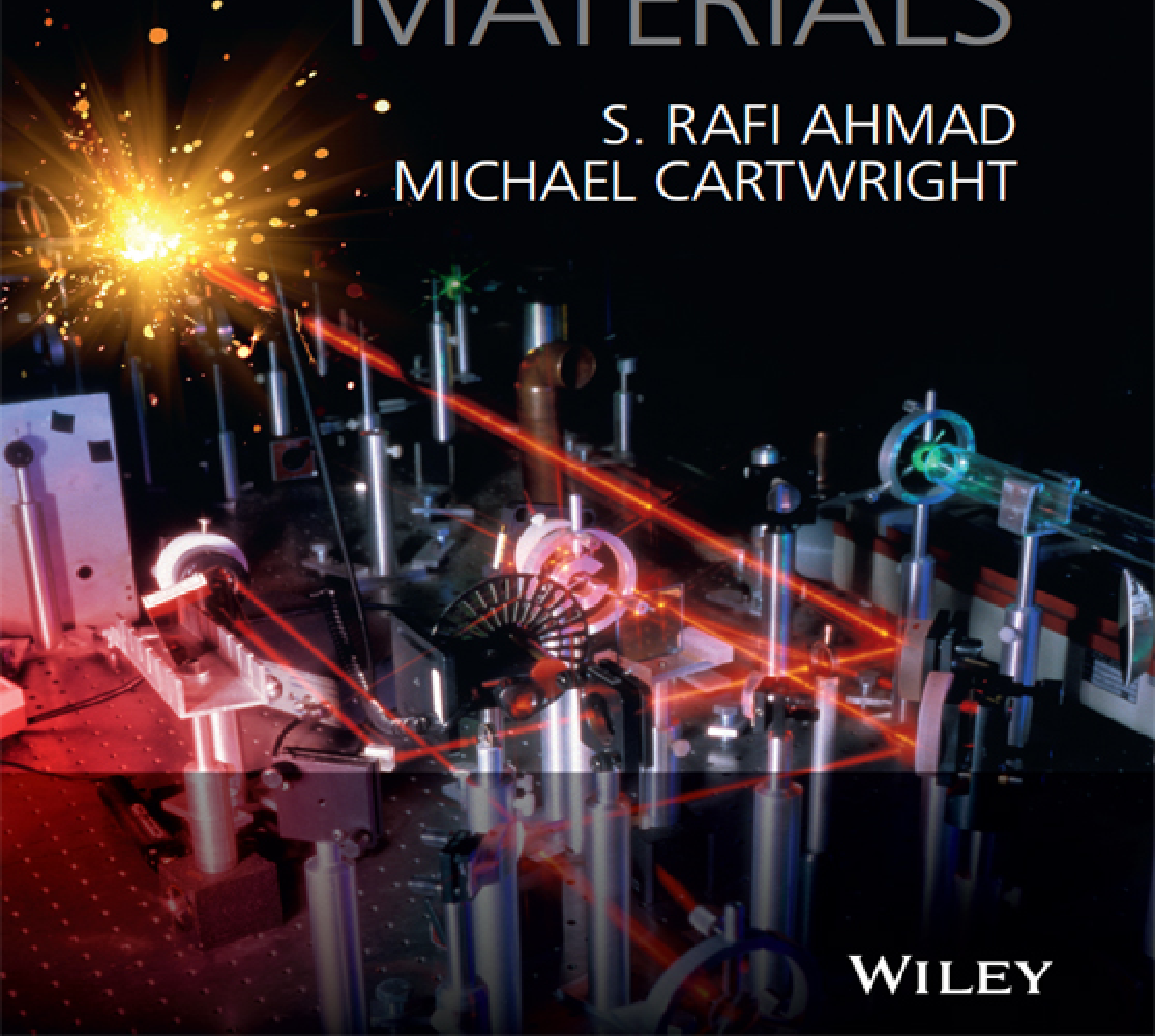
LASER IGNITION OF ENERGETIC MATERIALS

S. RAFI AHMAD
MICHAEL CARTWRIGHT



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Dedicated to our spouses Angela & Estelle for their support, patience
and encouragement during the preparation of the book.

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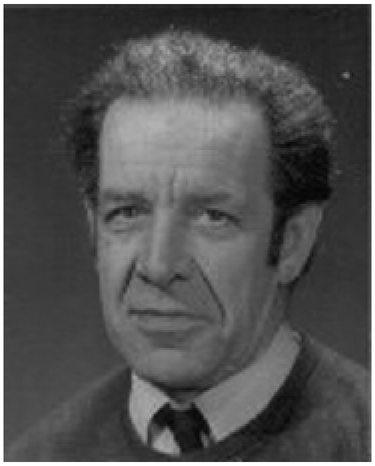
About the Authors

 **Dr S Rafi Ahmad**

Dr Ahmad founded the Centre of Applied Laser Spectroscopy within Cranfield University (CU) in 1988 and led it until he retired in 2012. He received the degree of D.Phil. from the University of Oxford (UK) in 1972 on his thesis on ‘Laser Interaction with Solid Materials’. During his career as a scientist within the Ministry of Defence (UK), and later as an academic at CU, the scope of his research areas expanded to include, among many diverse topics, laser ignition of energetic materials and laser-induced processing of natural and synthetic polymers for biomedical applications. His research was funded by many national and international bodies and he was the principal investigator and the coordinator of a number of EU funded projects involving many partners from EU countries in research topics including Jute modification (INCO-DC) and plastic identification (BE-7148). He also served as the UK representative in the management committee of the EU's EULASENET network and one of the co-coordinators of the COST-G7 action on artwork preservation using lasers. Dr Ahmad retired from Cranfield University in 2012. He has supervised 11 PhD students and published 62 peer reviewed papers and other books.

 **Dr Michael Cartwright**

After graduating in chemistry from London in 1963, Michael Cartwright gained industrial experience in the nuclear industry at Windscale and pharmaceutical research in London, before moving to Bath University as a researcher in nuclear chemistry. He was awarded a D.Phil by London University in 1974 for a thesis on ‘Radiation Damage in Solids’, based on research work performed at Bath University. He then proceeded to do research in inorganic thermo-chemistry and organo-metallic coordination complex chemistry. His interest expanded towards structural chemistry and X-ray diffraction which resulted in later years in his inauguration of the University's first single crystal four circle structure determination facility.

He moved to Cranfield University, at RMCS Shrivenham, in 1986, to lecture and perform research in energetic materials. His major interest was the relationship between molecular structure and explosive sensitivity, which developed into a series of lectures for the M.Sc in Explosives Ordnance Engineering. He was co-founder of the M.Sc. Forensic Engineering and Science course and he helped to develop the university's interests in the environmental impact of explosives, particularly in waste waters from manufacturing plants and land contamination at munitions disposal sites. He helped to design the intersite master's courses on environmental diagnostics and waste water chemistry. Energetic materials research was funded by the MOD, government agencies, research organisation and private companies. He represented CU on the SCC of the MOD, devising test methods for assessment of accidental initiation risks for energetic materials. He also represented CU on several NATO organisations, examining various aspects of energetic material science. He retired from Cranfield in 2009.

Preface

The practical laser was invented by T. H. Maiman at the Hughes Research Laboratories in the USA, way back in 1960. It was then hailed as ‘the tool looking for applications’. In no time, the tool found applications in almost all fields of science and technology. The headline defence application was in a ‘Star Wars’ anti-missile system but, not surprisingly, within a couple of years, research and development on its applications in the defence industry, particularly for high explosives ignition/initiation, got under way. Due to the ‘Cold War’ prevailing at the time, most of this research was shrouded in secrecy. However, for a variety of reasons, there has been a long pause in tangible developments in this field until recently. Current emphasis on the safety of energetic materials during manufacture, storage, use and transportation, has prompted a spate of research activities throughout the industrial world on the synthesis and ignition initiation of high-performance munitions. These must have whole-life cost-effectiveness, through-life safety and end-of-life environmentally friendly disposal options. These aspects are the objectives of research and development in this field, and the book aims to elucidate the background and the current state of the art in the field of laser initiation.

The book starts with a brief chronological resume of the invention, development and the use of materials generally termed ‘explosives’. This is intended as a purely historical background introduction and is compiled from various sources. An extensive review of the research and development in the application of lasers for ignition/initiation in energetic materials, identifying some of the critical parameters involved, is provided in Chapter

2. This includes a number of references, in addition to a bibliography of recent relevant publications.

Since the book topic encompasses two very different fields of science and technology, these are, for completeness and convenience of the readers, elaborated in Chapters 3 and 4. Chapter 3 provides the basic science behind the technologies, manufacture and general properties of lasers, while Chapter 4 provides a background to the general properties and synthesis of energetic materials. This includes the essential components, both as mixtures of fuels and oxidiser and single energetic molecules, with a chemical classification of these latter materials. The contents are considered to be adequate background for researchers in this field. There are also references and bibliography for the inquisitive reader. Note that further information on these topics is readily available in a number of open literature sources.

Chapter 5 examines the limitations of the current materials and methods of improving safety, for example, with plastic bonded explosives, PBXs and so on. Consideration is also given to the synthesis of new explosives, an active field of research and development. Some of these newer materials are less environmentally toxic. It was therefore considered prudent to include a chapter reviewing these aspects and, in particular, high nitrogen materials, since some of these materials may find future applications in laser ignition.

Fundamental processes associated with the decomposition of energetic materials, ranging from simple burning through deflagration to detonation, are discussed in Chapter 6, along with the effects of explosives in terms of shock pressure and explosive power. Additional methods of improving explosive power are discussed. A brief appendix details some of the methods used for measuring velocity of the shock wave. Chapter 7 examines the energetic changes associated with the initiation process and the currently used techniques for the initiation of energetic materials, with only brief reference to the use of optical or laser systems. Classification of explosives by ease of initiation and the use of explosives trains to minimise hazards are considered, along with the basic properties of current initiatory primers. For both general safety and for safe ignition using lasers, a synopsis of the development of alternative primary explosives is presented in Chapter 8. Some of the materials discussed show particular sensitivity to laser radiation and have high explosive performance, sometimes in excess of existing high explosives.

The theoretical basis of laser interaction with energetic materials involves both optical and thermal properties of materials and both these aspects are covered in Chapters 9 and 10. Chapter 11 provides a synopsis of practical research conducted in this field, mainly citing examples of work carried out at the authors' laboratories. Finally, a general conclusion of the work conducted so far in this field, and the future prospects and direction of research, is included in Chapter 12.

Acknowledgements

One of the authors wishes to acknowledge the assistance of Mr Edwin Billiet and Dr X Fang for assistance with laboratory work for most of the data presented in the book and also for drawing some of the figures. The authors also acknowledge Cranfield University (Defence Academy) for providing the environment and opportunity to conduct tests and evaluations which are now in the public domain.

1
Historical Background

1.1 Introduction

Historically, mankind has tried to dominate both fellow human beings and other animals for as long as humans have been around. Some of this domination was achieved by killing other species. This had two aspects; survival and providing food.

Survival was dictated by the fact that many animals regarded humans as excellent sources of food and were quite capable of killing humans. Humans could have two approaches; avoid areas known to contain threatening species or produce devices – weapons – which would enable humans to kill the threatening animals. Humans then developed a taste for the flesh of some of the animals they had killed, thus increasing the sources of food available. As the human population increased, conflict between humans for food and territory increased, and so humans started to fight amongst themselves. By using weapons, humans could overcome physical disadvantages, and the optimum situation was to be able to kill your opponent before they could kill you.

The sword and lance effectively extended the human arm and kept your opponent at bay but, as lances became longer and longer, they became more unwieldy. A remote killing weapon was required. Simple javelins, which could be thrown at the opposition, extended the distance between opponents but required considerable physical stature and skill to achieve the correct flight trajectory for the javelin. Therefore, in order to overcome human physical limitations, mechanical advantage devices were used. The earliest weapons for remote killing were simple slings. These could carry a stone and were capable of accelerating it to high velocity by spinning the sling in a circle. When one of the supporting thongs was released, the stone would travel in an almost straight line from the point of release. Impact of the stone with an animal or human was capable of killing or injuring the animal.

With the development of wood manufacturing skills, bows and arrows became individual weapons or, when grouped together became a lethal hail of arrows which did not depend on the individual accuracy of the archer. The longbow was the ultimate in these weapons. Improved performance came when mankind developed stored energy devices, such as the ballista and crossbows, both of which stored mechanical energy in wooden elements but required winding up before loading the stone or arrow projectile. These overcame the limitations of physical stature required to effectively use the longbow. The ballista, Figure 1.1, was also used to fire barrels of burning oil at the enemy when they had formed shield walls against arrows. The oil container burst on impact and was one of the first deployments of pyrotechnics weapons.