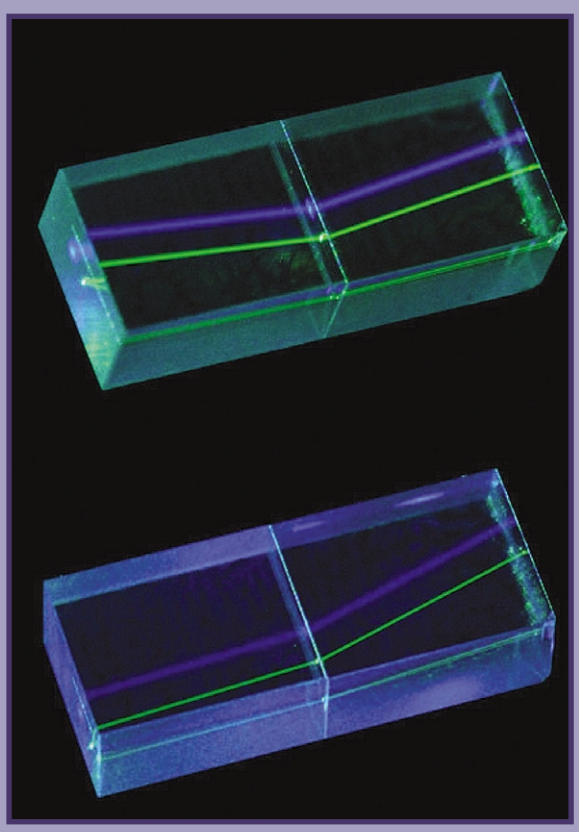
Clifford M Krowne

Clifford Krowne is described as a theorist investigating the physical basis of negative refraction, who feels that a new physics is involved. "We are beaming waves around active devices that are quantum-sized [the structures have sizes in the same range as the wavelengths of the radiation]," he says. "We are looking for basic physics solutions that haven't been studied before." He reports on this year's American Physical Society meeting in Montreal.

Current thinking on Left-Handed Materials

A general impression from two sessions [1], [2] of contributed papers at the American Physical Society meeting in Montreal in March (and recent published literature and other conferences in physics and optics [3] and electronics [4]), is that Left-Handed Material (LHM) properties can indeed be made and measured, even with the significant degree of loss seen in metallic based structures.



Images of light propagation in a YVO_4 bicrystal showing total refraction. Furthermore the material is amphoretic: it can refract in a positive or a negative way. The upper panel shows an example of abnormal (negative) refraction, the lower panel shows an example of normal (positive) refraction. Note that no reflection is visible at the bicrystal interface to the naked eye. The green light ray has a wavelength of 532 nm, while the blue ray has a wavelength of 442 nm.
Reported by: Zhang et al., Physical Review Letters, *10 October 2003*

For low loss optical focusing lenses and guided wave electronic components based on LHMs, this loss may present an obstacle for implementation in real systems. But that could be overcome by the use of metallic structures with reduced amounts of metal, or non-metallic structures, some of which were treated in these sessions.

In the morning session on Metamaterials for Negative Refraction and Related Phenomena, Willie Padilla began by showing how one can scale down in size the metallic split ring resonators and rods (SRR-R) to make terahertz left-handed material. Sizes are now on the order of microns for these elements of which the LHM is composed. The LHM property is created by simultaneous attainment of negative permittivity and permeability values.

Yong Zhang then demonstrated that ordinary material bi-crystalline arrangements can be found, which give total refraction, while producing for certain incidence angles either positive or negative refraction, the latter mimicking a basic property of LHMs.

My paper finds that similar arrangements of bi-crystals found by Zhang et al can generate asymmetric electromagnetic field distributions in guided wave structures, something that could potentially be used in electronic devices.

Yuri Kivshar discussed the nonlinear aspects of the SRR-R combination, and pointed out that the

The material politics of left and right

In a 2003 article in *IEEE Spectrum* on Left-Handed Materials Go from Fact to Fiction and Back Again, author Alexander Hellemans looked at the theoretical conundra and pointed out that: "For nonspecialists in optics or microwave communications, the job of sorting out experimental findings is not helped by disagreements among the top experts on left-handed materials. The idea of a flat optical lens that escapes the diffraction limit, considered by some like Imperial College's (London) John Pendry to be the Holy Grail of negative refraction, is considered by others to be flatly absurd. By the same token, the notion that negative permeability and permittivity are what's needed to make negative refraction possible – a truism since the 1960s, when the Russian physicist Victor Veselago postulated the phenomenon – now are said to be not absolutely necessary after all.

"Despite the extraordinary properties of metamaterials, Rodger Walser, of the University of Texas (Austin), argues that they may turn out to be of merely academic interest, with little or no applicability to radio frequency engineering. Though he agrees that the carrier waves of microwave beams can be negatively refracted, he thinks that the modulation of the beams - which carries their information - will be lost because of the inhomogeneous nature and low intensity of the refracted wave. "We have no problem with the carrier waves refracting. Our argument is that the information cannot negatively refract," says Walser.

If he's right, the story of left-handed materials could end the same way cold fusion did ... While the materials and the phenomena do exist, whereas cold fusion does not, they may still have no practical use.

[Source:http://www.spectrum.ieee.org/WEBONLY/wonews/jul03/lhand.html]

Intrigued by what is obviously a heavily political issue research topic, *III-Vs Review* canvassed opinions.

Yet another and pragmatically interesting angle on the controversy to emerge from researchers was: that "If physics and optics specialists stopped hogging the playing field in major US journals, and stopped dominating the US American funding agencies, to allow in others with different insights, this area is capable of fruition.

"Without this, however, the few heavily funded research areas which appear in lead journals, will have funded their own private enterprises, and jilted the field's future.

"The ideas, in the optics and physics of LHM focusing and the physics of field distributions in LHM guided wave devices, are all sound and there are distinct cases where specialised LHM focusing uses will become apparent in the optics area, and specialised uses for LHM guided wave devices in the integrated circuit compatible microwave and millimeter wave areas.

"Substrates will have dual use LHM optical and LHM microwave electronic uses.

"Furthermore, in the microwave community, people are exploring lumped element realisations of lower dimensionality left-handed circuits.

"These are then 'lumped element' type left-handed materials. Not materials in the sense of being intrinsic crystals or fully tiny microscopic metamaterials, but something between this and hybrid circuits."

Any other voices?

Gail Purvis

hysteresis-type dependence of the magnetic permeability on the field intensity can cause a LHM to become a right-handed material (RHM). Costas Soukoulis discussed LHMs made of SRR associated with continuous (instead of short-rod) wires, and made the very important point that transmission measurements must be examined quite carefully to extract out the equivalent negative ε and μ regions of operation.

It was refreshing to hear this speaker's candor and honesty, where he noted that previous research, presented either by himself or others had thought they obtained LHM behaviour, when, in some cases, they did not.

Visa problems with a speaker being unavailable, meant that Soukoulos gave the next talk too, and mentioned that the extra time a wave spends at an interface of a photonic crystal is twice as large for a negative refractive index (NRI) material as for a positive refractive index (PRI) material.

Suzanne Erickson presented work on a 1D metamaterial, periodically loaded, transmission line, that exhibits negative and positive group delays. This work is from a group looking at lumped element LHM behaviour, with wider frequency bands as against the narrower bands of LHM behaviour seen in SRR-R based or photonic LHMs. Emiliano Di Gennaro then covered microwave pulse propagation measurements in LHM, which suggest that the group velocity is very low in LHM composed of SRR-R. Such measurements were also made in photonic crystals.

In the afternoon session, S.T. Chui began by presenting a study on metallic mag-

Chemical chirality accepted ...

The National Science Foundation is supporting development of Christopher Levy's innovative chemistry courses at Kansas State University with a five-year, $500,000 grant to the K-State assistant professor of chemistry. It also supports Levy's research into developing molecules shaped like helices from inexpensive, easily obtainable starting materials.

He hopes to use these as catalysts to drive chemical reactions that produce an excess of molecules that are either right- or left-handed. Such handed or 'chiral' molecules can serve as critical building blocks for biologically active compounds, such as pharmaceuticals. Controlling the handedness of drug molecules is essential for them to have the desired effect, and to avoid dangerous side effects.

netic nanoparticles embedded into an insulating host matrix, using an effective medium approximation, which seemed to suggest that such anisotropic composites may give LHM behavior near the ferromagnetic resonance. The following speaker, Graeme Dewar discussed a similar system, in that it used non-conducting magnetic material. Here however, the host matrix is the ferromagnetic material, with periodic inclusions of metal wires coated with a dielectric. One looks for frequency regions where the host material and the coated wires give $\varepsilon < 0$ and $\mu < 0$, and sees where the index of refraction goes negative.

Mark Wheeler showed that it may be desirable to look at other metallic inclusion designs, like metallic crosses which have large capacitance between elements, to provide the negative effective index of refraction (NIR). His 2D structure, modelled using finite difference and matrix pencil methods, may be much easier to fabricate than the conventional SRR-R based LHM, since it is not a composite.

Alexei Efros followed, emphasising that photonic crystals (he looks at 2D) are a great way to get LHM behavior, and that it can be shown that equivalent ε and μ can be extracted, which are both negative, just as in metamaterials made from SRR-R combinations where explicit regions of $\varepsilon < 0$ and $\mu < 0$, are seen.

Zhen Ye et al used multiple scattering theory to examine 2D photonic crystals and demonstrated that care should be used in interpreting a material as LH.

In the first of his group's two papers, Srinivas Sridhar et al studied NR and imaging in a 2D photonic crystal made up of alumina rods in a square lattice in a parallel-plate waveguide setup at microwave frequencies.

I then showed the effects of introducing anisotropy to LHMs and the effect on propagation in guided wave microwave structures. Amongst various features seen, it is found that one may switch the field distributions, causing change from bulk to surface waves. Finally, Sridhar discussed studies of triangular lattice based metallic photonic crystal prisms, both in parallel-plate and free space laboratory configurations. Their X-band results are in agreement with angle of refraction numerical results, and band structure and equi-frequency surfaces were used to find regions of NR.

References:

[1] Session P19 on Metamaterials for Negative Refraction and Related Phenomena: I at the March 2004 American Physical Society Meeting, *Bulletin APS,* Vol. 49, no. 1, Pt. 2, pp. 927 - 929.

[2] Session S19 on Metamaterials for Negative Refraction and Related Phenomena: II at the March 2004 American Physical Society Meeting, *Bulletin APS*, Vol. 49, no. 1, Pt. 2, pp. 1068 - 1070.

[3] For focusing physics and optics research done using LHM, refer to *Physical Review* B and E in the last five years, *Physical Review Letters* in the same time period, *Journal Applied Physics* in the same period, sessions at the June 2003 CLEO /QELS Conference on Left Handed Materials, session K22 on Optics of Negative Index and Left-Handed Materials at the March 2003 American Physical Society Meeting (*Bulletin APS*, Vol. 48, no. 1, Pt. 1, pp. 578 - 580), and the online April 2003 issue of *Optics Express* (Optical Society of America).

[4] For antenna structures providing focusing, antennas using LHM, and non-radiating electronic circuit components, refer to the special Oct. 2003 issue of *IEEE Trans. Antennas and Propag.* (Vol. 51, no. 10) on Metamaterials, sessions at the June 2003 IEEE MTT-S Intern. Microwave Symp. on Negative Refractive Index Materials and Applications and on Negative Index Materials and Microwave Applications (Vol. 1 of the *Digest*), and the *IEEE Trans. on Microwave Theory and Tech.* in the last few years. Also this years session at the June 2004 IEEE MTT-S Intern. Microwave Symp. on Metamaterials: Left-Handed Materials and Transmission Lines.