



普通高等教育“十一五”国家级规划教材

INITIATION THEORY AND TECHNOLOGY

起爆理论与技术 (英文版)

严 楠 何远航 焦清介 编著

 北京理工大学出版社
BEIJING INSTITUTE OF TECHNOLOGY PRESS



INITIATION THEORY AND TECHNOLOGY

启蒙理论与技术

王 德 海 著 王 德 海 译



北京理工大学出版社



普通高等教育“十一五”国家级规划教材

INITIATION THEORY AND TECHNOLOGY

起爆理论与技术 (英文版)

严 楠 何远航 焦清介 编著

 北京理工大学出版社

BEIJING INSTITUTE OF TECHNOLOGY PRESS

Brief Introduction of Content

This book is an English version regarding initiation technology of energetic material. It introduces the initiation theory and technology of explosives, propellants and pyrotechnics, in which various stimulus energy modes such as thermal, mechanical, electric, light, and shock energy are transformed into ignition or detonation initiation, and the initiation application technology such as the constitution, the construction, the functioning principle and the design consideration of various energy transform system are also included. The book can be used as the professional English textbook and bilingual-teaching textbook for the undergraduates and postgraduates of relative majors.

内 容 简 介

本书是关于含能材料起爆技术的英文版读物,主要介绍炸药、火药、烟火药的起爆理论与技术,包括将各种不同刺激能量形式如机械能、电能、光能、冲击波能、热能等转换成点火或起爆的换能技术,以及各种换能系统的组成、结构、作用原理和设计考虑的起爆应用技术。本书可作为相关专业的本科生和研究生的专业英语教材及双语教学教材。

版权专有 侵权必究

图书在版编目(CIP)数据

起爆理论与技术 = Initiation Theory and Technology: 英文/严楠,何远航,焦清介编著. —北京:北京理工大学出版社,2007.5

普通高等教育“十一五”国家级规划教材

ISBN 978-7-5640-1257-1

I. 起… II. ①严… ②何… ③焦… III. 起爆-高等学校-教材-英文 IV. TB41

中国版本图书馆 CIP 数据核字(2007)第 076207 号

出版发行 / 北京理工大学出版社

社 址 / 北京市海淀区中关村南大街 5 号

邮 编 / 100081

电 话 / (010)68914775(办公室) 68944990(批销中心) 68911084(读者服务部)

网 址 / <http://www.bitpress.com.cn>

经 销 / 全国各地新华书店

印 刷 / 北京圣瑞伦印刷厂

开 本 / 787 毫米×1092 毫米 1/16

印 张 / 12.25

插 页 / 2

字 数 / 247 千字

版 次 / 2007 年 5 月第 1 版 2007 年 5 月第 1 次印刷

印 数 / 1~2500 册

定 价 / 32.00 元

责任校对 / 陈玉梅

责任印制 / 吴皓云

图书出现印装质量问题,本社负责调换

The Author

作者简介



Yan Nan, born in 1960 and from Guilin city, Guangxi Province. PhD graduated from the Mechanical Engineering Department, Beijing Institute of Technology. Being the associated professor as a doctor and master supervisor. Be engaged in the work of teaching and research in the pyrotechnic theory and technology. The representative research work includes the reliability theory and test procedure, the failure analysis and prevention of combustion and explosive devices, the new technology and theory of initiating explosive devices, laser ignition technology, explosion dynamic test technology, dust explosion and industrial safety, and et al. More than 60 papers have been published. Wish to promote the development of pyrotechnic theory and technology with persons who have lofty ideals in this field.

严楠，1960年生，广西桂林人，1996年于北京理工大学力学工程系博士毕业，现为北京理工大学宇航科学技术学院副教授、博士生和硕士生导师。从事火工理论与技术的教学和科研工作。主要从事的科研工作有可靠性理论与试验方法、燃爆产品失效分析与预防、火工理论与新技术、激光点火技术、爆炸力学测试技术、粉尘爆炸与工业安全等，已发表学术论文60余篇。愿与有志之士协同推进火工理论与技术的发展。

EXPLOSION MEASUREMENT TECHNIQUES

爆炸测试技术 (英文版)

黄正平 何远毅 编著

北京理工大学出版社
Beihang University Press

Preface

This book gathers the research achievements well reflecting the modern initiation theory and technology. They are classified and introduced respectively, and can represent the present status and development in the field of initiation technology. The book has eight chapters which cover the theory and technology involving thermal initiation, mechanical initiation, electric initiation, laser initiation, flyer initiation, shock initiation, EFI initiation, SCB initiation. A few of well-chosen exercises are attached to the end of each chapter, which are helpful for students to enhance their understanding and expression ability for professional English.

This book is a teaching textbook. It can be used for the study of both the professional knowledge and the professional English, suitable for the Chinese students such as the undergraduates, postgraduates and foreign students in the majors such as special energy source and pyrotechnics, ammunition engineering, fuze, explosion dynamics, explosive theory, blasting engineering and safety engineering. It can also be used as the bilingual teaching for Chinese college students, and the professional learning and training books for researchers and engineers in the relative fields.

Initiation theory and technology is a polytechnic subject which bases on chemical reaction kinetics, mechanics, combustion, explosion dynamics, electronics and dynamic measurement techniques. It contains the theory and technology on the burning and explosion characteristics of energetic materials, various initiating principles of energy transform, and initiating control principles etc. These theory and technology have the important guidance function for the property design, safety of ammunition and weapon system.

This book respectively introduces various initiation theories and technology according to the different initiation modes based on the extensively gathered literature researches of present and rearranged them. The book well reflects the present development state and tendency in initiation technology. It can help readers to master and understand the knowledge in this field rapidly, and meanwhile to learn the professional English terms.

The relative Chinese textbooks generally introduce the comparatively conventional initiation by thermal, mechanical, electric, or shock action in details. And overseas monographs contain the relative contents in partial sections of the books such as explosive engineering, explosive technology, and etc. But all of them merely introduce the initiations by laser, EFI and SCB developed from the 80s of last century briefly. This does not match

the requirements for the present initiation technology development. There has been short of a textbook which fully introduces the modern initiation theory and technology up to date. This book meets the needs in the field.

The book includes the following 8 chapters:

Chapter 1 describes the initiation concept, ignition theory of solid, gas and heterogeneous phases, and the technology application of thermal initiation.

Chapter 2 describes the mechanical initiation concept, the initiation mechanism by percussion, friction and stab, and the technology application of mechanical initiation.

Chapter 3 describes the electric initiation concept, electric initiation mechanism, the electric initiation by hot bridgewire, conductive mixture and spark gap, and the technology application of electric initiation. The bridgewire initiation is emphasized.

Chapter 4 describes the laser initiation concept, laser initiation mechanism, laser initiation characteristic parameters, the laser initiation technology application for laser detonators and laser ignition system.

Chapter 5 describes the flyer initiation concept, the theory of exploding accelerated flyer, Gurney model, and effective charge.

Chapter 6 describes the shock initiation concept, shock and detonation theory, and actual detonation.

Chapter 7 describes the EBW and EFI initiation concept, electric burst initiation mechanism, electric burst characteristics, typical EFI initiator design, and EFI initiation system.

Chapter 8 describes the SCB initiation concept, SCB initiation mechanism, SCB electric burst characteristics, SCB manufacturing method, SCB produced plasma characteristics, and SCB initiation application.

The relative reference textbooks published domestically are *Explosion Measurement Techniques* and *Thermal Explosion*. The related contents can also be found in them when the explosion measurement technology or thermal explosion theory are needed.

To understand and master the knowledge presented in this book, readers need some familiarity with the elements of chemical reaction kinetics, mechanics, detonation theory, and electronics in advance.

In order for readers to master the professional English reading and writing habits, the writers make use of citations of the original to the most and then rearrange the contents in order. This will enable readers to acquire the sufficient enjoyment of the splendid languages in reading the original text. Therefore, sincere respect and thanks to those authors whose monographs, theses and technology reports are quoted in this book.

During the writing of the book, the graduate students, An Xiaoke, Pang Yan, Xie Yanling, Jia Hongwei, Zeng Yaqin, Li Kun, Zhu Feng, Yang Guili, assist to compile and

collate the text, figures and tables. Here deep gratitude to them for their valuable help.

This book is selected as a university textbook of the national 11th 5-year program by Ministry of Education. And in acknowledgement of the fund by the 11th 5-year textbook program from Beijing Institute of Technology & Beijing Institute of Technology Press, the book has been published.

the Writers

前 言

本书是一本英文教材,收集了充分反映现代起爆原理与技术的研究成果,分门别类地进行介绍,反映了当前起爆技术的现状及发展趋势。本书主要包括热起爆、机械起爆、电起爆、激光起爆、飞片起爆、冲击波起爆、爆炸箔冲击片起爆、半导体桥起爆的理论与技术 8 个章节内容。每章后附精选练习题,帮助学生提高专业英语理解和表达能力。

本书是一本关于起爆理论与技术的英文教材,可适用于特种能源与烟火技术、弹药工程、引信、爆炸力学、炸药理论、爆破工程、安全工程等专业的本科生、硕士研究生、博士研究生的专业知识和专业英语学习,同时适用于相关专业的双语教学,以及相关领域的科技人员、工程师和留学生的专业学习和培训。

起爆理论与技术是以化学反应动力学、力学、燃烧学、爆炸力学、电子学和测量技术为基础的一门综合技术学科。其主要内容包括含能材料燃烧和爆炸特性、各种起爆能量转换原理、起爆控制原理等理论与应用技术,这些理论与技术在武器弹药系统的性能设计和安全性方面具有重要指导意义。

本书在收集整理当代起爆理论、起爆技术文献研究的基础上,对不同起爆理论与技术分门别类地进行介绍,反映了当前起爆技术的发展现状及趋势,使读者能够迅速掌握国内外有关起爆技术的研究现状,同时学到有关专业英语术语。

国内有关的中文教材一般是详细地介绍比较传统的热起爆、机械起爆、电起爆和冲击波起爆技术,而国外同类著作则是将这类技术纳入到炸药工程、炸药技术著作中的部分章节。而所有这些书对 20 世纪 80 年代以来发展的激光起爆、爆炸箔起爆、半导体桥起爆技术介绍非常简略,这与当前起爆技术研究的需求极不相符。国内外一直缺少一个全面详细地介绍当代起爆理论与技术的英文教材。本书在该专业领域中可起到一定填补空白的作用。

本书包含以下 8 个章节:

第一章介绍热起爆概念、固相、气相、多项热点火理论和热起爆技术应用。

第二章介绍机械起爆概念、撞击起爆、摩擦起爆、针刺起爆机理和机械起爆技术应用。

第三章介绍电能起爆概念、起爆机理、桥丝电起爆、导电药电起爆和火花隙电起爆机理和电起爆技术应用,重点是桥丝电起爆。

第四章介绍激光起爆概念、起爆机理、炸药和烟火药的激光点火特性、激光点火系统、激光雷管等激光起爆应用技术。

第五章介绍飞片起爆概念、爆炸加速飞片理论、格尼模型、有效药量概念。

第六章介绍冲击波起爆概念、冲击波和爆轰波理论、真实爆轰。

第七章介绍爆炸桥丝和爆炸箔的起爆概念、电爆炸起爆机理、电爆特性、典型爆

炸箔起爆器设计考虑、爆炸箔起爆系统。

第八章介绍半导体桥的起爆概念、起爆机理、电爆特性、半导体桥制作方法、半导体桥产生等离子体特性、半导体桥起爆应用技术。

国内已经出版的可供参考的有关英文教材有“Explosion Measurement Technique”和“Thermal Explosion”，在阅读到有关爆炸测试技术或热起爆理论时可参阅相关内容。

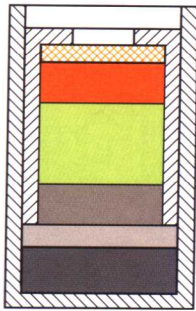
要深入理解和掌握本书的内容，读者需要具有一定的化学动力学、力学、爆轰学和电子学的基础知识。

为了使学习者掌握专业英语阅读和写作习惯，本书尽量摘录原文作为章节，进行了编排整理，这使得读者能够在阅读当中充分享受原著的精彩语言。为此，向被引用的专著、论文、科技文献的作者表示敬意和谢意。

在本书完稿过程中，研究生安晓科、庞艳、谢艳玲、贾宏伟、曾雅琴、李坤、朱峰、杨贵丽协助了文字、图表的编辑和校对工作，在此表示由衷的谢意。

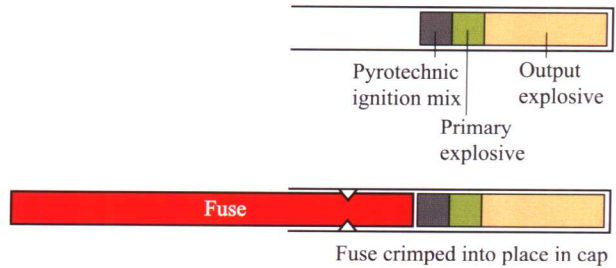
本书于2006年8月经教育部专家委员会评审，遴选为“普通高等教育‘十一五’国家级规划教材”。本书的出版得到了北京理工大学和北京理工大学出版社“十一五”教材规划项目的资助，作者在此表示衷心的感谢！

编著者

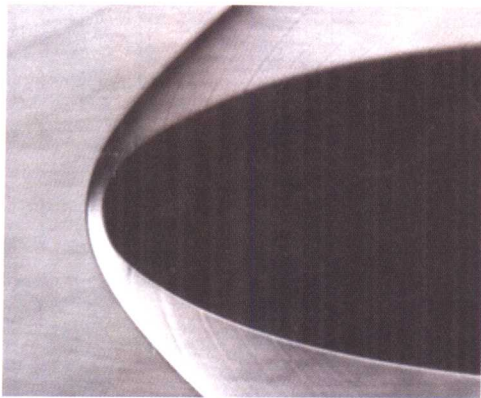


Military flash detonator

Pyrotechnic Fuse Type Blasting Cap



Commercial non-electric blasting cap



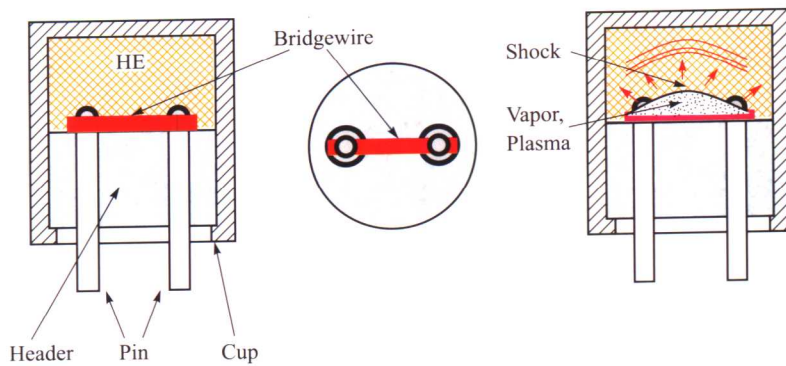
Schlieren photograph of supersonic flow over blunt object. Shock wave is approximately parabolic, and detached from object (Avco Everett Research Laboratory, Inc.)



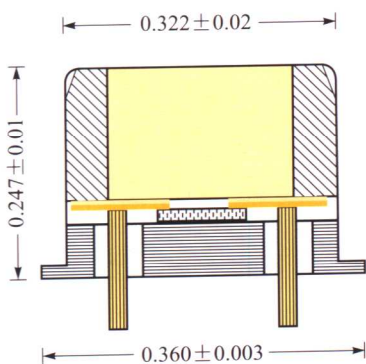
A weapon cache is detonated at the East River Range on Bagram Airfield, Afghanistan



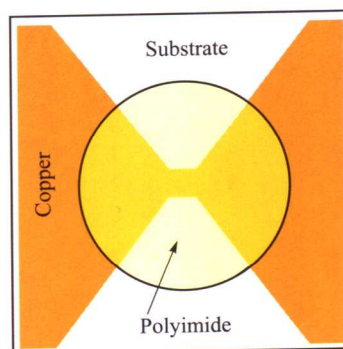
A log in a fire place



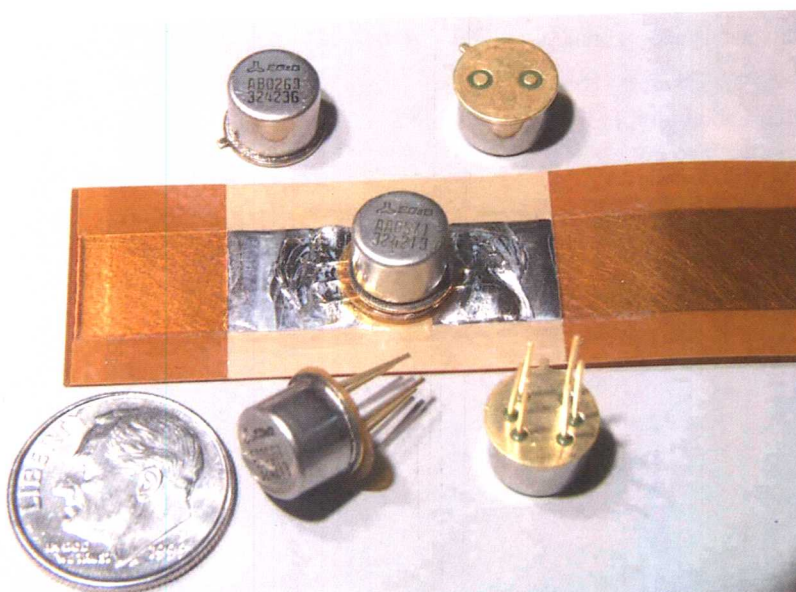
Typical EBW detonator design



Blue chip™ slapper detonator



Chip slapper



Various configurations of blue chip™ detonators^[15]

Contents

Chapter 1 Initiation by Heat	1
1.1 Concept and Classification	1
1.2 Thermal Ignition Theory	1
1.2.1 Ignition Theory in Solid	2
1.2.2 Ignition Theory in Gas	2
1.2.3 Ignition Theory in Heterogeneous Phase	3
1.3 Application of Initiation by Heat	3
1.3.1 Flame or Spark Initiators	3
1.3.2 Output of Primers	5
1.3.3 Hot Bridgewire Initiators	8
Exercises	8
 Chapter 2 Initiation by Mechanical Stimuli	9
2.1 Concept and Classification	9
2.2 Initiation Mechanism	9
2.2.1 Initiation by Impact or by Percussion	9
2.2.2 Initiation by Friction	12
2.2.3 Initiation by Stab	13
2.3 Application of Mechanical Initiation	15
2.3.1 Percussion Initiators	15
2.3.2 Stab Primer or Stab Detonator	19
2.3.3 Energy-Power Relationship	20
Exercises	24
 Chapter 3 Electric Initiation or Initiation by Electric Power	25
3.1 Concept and Classification	25
3.2 Initiation Mechanism	25
3.2.1 Electrothermal Initiation	25
3.2.2 Electric Spark Initiation	25
3.2.3 Conductive Mixture Electric Initiation	26
3.2.4 Electrical Burst Initiation	26
3.3 Application of Electrical Initiation	27
3.3.1 Hot Bridgewire Electric Initiators	27

3.3.2	Electric Spark Gap Detonator	41
3.3.3	Conductive Mixture Electric Detonator	42
3.3.4	Other Electric Initiators	42
	Exercises	43
Chapter 4	Laser Initiation Theory	44
4.1	Concept and Classification	44
4.1.1	Concept of Laser Initiation	44
4.1.2	Background for Laser Initiation	44
4.1.3	Advantages of Laser Initiation Systems	45
4.2	Laser Ignition Energy Transform Mechanism of Energetic Materials	46
4.2.1	Laser Ignition of Explosive	46
4.2.2	Laser Ignition of Pyrotechnics	53
4.2.3	Pyrotechnic Laser Ignition System Design	64
4.2.4	Mechanisms for Laser Ignition of Pyrotechnics	68
4.3	Application Technology	70
4.3.1	Literature Review	70
4.3.2	Laser Diode Ignition	71
4.3.3	Laser Detonator	72
4.3.4	Laser Ignited Actuator	73
	Exercises	76
Chapter 5	Flyer Initiation Theory	77
5.1	Concept and Classification	77
5.2	Acceleration Theory of Fragments	77
5.2.1	Gurney Flyer Acceleration Model	77
5.2.2	Effective Charge in Gurney Model	78
5.2.3	Flyer Impulse Estimation	79
5.2.4	Gurney Data for Explosives	80
5.2.5	Accelerated Flyer Electric Gurney by Electric Burst	81
5.2.6	Flyer Initiation Criterion	82
	Exercises	82
Chapter 6	Initiation Theory by Shock	83
6.1	Concept and Classification	83
6.1.1	Shock	83
6.1.2	Deflagration	84
6.1.3	Detonation	85

6.2 Initiation Theory.....	86
6.2.1 Shock Theory.....	86
6.2.2 Detonation Waves.....	90
6.2.3 Transition from Deflagration to Detonation.....	92
6.2.4 Actual Detonation	95
Exercises	106
 Chapter 7 Exploding Bridgewire and Exploding Foil Initiation Theory	107
7.1 Concept and Classification.....	107
7.1.1 Exploding Bridgewire (EBW) Detonator	107
7.1.2 Exploding Foil Initiators (EFI).....	108
7.2 Electric Burst Characteristics of EBWs	110
7.2.1 Explosion of the Bridgewire	110
7.2.2 Detonation of Initial Pressing.....	114
7.2.3 Effects of Cables	115
7.2.4 Function Time of EBWs	118
7.3 Electric Burst Characteristics of EFIs	119
7.3.1 Electric Burst Characteristics of EFIs.....	119
7.3.2 Flyer Acceleration Characteristics in Electric Burst Process	122
7.4 Application Technology	124
7.4.1 Typical Chip Slapper Detonator Design	124
7.4.2 New Slapper Design.....	133
7.4.3 Typical EFI Igniter Design.....	137
7.4.4 A Typical EFI Ignition System.....	139
Exercises	140
 Chapter 8 Semiconductor Bridge Initiation Theory	142
8.1 Concept and Classification.....	142
8.1.1 Concept.....	142
8.1.2 Classification.....	144
8.1.3 Brief Description of SCB Technique Development.....	146
8.1.4 SCB Production Process	148
8.2 General Initiation Mechanism.....	150
8.2.1 SCB Ignition Features in Comparison with HBW	150
8.2.2 Characteristics of Electric Burst Process	150
8.2.3 Characteristics of Electrothermal Performance.....	154
8.2.4 Interface Design of the SCB with Energetic Material	157
8.3 SCB Ignition Features of Different Energetic Material.....	160

8.4	Characteristics of SCB Plasma.....	163
8.4.1	Experimental Arrangement	163
8.4.2	SCB Phase Transition Observed.....	164
8.4.3	Temporal Evolution of SCB Plasma Appearance and Emission Intensity	165
8.4.4	SCB Plasma Fluid Characteristics.....	166
8.4.5	SCB Plasma Temperature Characteristics.....	167
8.5	Comparison of Plasma Generation Behaviors Between Single-SCB and Poly-SCB	168
8.5.1	Experimentation	168
8.5.2	Comparison of Electrical Burst Characteristics Between Two-type SCB Devices.....	169
8.5.3	Finite Element Analysis for Heating of Two-type SCB Devices.....	170
8.5.4	Theoretical Modeling for Thermal Structures of Two-type SCB Devices	171
8.6	Reactive SCB—A New Technique.....	173
8.6.1	Challenge Against the Conventional SCB	173
8.6.2	Reactive SCB Technology	174
8.7	Next Generation SCB Initiators	177
	Exercises	181
	References	182