Preface to the First Edition

The last two decades have seen a spectacular increase of interest for inorganic scintillators. This has been to a large part a consequence of the visibility given to this field by several large crystal-based detectors in particle physics. To answer the very challenging requirements for these experiments (huge data rates, linearity of response over a large dynamic range, harsh radiation environment, impressive crystal quantities to be produced in a short time period and at an affordable cost, etc..), an effort of coordination was needed. Several groups of experts working in different aspects of material science have combined their efforts in international and multidisciplinary collaborations to better understand the fundamental mechanisms underlying the scintillation process and its efficiency. Similarly, the stability of the scintillation properties and the role of color centers have been extensively studied to develop radiation hard scintillators. Dedicated conferences on inorganic scintillators have seen an increasing participation from different communities of users outside the domain of high-energy physics. This includes nuclear physics, astrophysics, security systems, industrial applications, and medical imaging. This last domain in particular is growing very fast since a few years at the point that the volume of scintillating crystals to be produced for positron emission tomography (PET) is going to exceed the one for high-energy physics. As more and more crystal producers are also attending these conferences, a very fruitful synergy was progressively built up among scientific experts, technologists, and end users. This aspect of a multidisciplinary collaboration is essential to help people design and build detectors of ever-increasing performance through the choice, optimization, or development of the best scintillator and a thorough investigation of the technologies to produce the crystals of the highest quality.

The idea for this book was born during one of the conferences of the SCINT cycle (eight conferences since the first one in Chamonix, France, in September 1992). It appears that the progress in understanding scintillation process and in material sciences in general opens new ways to answer the challenging requirements of an increasing number of customers. Whereas until recently the only possibility was to scan scintillator databases to select, among the few which are available, the one having reasonable properties, very often at the price of important compromises, the dream of engineering scintillators closely matching the user's requirements is becoming every day more realistic. This is why we have deliberately taken the end user's viewpoint. This book does not follow an academic scenario, starting from theoretical considerations, describing the different scintillation mechanisms in a didactic way, and concluding with a few examples. Several authors have already published excellent monographs of that sort. We have chosen instead a more pragmatic approach trying to answer practical problems and insisting on limiting factors which are not only of theoretical nature but also related to technological difficulties, production yield, and cost.

This book is therefore a practical guide for people, scientists, and engineers who intend to develop a detector using inorganic scintillators for basic research, medical imaging, or industrial applications. It will also interest students and teachers to get an overall picture of a field in rapid expansion. Its multidisciplinary approach is a good illustration of how modern challenges are met. It does not address organic and liquid scintillators.

The introduction defines the vocabulary and describes the different classes of scintillators. Definitions of *luminescence*, *scintillation*, and *phosphorescence* are given. The main parameters of interest for scintillating materials are described with a short and comprehensive definition for each of them.

The following chapter reviews the user's requirements for the different applications. Starting from the problem to be solved in domains as different as fundamental physics, medical imaging, security systems, oil well logging, and other industrial applications, it explains how these requirements influence the development of new scintillators.

The chapter on scintillation mechanism in inorganic scintillators is treated in a practical way. The point is to show how to answer high light yield, short decay time, good energy resolution, etc. as requested by the users. The fundamental mechanisms are of course explained, but a particular emphasis is put on the description of factors limiting these performances in good-quality crystals.

In the next section, the influence of crystal defects and their role in the degradation of the scintillator performance is thoroughly studied. In particular, problems of nonlinearity of the scintillator response and radiation damage are discussed.

At this stage, it is important to address the problems of crystal engineering. This is the subject of the next chapter where the reader will get familiar with the most frequently used technologies of crystal growth and their limitations. The mechanical processing and different methods to optimize the light collection are also discussed in this part.

Finally, two examples of recently developed scintillators are given as an illustration of the approach proposed in this book. The first one describes the huge effort on lead tungstate (PWO) for the largest electromagnetic calorimeter ever built in high-energy physics. The second one concerns the development of the lutetium aluminum perovskite (LuAP) for medical imaging devices.

The authors hope through their work to contribute to the development of this very active domain of material sciences, to help the people interested in the use of inorganic scintillators, and to promote education in this field.

Acknowledgments

The authors express their warm thanks to all their colleagues who contributed a lot with their research to the development of new scintillation materials. Special thanks go to the members of the Crystal Clear Collaboration, the CMS Collaboration at CERN, the CERN management, the ISTC Foundation, and the different National Science Funding Agencies for their support to this research. We are also very grateful to Dr. S. Sytova for her efficient technical support for assembling the book. Finally the authors express their gratitude to Dr. A. Fedorov, Dr. O. Missevitch, Dr. A. Hofstaetter, Dr. R. Novotny, Dr. M. Kirm, Dr. P. Dorenbos, Dr. A. Belsky, Prof. A. Vasil'ev, and Prof. V. Mikhailin for collaborative research and fruitful discussions at the preparation of this book.

August 2005 Paul Lecoq

Preface to the Second Edition

Since the publication of the first edition of the book in 2006, an impressive progress has been made in fundamental understanding, engineering, and applications of inorganic scintillators. The discovery of the Higgs boson at CERN where the CMS electromagnetic calorimeter using 100 t of lead tungstate crystals played a major role was also an illustrative example of the potential of scintillation crystals for precision measurements. With the development of a new generation of halide and garnet scintillators, it became clear that we have entered an era where engineering of new scintillators with specified properties becomes possible.

This has been made possible by decisive progress in theory and modeling of scintillation phenomena. In recent years, a strong effort has been made in different directions and in particular to understand the mechanisms responsible for the scintillators' nonprorportionality at the registration of low-energy γ-quanta, to evaluate the ability for fast timing at the picosecond level with different scintillators, and to delineate the damage effects in scintillation materials under high-energy charged hadrons.

The progress made in this field has promoted a spectacular spread of the scintillation-based methods in the detection of ionizing radiations. So three of the authors have therefore decided to write a second edition of the book, in which we have made an attempt to complete the first edition with a review of the achievements made during the last decade.

Following the spirit of the first edition, this book has been written in such a way as to satisfy primarily the needs of the end users. We tried to address practical problems and highlight the new demands and the limiting factors related not only to theoretical considerations but also to technological difficulties, such as production yield and cost.

This book is addressed to scientists and engineers who intend to develop detectors using inorganic scintillators for basic research, medical imaging, or industrial applications. It will also be of interest to students and teachers, allowing them to catch an overall picture of a rapidly developing field. Its multidisciplinary approach is a good illustration of how modern challenges are met. It does not address organic and liquid scintillators.

In the second edition we updated all chapters. Chapter 9, dedicated to several examples of the latest developments, was written anew, and two new chapters, Chaps. 3 and 7 have been added.

Chapter 3 discusses the new developments opening prospects for fast timing with inorganic scintillation materials.

In Chap. 7, we describe the origin of the damage in crystalline scintillation materials under high-energy proton irradiation. The limits of application of scintillation materials at collider experiments are also discussed.

This book is dedicated to the memory of the late Prof. Vitaly Mikhailin, who was a mentor for many of us.

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The authors would like to express their warm thanks to all their colleagues who contributed a lot with their research to the development of new scintillation materials. Special thanks are go to the members of the Crystal Clear Collaboration, the CMS Collaboration at CERN, the CERN management, and the different National Science Funding Agencies for their support of this research. We are thankful to the Horizon 2020 MSC RISE INTELUM project supporting mobility of our colleagues to make joint research at different places worldwide. We are also very grateful to Dr. S. Sytova and V. Mazurova for their efficient technical support for assembling the book. Finally, the authors would like to express their gratitude to Dr. E. Auffray, Dr. E. Bourrett-Courchesne, Dr. N. Cherepy, Prof. P. Dorenbos, Dr. A. Fedorov, Dr. R. Novotny, Dr. N. Shiran, Prof. G. Tamulaitis, Prof. A. Vasil’ev, Dr. M. Vasiliev, and Prof. A. Yoshikava for collaborative research and fruitful discussions during the preparation of this book.

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