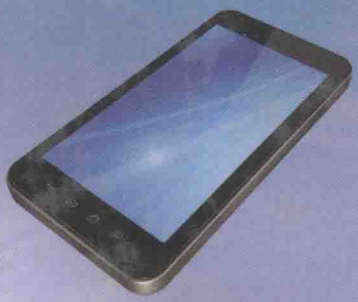
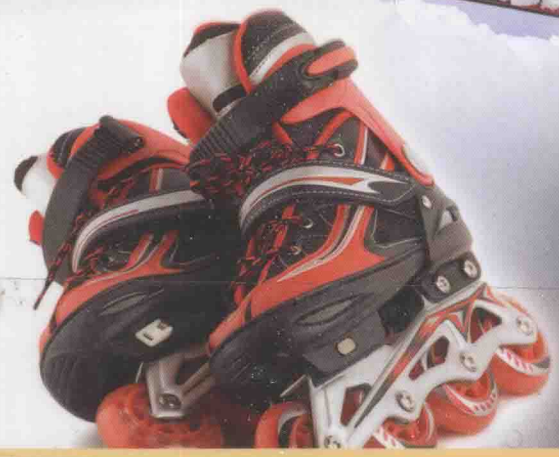
David W. Richerson

The Magic of Ceramics

Second Edition





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The American Ceramic Society
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Second Edition

David W. Richerson

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THE MAGIC OF CERAMICS

PREFACE & ACKNOWLEDGMENTS FOR THE FIRST EDITION

The *Magic of Ceramics* was written as part of an educational outreach project of The American Ceramic Society (ACerS). ACerS, founded in 1898, scheduled a year of centennial activities in 1998 and 1999. As part of the celebration, the Education Committee created a museum exhibit to introduce the general public and students to the amazing uses of ceramics. This was the nucleus of *The Magic of Ceramics*.

The idea for *The Magic of Ceramics* was proposed to ACerS, but under special circumstances. The book would be different from the technical books that ACerS typically publishes; it would also be entertaining, colorful, and available to the general public. ACerS accepted this proposal. Mary Cassells and Sarah Godby provided the direction and support to make this book a reality.

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David W. Richerson

PREFACE & ACKNOWLEDGMENTS FOR THE SECOND EDITION

More than 10 years have now passed since the First Edition. Technology and innovation have not stood still, and advances in ceramics and other materials have played an important role. This Second Edition updates some of the applications of ceramics described or introduced in the First Edition, but emphasizes major developments that have occurred during the past 10–15 years. Many of these advances have been in pollution control, energy harvesting and conversion, digital electronics, medicine, and "nanotechnology."

Several figures have been added to Chapter 2 "From Pottery to the Space Shuttle" to better illustrate the role of ceramics in the evolution of civilization. The remarkable growth in the use of light-emitting diodes (LEDs) has been added to Chapter 4 "Ceramics and Light." The role of advanced composites in the next-generation space telescope is now included in Chapter 5 "Amazing Strength and Stability." Discussions and illustrations of the role of ceramics in neural arrays, prosthetic feet, and spinal surgery are now part of Chapter 8 "Medical Miracles." Chapter 10 "Heat Beaters" has been modified with a discussion of the ceramic requirements to make possible the next generation of hypersonic aircraft and the replacement for the Space Shuttle. The discussion of the reasons that diamond is so hard has been expanded in Chapter 11 "The Hardest Materials in the Universe." All of these changes and updates in Chapters 1–11 are relatively moderate. The major modifications for the Second Edition appear in Chapters 12–14.

Chapter 12 from the First Edition has been expanded into two chapters. The new Chapter 12 "Energy Conservation and Conversion Efficiency" reviews the role of ceramics in conservation of electricity through new lighting technologies, increasing fuel efficiency of vehicles, and increasing efficiency of our processes of converting energy from fuels into electricity. Chapter 13 "From Pollution Control to Zero Pollution" then reviews the evolution of technologies, such as the catalytic converter, that have greatly reduced the pollution from automobiles and trucks. This new chapter then discusses ways that ceramics and other materials are making low-pollution renewable energy such as wind and solar technically feasible and cost-effective.

Chapter 14, the final chapter, discusses "What's New and What's Coming." It describes how ceramics have helped make possible the digital electronics revolution and miniaturization, how ceramics can now be assembled atom by atom to achieve remarkable nanostructures, the role of ceramics in the advanced batteries we need desperately for energy storage, and the emergence of applications for electrochemical ceramics.

Many additional individuals have been very helpful in suggesting or gathering information for the Second Edition: Elizabeth Dann, Peter Bocko, Willard

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FOREWORD TO THE FIRST EDITION

I was born and raised in the Yakima Valley of eastern Washington State. My parents had homesteaded there in 1948, creating a ranch and farm in the middle of largely unirrigated, unpopulated land punctuated with sagebrush. We had no neighbors that I could see to the north, at the base of the Rattlesnake Mountains, and few to the south, east, or west. A two-lane dirt road ran by our house, which was later covered with gravel. During the summer months, after our chores were done, I would ask for my parents' permission to walk up and down that road for a certain distance to look for agates. But I collected more than agates; I collected all manner of interesting rocks, including chunks of quartz, mica, feldspar, and granite.

At night, there were no outdoor lights to diffuse the brightness of the stars. In fact, the Milky Way was a very large stripe across the sky. In the fall of 1957, my parents and I lay on the grass and looked for the first satellite launched into space—a Russian silver sphere called *Sputnik*. It was during that time that I formed my own dreams to fly into space. Little did I realize at the time that my rock collection and flying in space would have something in common: they were both dependent on chemical compositions that we call *ceramics*.

How these two apparently diverse worlds are joined is eloquently explained in *The Magic of Ceramics* by David W. Richerson. This wonderfully unique and readable book describes how humans have taken the rocks around us and, through chemistry, heat, and advanced technology, applied them in glass, fiber optics, electronic and computer components, motor parts, tennis rackets, art work—in fact, the core of today's civilized technological society.

Materials have been referred to as the *enabling technology* of all other new engineering endeavors. Within this realm fall metals, organics, and ceramics. Readers may not be familiar with the breadth of "ceramics," but they will find described in these pages the many applications of ceramics in their lives. Additionally, they will be given the opportunity to understand how and why ceramics work in the applications described. For example, the author summarizes the historical evolution of high-temperature inorganic nonmetallic chemistry in the chapter "From Pottery to the Space Shuttle." He discusses how ceramics have formed the core of art since antiquity in "The Beauty of Ceramics," and how variations in the atoms of a single ceramic compound can change the mechanical and optical properties of the material in "Ceramics and Light." Ceramics are central to developments in bioengineering and medicine, energy, and pollution control and could revolutionize electronics through new nanotechnology research.

Our world revolves around ceramics on a daily basis; we may utilize a computer dependent on a ceramic integrated circuit, gaze out through glass win-

dows, drive our automobiles powered with ceramic component engines, walk on concrete walks, eat from china dishes, admire a new glass sculpture, hit a few golf balls with a composite five iron, send data over high-speed glass fiber optics, or brush our teeth over a porcelain sink. The reader will gain a better appreciation of all of these applications in *The Magic of Ceramics*. The author has translated a very complex and technical subject with the inherent fundamentals of chemistry, physics, and mathematics into a readable, engaging, and interesting text.

It is also my hope that the readers will gain a better appreciation for the researchers, engineers, and technologists who dedicate their lives to better understanding the composition and properties of ceramic materials and to the development of new materials—even to the extent of manipulating individual atoms.

My rock-collecting days were ended when my mother inadvertently pulled open the top drawer of my dresser a bit too far and it fell rapidly to the floor, narrowly missing her feet. All those years of collecting had yielded a sizeable poundage of rocks. I eventually attended the University of Washington, where I was introduced to ceramic engineering by the then department chair Dr. James I. Mueller. The department also had a NASA grant to help develop the ceramic tiles that cover the exterior of the Space Shuttle. It was enough to lead me through two degrees in ceramic engineering. A decade later, I was selected to be a Space Shuttle astronaut. My career as an astronaut continues, and, as I now well know, the Space Shuttle program depends on many ceramic material applications: from the quartz windows to the computer components to the heat-resistant properties of the ceramic tiles. The reader will also learn much more than I knew during my rock-collecting youth. It is my privilege to have been a part of the ceramic engineering discipline and to provide this foreword for *The Magic of Ceramics*.

Bonnie J. Dunbar, Ph.D.
NASA Astronaut

INTRODUCTION

Ceramics are amazing materials! Some are delicate and fragile; others are so strong and durable that they are used to reinforce metals and plastics. Some ceramics are transparent. Others are magnetic. Many ceramics withstand temperatures many times the temperature of your oven and are untouched by erosion and corrosion that destroy metals in days. Ceramics have so many different characteristics and make so many things possible in our modern society that they seem magical.

Without ceramics, we wouldn't have television, miniature computers, extraordinary action in computer-generated movie scenes, digital electronics and wireless communications, the Internet, the Space Shuttle, CDs, synthetic gemstones, or even cars. We wouldn't be able to refine metals from ores or cast them into useful shapes. We wouldn't have many of the modern tools of medicine such as ultrasonic imaging, CT scans, and dental reconstructions. How can ceramics do so many things? Seems like magic, doesn't it?

Have you ever seen a magician perform an amazing feat and wondered how it was possible? No matter how spectacular the illusion is, there is always an explanation or trick, and often the trick is as fascinating as the illusion. The magic of ceramics is much the same—the feats and explanations are equally amazing. Reading this book will show you some of the magic that ceramics do and will explain the fascinating science that makes the magic work.

You'll learn how ceramics interact with light to produce great artistic beauty and to make the laser possible, how some ceramics can be stronger than steel and are used for inline skates and bulletproof armor, how magnetic ceramics made the first computers possible and are the secret behind recording tape and CDs, and how a whole new field of "bioceramics" has emerged to enable miraculous medical cures and repairs. Ceramics touch and enrich our lives in so many ways! I take great pleasure in sharing some of that magic with you!

DID YOU KNOW?

- Some ceramics are so strong that a 1-in-diameter cable could lift 50 automobiles
- By the late 1990s, enough fiber-optic cable was installed to go to and return from the moon 160 times
- More than 3 million spark plugs are manufactured each day
- Ceramic automotive emission control systems have saved us from billions of tons of pollution since 1975
- Each year more than 1 billion tons of concrete are poured
- Some ceramics conduct electricity better than metals
- Diamonds, rubies, and cubic zirconia are ceramics
- Glass microspheres smaller than a hair provide a promising new liver cancer treatment
- Enough ceramic tiles are produced each year to pave a path 300 ft wide around the world
- Ceramic fiberglass house insulation has conserved more than 30,000,000,000,000,000 Btu of heat since 1938

CONTENTS

1 OUR CONSTANT COMPANIONS

It's hard to imagine the tremendous role that ceramics play in our everyday lives. Ceramics come in nearly infinite forms and behave in equally diverse ways. Nearly everything we do brings us in contact with either ceramics or something that was made using ceramics. In fact, ceramics are virtually our constant companions; they affect our daily lives in ways that border on magic. If you think of ceramics only as decorative materials or "the stuff that dishes and toilets are made of," you're overlooking an important part of your world.

PRODUCTS AND USES

Brick, block, cement
Electrical insulators
Television parts
Watch, clock parts
Windows, mirrors
Knickknacks
Magnets
Dishes, glasses
Lightbulbs
Water faucet seals
Toilets, sinks
Ingredients in cosmetics
Knife and scissors blades
Computer, printer parts
Sporting goods
Buttons
Wall and floor tiles

FROM STONEWARE TO SUPERCONDUCTORS

What, exactly, are these remarkable materials that have such an effect on our lives? One highly regarded professor and author (W. David Kingery, in his classic text *Introduction to Ceramics*) defines ceramics as "the art and science of making and using solid articles which have as their essential component, and are composed in large part of, inorganic, nonmetallic materials." Simply stated, most solid materials that aren't metal, plastic, or derived from plants or animals are ceramics.

As you might imagine from this definition, the term *ceramics* covers much ground: from *traditional ceramics* such as pottery, tile, and glass that date from antiquity to amazing new *advanced ceramics* that sport strange names such as silicon nitride, aluminum oxide, and cordierite. Even synthetic gemstones such as ruby, sapphire, and cubic zirconia are ceramics. What would we do without glass or bricks or concrete? Although these traditional ceramics have been used for centuries, they are still a vital part of our lives. They're everywhere we look. Even advanced ceramics have entwined themselves in our daily lives in an incredible number of hidden, and often magical, ways. To initiate your entry into the world of ceramics, let's take a ceramic

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