolution exhibits universal features, independent of model details. Luo *et al.* [2] have studied the subwavelength imaging in PhCs. Moussa *et al.* [11] have analyzed the negative refraction and superlens behavior in a two-dimensional PhC. Parimi *et al.* [1] have studied imaging by a flat lens made of PhCs. With the evolution of the field, the perfect cylindrical lenses have also drawn the attention of the scientists in this area [12]. Pendry and Ramakrishna [13] have gone further and suggested the refining of the perfect lenses. Grbic and Eleftheriades [10] have shown how to overcome the diffraction limit with a planar LHM lens. This work has been extended by Parazzoli *et al.* [14] who have studied the performance of such lenses of various designs. With the advent of new designing techniques, Wang *et al.* [15] have shown unrestricted superlensing in a triangular two-dimensional PhC.

Considerable work has also been done during the year 2005 regarding the theory, simulation and the testing of lenses. Lu and Sridhar [16] have given the theory of imaging by a flat lens without the optical axis. The case of a lens with graded negative refractive index has been studied by Parzzolli *et al.* [17]. Podolsky *et al.* [18] have given a technique to improve the resolution of the superlens by optimizing its geometry. Schurig and Smith [19] have made use of compensating bilayers in such lenses to achieve imaging. Vinogradov and Dorofeenko [20] have considered the energy transfer through the Pendry's lens and demonstrated that a part of the energy transmitted by the evanescent waves is totally determined by losses and causes phase shift between the evanescent waves forming the source and the image fields. Zharov *et al.* [21] have given the conditions when these lenses with a subwavelength resolution can create an image of the second harmonic field of the source when the source is opaque for its fundamental frequency. The dawn of the year 2006 has sparked off an explosive effort in the studies related with the various forms of the lens shape and the designs of the medium architecture (*e.g.*, split–ring resonators and PhCs). Tassin *et al.* [22] have applied the full wave optics calculations to show that the Veselago's lens can be considered as an imaging system and derived the appropriate lens formula. Li *et al.* [23] have made a detailed study of evanescent waves in such a lens made of PhC and analyzed the far-field imaging. The aberrations in the lenses of the negative refractive index and their use as traps have also drawn the attention of the workers. The chromatic aberration of a magnetic PhC plano-concave lens and its focusing have been studied by Yang *et al.* [24]. Lin and Zou [25] have studied the multilayer flat lenses using negative index materials and shown that the increment in the layer number results in the reduction of the spherical aberration and oblique aberration. Lu *et al.* [26] have come up with a new and realistic application of the "perfect lens" *viz*. electromagnetic traps or tweezers. They have shown that a perfect lens makes a perfect trap by experimentally demonstrating microwave, electromagnetic trapping, and manipulation of neutral particles using a negative refraction flat lens. They have also shown that the advantages of the flat lens, including super-resolution and the absence of the field-curvature, play an important role in improving the overall performance of electromagnetic tweezers. It is expected that the use of a flat lens for optical tweezers will have widespread applications of the technique.

Negative refractive index materials are difficult and costly to produce as they involve complex assemblies of intricately shaped conducting components embossed in the non-conducting platforms. Researchers seem to have overcome this problem by giving a simple method of making such materials by blending two substances together, neither of which refracts negatively by itself. It has been predicted that their homogeneous mixture refracts negatively, provided the relative properties of the substances are chosen appropriately. It seems that Veselago's hypothesis [27] of materials with negative refractive index is being appreciated during this decade. Two important characteristics of these materials are that they exhibit frequency dispersion and their usable bandwidth is relatively narrow compared with positive index materials. The negative refractive index implies that the phase of a wave advancing through the medium is negative rather than positive. Veselago had himself pointed out that this fundamental reversal of wave propagation contains important implication for nearly all electromagnetic phenomena. But the most immediately accessible phenomenon is the reversal of the wave refraction. Another interesting aspect of negative refraction is that the negative media behave like optical antimatter. A slab of material with $n = -1$ acts like a lens, because when the waves enter the negative medium, their phase is wound backwards during the propagation. In this manner , the slab undoes the effect of an equal thickness of vacuum. In the same way, the decaying waves have their amplitude restored by passing through the slab. Thus, the slab seems to annihilate an equal thickness of vacuum, thereby acting like optical antimatter. It is to be noted that the practical application of LHMs requires low loss materials and so there is a great challenge to the designers of the new metamaterials.

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Forthcoming Events

XXXIII Optical Society of India (OSI) Symposium on Optics and Optoelectronics

Tezpur, Assam, December 18-20, 2007
Contact: Dr. P.P. Sahu, Convener, OSI Symposium,
Department of Electronics and Communication Eng.
Tezpur University, Napaam,
Tezpur-784028, Assam
E-Mail: osi@tezu.ernet.in
URL: www.osiindia.org

International Conference on Microwaves and Optoelectronics (ICMO – 2007)

Aurangabad , December 17-20, 2007
Contact: Prof S.C. Mehrotra,, Chairman ICMO – 2007
Department of Computer Science & IT
Dr Babasaheb Ambedkar Marathwada University,
Aurangabad – 431 004, Maharashtra State
E-Mail: suresh_mehrotra@yahoo.com

Recent Ph.D. Theses

Renu John , *Investigations on content-addessable holographic memories and optical data Security* (Indian Institute of Technology, Delhi, 2006); supervisor: Prof. Kehar Singh.

Anuj Kumar Sharma, *Studies on surface plasmon resonance based fiber optic sensors* (Indian Institute of Technology, Delhi, 2006)*;* supervisor: Dr. B.D.Gupta.

Charu Kakkar, *Studies on fiber designs for enhanced optical fiber amplifier performance* (Indian Institute of Technology, Delhi, 2006); supervisor: Prof. K Thyagarajan.

Amarendra Kumar Sarma, *Variational and numerical study of soliton switching in two and three core couplers with higher order perturbations* (Indian Institute of Technology, Delhi, 2006); supervisor: Prof. Ajit Kumar.

Priti Singh, *Application of shearing interferometry in optical metrology* (Indian Institute of Technology, Delhi, 2006); supervisors: Prof. Chandra Shakher, Prof. Ajit Kumar and Prof. R S Sirohi.

Saba Mirza, *Use of phase shifting Talbot interferometry for surface profiling and DSPI for montitoring measurement of vibration* (Indian Institute of Technology, Delhi, 2006); supervisors: Prof. Chandra Shakher and Dr. A L Vyas.

(Members are requested to send items for this column to the Editor for future issues).

News

Dehradun Chapter of the OSI

Annual meeting of Dehradun chapter of Optical Society of India was held on 19 May 2006 at IRDE, Dehradun. Around 150 participants attended the meeting including seventy members of OSI. The members felicitated Shri. J. A. R. Krishna Moorty, Outstanding Scientist and Director IRDE on being elected as President of Optical Society of India for 2006-07. Dr. A.K. Gupta briefed the member about the events of previous year and activities planned for next year. The following executive body nominated for the current year

President: Dr. A.K. Gupta
Secretary: Dr. A.N. Kaul
Joint Secretary: Dr. Naveen Nischal

Delhi Section of the OSA

The Delhi Section of the Optical Society of America has been awarded the 2006 Excellence Award by the OSA. The award carries a certificate and a cash prize of US$1,000. For more information about the Section, please contact the Secretary: Professor Anurag Sharma (asharma@physics.iitd.ac.in).

(Members are requested to send items for this column to the Editor for future issues).

Reports on Events held

International Conference on Optics and Optoelectronics (ICOL-2005)

(XXXI OSI Symposium)

Dehradun, December 12-15, 2005

ICOL-2005, jointly organized by the Optical Society of India and the IRDE, Dehradun, aimed to provide a wide forum for interaction and exchange of ideas among scientists, engineers and researchers actively engaged in the area of optics & optoelectronics. The conference started with the inaugural address by Sh. M. Natarajan, DG R&D and Scientific Adviser to Defence Minister, followed by a plenary talk entitled, The role of electrooptics in the new battlefield by Dr. Gabby Sarusi, Israel.

The conference received overwhelming response from academicians, scientists, engineers, and industry professionals located the world over. Besides India, the conference had participation from 26 countries, especially from Argentina, Bangladesh, Canada, China, Czech Republic, Denmark, Finland, France, Germany, Iran, Israel, Italy, Japan, Korea, Mexico, Netherlands, Pakistan, Poland, Russia, Serbia, Singapore, Spain, Switzerland, Taiwan, UK, USA. . In addition to DRDO, the other Government funding agencies, which sponsored the conference, were DST, CSIR, INSA, DIT and DAE. Internationally, the conference was sponsored by Optical Society of America (OSA), SPIE, ICTP and International Commission for Optics (ICO).

Professors Ajoy Ghatak and Kehar Singh from Indian Institute of Technology Delhi were the technical chairs of the conference. There were 85 invited talks delivered by leading scientists/experts in their respective areas of specialization. In all 68 speakers from abroad and 17 from India delivered invited talks during the conference. There were 100 (25 from abroad & 75 from India) contributed oral papers and 360 (27 from abroad & 333 from India) contributed poster papers. In all, there were 47 technical sessions distributed into five parallel sessions. The total number of registered delegates was 647 including 57 exhibitors and 196 student delegates. Besides India, exhibitors from 10 countries also participated actively in the conference. Two techno-commercial sessions, parallel to poster sessions, were also organized on 13th and 14th Dec., 2005.

The focal theme of the conference was Optics and Optoelectronics for Strategic Applications and the conference deliberations were classified into 14 research topics viz. Adaptive Optics; Bio-photonics; Fiber & Integrated Optics; Holography & Diffractive Optics; Laser & Applications; Nonlinear Optics; Optical Design, Fabrication & Technology; Optical Interferometry & Metrology; Optical Information Processing; Optical Materials, Sensors & Displays; Optics & Optoelectronics for Strategic Applications; Optoelectronics & Photonic Devices; Photonic Bandgap Structures; and Quantum Optics & MOEMS.

OSA and OSI had announced best paper awards to the young scientists presenting papers in the conference. Two OSA awards of US$ 1,000 each were given to the research students Mr. Anith Nelleri of IIT Delhi and Ms. Rijuparna Chakraborty of Calcutta University. Five young scientists, Mr. Deepak Gupta and Ms. Sonali Das Gupta of IIT Delhi, Ms. Pubali Mukherjee of Calcutta University, Mr. Pranab Mukhopadhyay of CAT Indore and Ms. Sakshi Gupta of LASTEC Delhi were selected for ICOL-2005 cash awards (given on behalf of Optical Society of India).

Further details of the conference program, invited talks and exhibition are available at the conference website: www.icol2005.com.

Response from Readers

Optics Industry in India: An Important Omission

I am a founder member of the Optical Society of India, and also a student of Prof. M.De at the then Applied Physics Dept. of Calcutta University in 1950-52 Though I have not kept much contact with the OSI in recent times, particularly after my retirement from B.O.G.L. Durgapur in 1988, I am a regular reader of the Journal of Optical Society of India.

I went through the article 'A review of Optical Manufacturing Industry in India' by Sri. Basant Bande published in the OSI Newsletter of June 2005, and found a serious lapse, if I am permitted to say so! The article does not mention of the valuable contributions of the Bharat Ophthalmic Glass Ltd. (B.O.G.L.), Durgapur, in the field of optical industry in India !

I have tried to give a short description and history of the Undertaking (*please see a short article in this issue- Editor*). I shall be obliged if this is put up as a note, supplementing the article of Sri Bande, to acquaint the readers of the contribution of B.O.G.L. towards the development of optical industry of India.

MALAY KUMAR SEN GUPTA.
Ex CMD and Chief Technologist,
B.O.G.L., Durgapur
R.B./ 3 Komrov Path,
Bidhannagar, Durgapur.

(Members are requested to responses to the Editor for future issues)

Bharat Ophthalmic Glass Limited, Durgapur

MALAY KUMAR SEN GUPTA

The B.O.G.L. was set up as a P.S.U., in collaboration with the Govt. of U.S.S.R., in 1968 at Durgapur, initially to manufacture the total requirement of ophthalmic glass in India, but in the subsequent years it started manufacturing various types of optical glasses also, on a commercial scale. It also manufactured various types of finished optical lenses and components, both for the Defense Dept. and the private optical industries. There is hardly any optical manufacturing unit in India, which has not used the various types of optical glasses such as H.C., B.S.C., D.F., E.D.F., D.E.D.F. and filter glasses manufactured by B.O.G.L. In addition, of course, the spectacles manufacturing units of the country were regular users of its ophthalmic glasses. A large portion of the periscope prism blanks required for battle tanks by the Ordnance Factory, Dehradun used to be supplied by B.O.G.L. even in the recent years, before its production came to stop a few years back due to various reasons.

A most important achievement of B.O.G.L. was that it was the first to manufacture a few types of large size Radiation Shielding Windows for the B.A.R.C. for some of its nuclear facilities, the Kalpakkam nuclear plant being one of them. It is true that some small R.S.W. were manufactured and supplied by C.G.C.R.I. initially, but large size R.S.W. of more than a Meter dimension goes to the credit of B.O.G.L., for which it won the President's Silver Award!

The Undertaking was run by the Ministry of Industrial Development, Govt. of India. However, necessary modernization of the plant was not done, and after relaxation of the import policy of the Government production had to be closed due to lack of market, as the prices were not competitive.

Professor I.C. Goyal

AJOY GHATAK

It is with great regret that we announce that after a brief illness, Professor Ishwar Chandra Goyal passed away while visiting University of Braunschweig, Germany on August 18, 2006. Ishwar (as I used to call him) was born on June 10, 1941 in Gangoh (a small town in UP) and did his MSc in Physics from Roorkee University (now IIT Roorkee) in 1962. He was an outstanding scholar and stood first in the MSc examination. Subsequently he joined Delhi University to do his PhD with Professor LS Kothari in Neutron Transport Theory. I came back from the US in October 1964 and at

PROFESSOR ISHWAR GOYAL WITH PROFESSOR GHATAK (ON THE LEFT) AT IIT DELHI WHILE WORKING ON THEIR BOOK ON *MATHEMATICAL PHYSICS*. THE PHOTOGRAPH WAS TAKEN BY PROFESSOR RAMAKANT SRIVASTAVA AROUND 1992.

that time I was also working in the same area and right away we started working together on some very interesting problems (and therefore for me it has been a close association of 42 years!). Ishwar had an amazing capability of solving very difficult problems using the computer. I very vividly remember that both of us developed a (Fortran) program to diagonalize a 30x30 Hermitian matrix; in 1965, the Physics Department of Delhi University had a very small IBM computer with very little memory; as such, Ishwar wrote the entire program in machine language to diagonalize the matrix. Everyone there was amazed to see his capabilities. In 1966, I joined IIT Delhi and in 1967 he also joined IIT Delhi. We both continued to work together in Neutron Transport Theory and had 4 students who eventually got their PhD degree in this area. Around 1970 Professor Sodha asked me to work in the general area of fiber optics and Ishwar also joined me in this endeavour. We then worked on a variety of problems together starting from the analysis of gas lenses to making aberration analysis of graded index media and studying wave propagation in guided structures. During 1973-74, Ishwar spent about one year in Professor Gambling and Professor Payne's group at University of Southampton and then in 1981 he went to University of Braunschweig in Germany (as an Alexander von Humboldt fellow) to work in the group led by Professor Hans Unger; he made 2 more visits there and it was during his last visit to Braunschweig (in summer of 2006) that he breathed his last. Just before his illness, he was working with Dr Reinhard Caspary (at University of Braunschweig) on the design of special fibers. From January 1989 to June 1990, he was at NIST (National Institute of Standards and Technology) at Boulder and started working on the use of Airy functions for problems in waveguide theory and also in the analysis of quantum well structures. This resulted in a large number of research papers of extremely good quality because of which he went to NIST for 5 consecutive summers. Our collaborator in NIST was Dr Bob Gallawa and between us we would call the methodology developed by us as the GGG method!

Apart from his extremely important research contributions, he was an exceptionally good teacher and his students would always consider him as one of the best teachers at IIT Delhi. He also coauthored three books: the first one was on the use of Airy functions in solving problems in waveguide theory and also in quantum mechanics; the second book was on Mathematical Physics – a subject that he dearly loved and the third book was on developing a software for the analysis of optical waveguides. This shows the versatility of his thoughts.

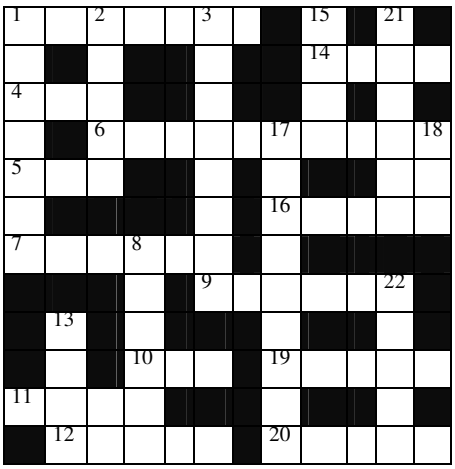
Ishwar was an avid bridge player and would help a large number of his friends in tax saving and tax calculations; in fact, he would try his level best to help anyone who would come to him. Ishwar's premature death has robbed us of an outstanding teacher, a dedicated researcher and above all, a great human being; we miss him greatly. On a more personal level, I have lost a very dear and close friend and colleague.

Suggestions & Contributions

A regular publication this OSI NEWSLETTER can be sustained only through active participation of the members and we seek suggestions to improve its contents and presentation. We also seek contributions from members to various columns of the OSI NEWSLETTER. In additions to the columns in this and the earlier issues, the future issues will also have interesting anecdotes/incidents involving optics or members, historical notes and any other information that could be useful or interesting to the members. Readers are particularly urged to send their responses/reactions to this and earlier issues. Contributions and proposals may please be sent to the editor. The next issue is scheduled for August, 2007. Members who want to receive the future issues of the OSI NEWSLETTER by email may send their email addresses to the editor.

OPTICS CROSSWORD

KALLOL BHATTACHARYA



ACROSS

1. Famous for microscopic phase visualization (Nobel 1953) and his polynomials(7)
4. Pre-recorded CDs discs are optical this (3)
5. Film speed with confused noise (3)
6. The process quantified by Beer-Lamberts' law (10)
7. He and Binnig (Nobel 1986) were the inventors of scanning tunneling microscope (6)
9. Full-silvered optics – plane, vex, cave or whatever (6)
10. Excess of these causes electric spark, lightning and thunder (3)
11. Gradually changing refractive index materials with broad smile! (4)
12. Referenceless On-Axis Complex Hologram; a detestable pest (5)
14. A pet name for the ubiquitous gas laser (4)
16. Light that first emerged in 1960 from a lopsided population.(5)
19. Femto powered minus six, atto powered minus three (5)
20. Known for his interferometer – used in transmission interference microscope (5).

DOWN

1. Trade name of a low thermal expansion glass ceramic material commonly used as substrate for telescope mirrors (7).
2. The Nobel (1930) man of India (5).
3. A generic term for computer generated surface relief phase holograms (8).
8. Active screen of the visual system (6).
13. Quadratic electro optical effect is named after this Scottish physicist (4).
15. Photometric unit of illuminance (4).
17. Light emerging from a Polaroid filter is this (9).
18. Acronym for the range of wavelengths from 0.75 – 1.4 microns (3)
21. To convert information into data for transmission or processing (6)
22. Suffix for prismatic reflectors that returns light in nearly the same direction as the incident beam (5)

Answers will be given in the next issue

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