

Surface Emitting Semiconductor Lasers and Arrays

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Semiconductor laser diodes come in different shapes and sizes. Traditionally, devices with lasing emission in the plane of the substrate—edge emitters—have been used in long-distance telephone fiber-optic transmission systems, laser printers and audio compact-disk players. These edge-emitting devices can be of the Fabry-Pérot type, with lasing in multiple longitudinal modes, or emission can be made single mode by coupling to an integrated, distributed feedback grating. An alternative to edge emission is vertical emission with lasing light emerging perpendicular to the surface of the semiconductor substrate.

This book deals with engineers' efforts over the last 15 to 20 years to improve the performance and increase the number of potential applications of surface-emitting laser diodes. As such, the book makes a useful reference for those with an advanced interest in designing, fabricating and testing such devices.

In reading the book, I was amazed by the extraordinary efforts that have been devoted over the years to the development of surface emitting lasers. The use of edge-emitting Fabry-Pérot laser diodes arranged in two-dimensional arrays with integrated turning mirrors, lenses, sophisticated heat-sinking strategies, and output power measured in tens of watts particularly caught my attention. These devices might be used for specialized applications such as optically pumping Nd:YAG solid-state lasers. The use of gratings as an alternative to turning mirrors is also extensively covered in the book. Another well discussed subject is evanescent optical coupling between closely spaced arrays of laser diodes.

Most interesting from a historical perspective is the discussion of the pioneering work of Kenichi Iga and his colleagues at the Tokyo Institute of Technology on vertical cavity surface-emitting laser diodes. Here we have an example of a Japanese team aggressively pursuing scientific research in a subject of general technological interest. It is a historical fact that only after Iga and his colleagues demonstrated encouraging results did

researchers in the US make significant contributions. For example, workers at AT&T Bell Laboratories and Bellcore realized that very-high-finesse dielectric mirrors could be fabricated using state-of-the-art molecular beam epitaxial crystal growth techniques and that optically active quantum well gain regions could be accurately placed at an optical antiresonance between the upper and lower mirrors. The combination of the Japanese and US efforts produced the modern vertical surface-emitting laser diode. While many practical issues still need to be addressed, such as the high series resistance for current flowing through the mirror stacks and (according to Iga) the absence of polarization control in lasing light output, initial results are encouraging enough that some companies (Hewlett-Packard is one) are considering developing vertical cavity surface-emitting laser arrays for use in high-speed parallel optical data links.

It would be encouraging if the research and development of surface-emitting lasers resulted in new products. For example, surface-emitting lasers could replace the enormously successful edge-emitting Fabry-Pérot laser diode manufactured almost exclusively by the Japanese for use in their compact disk players. This so-called CD laser is a device produced in quantities of several million per month and is probably the most successful example of volume manufacture and commercialization of a laser-diode-based consumer product.

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The Broken Dice and Other Mathematical Tales of Chance

Ivar Ekeland (Translated
by Carol Volk)

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If the two centuries of Newtonian scientific hegemony can be called the Era of Determinism, the 20th century seems destined to go down as the beginning of the Era of Chance. Chance first entered physics via the practical necessity of treating the macroscopic effects of atoms by statistical methods and soon became imbedded within the heart of quantum theory. Over the past two decades, chance has invaded the classical do-

main through studies of chaos; in *Broken Dice*, Ivar Ekeland deals with it from the point of view of a highly literate mathematician.

All thoughtful human beings realize that much of what matters in their lives is at the mercy of fate, and they have personal strategies for dealing with this predicament. These strategies often have more to do with psychological comfort than with rational calculation: Most people will accept a high level of familiar risk rather than take their chances with the unknown. Any rational assessment, for example, would lead one to fear the drive to the airport more than the flight that follows, but that is not how our minds deal with risk. What Ekeland is trying to do in his book is form a bridge between the scientific and personal dimensions of chance, with the latter exemplified by fables chosen mainly from Scandinavian folklore.

The book draws its title from a fabled toss of the dice by King Olaf Haraldsson of Norway to decide the ownership of an island. The King of Sweden having already thrown two sixes, Olaf's situation seemed hopeless. But on his toss, one die came up a six, while the other split in two, displaying a six and a one. The fable takes this highly improbable event as a clear sign of the divine favor that ultimately led to sainthood for the revered 11th-century monarch.

As a mathematician, Ekeland is particularly intrigued by the emergence of chance within his orderly discipline. Addressing the problems of the pseudorandom-number generators employed in computing, he uses very simple algorithms to illustrate how easily these generators lapse into periodicity or bias. Even though every number in the sequence is predetermined from the start, the best of them can pass an impressive battery of tests for randomness. This introduces a central theme of the book: how apparent randomness can arise from determinism, and *vice versa*.

In one particularly dramatic example, Ekeland cites Thucydides's account of the lifting of the siege of Syracuse as the result of an Athenian commander's hesitation when faced with the spectacle of a lunar eclipse. This battle was a major factor contributing to the ultimate defeat of Athens in the Peloponnesian War. It is this eclipse, seemingly random to the ancient Greeks, that enables us to date the event precisely to 27 August 413 BC.

Ekeland shows that in contests that require a blind guess at an opponent's strategy, such as the "rock-