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View on the history of electromagnetics of metamaterials: Evolution of the congress series of complex media

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Abstract

This article describes some of the paths through which electromagnetics research of complex media and metamaterials has reached the present active state. In particular, events of a period in 1990s will be illuminated during which new scientific contacts between Former Soviet Union and the West were established. The series of chiral and bianisotropic meetings between 1993 and 2006 appear as a precursor to today's series of metamaterials congresses.

Keywords: Chirality; Anisotropy; Bianisotropy; Metamaterials; Electromagnetics; Optics

1. Introduction

In today's electromagnetics, metamaterials have secured an important position as a general research paradigm. Furthermore, it is not only the electromagnetics scene in which metamaterials have changed the topics and modes of research but also areas like optics, acoustics, thermodynamics, materials science, and others have been strongly affected by the potential of the new findings in this field. Complex materials research has attracted the attention of many investigators over the past decades; however, the word *metamaterials* is most probably an invention of the present century [1]. It seems that the classical electromagnetics literature does not recognize this term. The presently accepted opinion is that the term was coined by Rodger Walser around 2001 [2] for a man-made and optimized periodic material structure that displays novel and desired macroscopic properties. The definition of the term ''metamaterials'' has been a matter of discussion for a long time; see for example [1,3–5] and references therein for various ideas and aspects on how the word has reached new meanings during recent years.

However, nothing emerges from total emptiness. Not even metamaterials research. There exists a fascinating prehistory of the topic of metamaterials in the scene of microwave and electromagnetics communities. It is the intention of the present article to bring into forefront some of the developments that have led to the flourishing state of metamaterials studies across physics and engineering disciplines. In particular, the aim is to cast light onto the precursors of the series of various ongoing meetings and congresses that attract hundreds of participants yearly [6,7].

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In the latest *Metamaterials* Congress (Bordeaux, France, 16–21 September 2013), an Evening Special Session took various viewpoints into the past, present, and future of metamaterials research, concentrating also on the roots of the *Metamaterials* congress series [8–12]. Here we present an extended version of the talk [8] in the Special Session. The article focuses on the connections of the metamaterials field with the optics and radiophysics activities in the former Soviet Union and Belarus. It is important to point out that the today's series of metamaterials meetings have also other ancestors, like the Italian workshop series under the label *Metamaterials and Special Materials for Electromagnetic Applications and Telecommunications* [10].

2. Over hundred years of complex media and electromagnetics

Dielectric matter refracts the propagation of the ray of an electromagnetic wave. The refractive power of matter depends on the polarizable character of the inclusions that constitute it, and this connection was described in late 1800s by the Clausius–Mossotti relation [13–15]. It was observed already in the first part of the 19th century, however, that the effect of matter of wave propagation can be more complicated if the medium is birefringent. The analysis of such effects in anisotropic and chiral materials requires understanding of the concept of polarization of light. Advances in these areas were championed by French scientists: Malus, Arago, Biot, Fresnel, and Pasteur, among others.

The effect of birefringent and dichroic media to radio waves could be manifested after the experimental demonstration of the existence of Maxwellian electromagnetic radiation by Heinrich Hertz in the late 1880s. And the earliest researches on radio wave propagation in artificial materials can be traced back for over a hundred years. The studies of Jagadish Chandra Bose and Karl Ferdinand Lindman [16] showed that by fabricating a mixture of handed elements in a neutral background medium, the polarization of a plane wave will be rotated during transmission through the medium. Their experiments were at millimeter and microwave frequencies, respectively.

The advances in radio engineering were rapid as both the theoretical understanding in electromagnetics and fundamental technologies in electronics progressed during the 20th century. Along with this evolution, several studies on optically active media and their effects on wave propagation, like manipulation of the polarization, were published. But it was not until in the 1980's when more systematic and analytical studies on chiral media appeared on the electromagnetics arena (see, for example [17,18]). These researches gave impetus to increased activity in bianisotropic materials studies in the 1990s. Bianisotropic media are more general than chiral materials in that they allow for non-reciprocal magnetoelectric effects (chirality is a reciprocal magnetoelectric phenomenon), and also due to their anisotropy (the response is dependent on the vector direction of the exciting field) [20]. Concerning the terminology, an interesting detail is that the term *bianisotropic* first appeared in the doctoral thesis of Jin Au Kong in 1968 [19], in connection with his research work supervised by David K. Cheng in the Syracuse University, USA.

3. Fedorov–Bokut school in Belarus

During the Cold War, the political relations between "West" (meaning Western Europe and the USA) and "East" (the Soviet Union and the socialist block in Eastern Europe) were tense. Inevitably and unfortunately, this was reflected in the lack of scientific contacts over the iron curtain. Also the field of electromagnetics of complex media was a victim of this separation. Without natural interaction between East and West, much of the research on optics of anisotropic media was duplicated, and the lack of communication led to different traditions in the formulations and notations in analysis of the phenomena.

In particular, there flourished an active community in theoretical physics in Belarus, founded by (later Academician) Fedor I. Fedorov (1911–1994) already in the 1950s [16,20]. Another contributor to this research program was B.V. Bokut (1926–1993). The fruitful Fedorov–Bokut school produced over the years a number of scientists, publications, books, and research results within electrodynamics and optics of complex media.

During early 1990s, increasing contacts were established over the political boundary. The 10th All-Union Symposium on diffraction and wave propagation took place in Vinnytsia, Ukraine, in Soviet Union in Autumn 1990. One of the participants was Sergei Tretyakov (Leningrad/St. Petersburg and Helsinki) who became acquainted with Igor Semchenko and Sergei Khakhomov (Gomel, Belarus), thanks to the common topics of their respective presentations [21,22].

This resulted gradually into close contacts between Belarus and Finland. In May 1992, Sergei Tretyakov and Ari Sihvola visited the Francisk Skorina Gomel State University in Belarus, to strengthen the scientific