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Introduction

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Optics has been identified as one of the key technologies for the 21st century. Already now in our daily lives we come across optical technologies in several areas:

- at the supermarket most of the tills work in conjunction with bar code scanning;
- ink jet printers perform automatic calibration and media detection;
- most new mobile phones have an integrated camera;
- music and movies are available on CD and/or DVD players;
- computers store data on optical disks;
- blood sugar measurements are based upon optical technology; and
- LED illumination exists in several applications.

Looking at the examples above, it can be concluded that optical technologies are part of various market segments: consumer electronics, lighting, medical, automotive, sensors in general, security, and biometrics.

In order for these markets to further develop and emerge not only do smart inventions have to be made but also suitable manufacturing technologies have to be developed. For optical technology to really reach out and find applications in the mass market it is essential that optical components and systems can be manufactured in high volumes and at low prices. Many of the other components for high-volume applications as described above are based on silicon technology. Light sources such as LEDs and laser diodes can be manufactured using already developed silicon processing and manufacturing technology. The same holds for detectors such as photodiodes and CCD or CMOS cameras. These wafer-based technologies can cope with (very) high volumes and are of low cost. For integration of optical systems together with silicon devices in high-volume consumer optics, injection molding is the manufacturing method of choice. Once a design is cut into a tool and the proper processing for the application is developed, hundreds of thousand of virtually identical products can be made from that master. Injection molding of optics is known for showing very little part-to-part variation once the proper process is defined. Also, using multi-cavity molding, low prices per piece and a fast production cycle can be achieved. Using 8-cavity – and

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sometimes even 16-cavity – molding, production volumes of well above a hundred thousand parts per week can be achieved. These are the kinds of volumes needed to keep up with silicon manufacturing technologies, enabling the high-volume applications. For these lager volumes injection molded optics are highly cost effective. Compared to classic optics production with limited capital investment in machines and tooling, many parts can be produced. Furthermore the injection molding process can be automated and run with few operators.

As well as being cost effective in high-volume applications the other big advantage of injection molded optics is the possibility to also include mechanical features in the optics parts. This allows for cheaper, faster assembly. If reference marks are included in the optomechanical design, and the design is such that critical surfaces are referenced to each other through precision tooling, assembly can be done in a plug and play fashion. Parts can be stacked together without extra alignment of the components. There is even a possibility for (semi-) automated assembly. This is again a necessity for high-volume/low-cost production. Chapter 2 discusses various examples of integrated optomechanical design. By making use of combined optomechanical design, where in some cases the number of parts in a system can also be reduced. In particular, mounting rings and spacers can be eliminated quite easily. Although in some cases the price of the individual components might increase slightly by this integration, on the scale of the whole system costs can be reduced.

Injection molded optics is predestined for integration of functions – another advantage of optics produced by this process. Complex shapes can be realized using advanced tooling and molding. Mechanical functions can be combined with optical ones, and also electrical and chemical functions can be added. The last mentioned one is especially important for the emerging field of biosensing and biotechnology.

The overall drive for integration of functions is usually miniaturization. In classic manufacturing technology it can be fairly difficult to produce parts that are less than certain dimensions. Handling between polishing steps and working on front and back surfaces can become a problem. Molding these small parts can be of significant advantage, since fewer handling steps are involved.

Another advantage as regards injection molded optics is that packing of molded components can be made very effective. It is no problem to place molded optical components into a tape and reel package. The optical components can than be combined with silicon parts using standard pick and place machines, as they are common in the printed circuit board industry. Figure 1.1 shows a typical CMOS camera module in an exploded view and then packed in a tape.

Along with these many advantages, the challenges for plastic optical components lie mainly in the area of environmental resistance and durability. Plastic optical components have a limited temperature range in which they can operate. Water absorption, thermal expansion, and change of refractive index with temperature are other problems one encounters while working with injection molded optical components. Chapters 5 and 6 describe these problems in detail and also

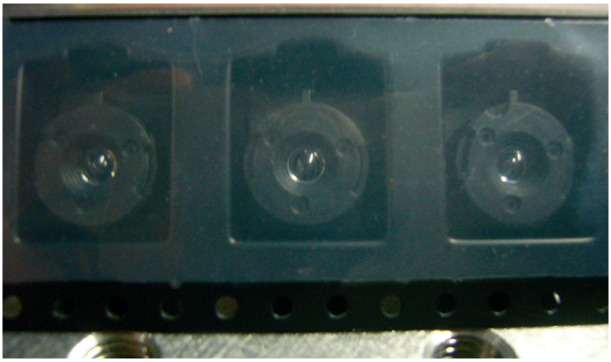

Figure 1.1 left: exploded view of a COMS camera module, right: tape of CMOS camera modules[3]

ways to circumvent some of them. However, in most cases the benefits of using injection molded optics by far out weight the disadvantages.

Many advances in injection molded optics have been made, which started to really penetrate into the market with the advent of CD players. Besides defining ever more applications, research and development has been taking place in the following areas:

- molding machine development;
- tooling for optical inserts and molds;
- materials;
- coatings; and
- processes.

Taking all these developments into account it should become clear to the reader that injection molding of optical components is state-of-the-art manufacturing technology for high-volume optics. Precision and quality of molded optical components is at a level comparable to glass optics and certainly way beyond the level of toy-like applications.

This book attempts to give a coherent overview of the current status of injection molded optics. Since injection molded optics is a subject with many facets, it was decided to ask several experts in their fields to contribute to this book. This way the specific disciplines are covered in sufficient depth. Also, since injection molding is a manufacturing technology, all of the contributors either work in or have very close links to the industry. Therefore this book reflects practical molding experience rather than theoretical reflections. After going through the book, the reader should have a basic understanding of injection molded optics in all of the relevant areas. He or she should be able to enter a detailed and specific discussion about his/her application with an injection molding company. Also, engineers working in a specific area of injection molded optics can use the book for broadening their knowledge in other areas of injection molding. A designer can learn more about metrology and a tooling engineer more about materials. By sharing experiences and knowledge the whole industry should profit and advance to the next level.

The basic idea that serves as a guideline throughout the book is the thought that all products have to go through a Design – Build – Test cycle. This idea has also been kept in the second edition of the book. Therefore, all the chapters of the first edition have been kept. Chapters 2, 3, and 5 have gone through some minor revisions and corrections. Chapters 4 and 6 have been substantially revised and updated. In order to make the book even more complete, three new chapters have been added: Process and Molding Equipment, Cost Modeling, and Applications. All the new chapters contain topics that are vital when talking about plastic optics, and deserve more attention than previously. With these additions and revisions of the previous chapter, this book is on its way to become more of a true handbook and reference for injection-molded optics.

Chapter 2, the first chapter after this introduction is devoted to optomechanic design of injection-molded optics. The unique opportunities in injection-molded optics to combine mechanical and optical features in one component are described. Special attention is paid to the thermal properties of the optical plastics and the proper design with these.

In Chapter 3 the building part of the cycle is covered. During the past few years immense advances in precision engineering and especially single-point diamond turning of optical surfaces have been made. The advances in tooling capability are essential for modern injection molded optics. While designing in glass gives the designer a freedom of material with preferably spherical forms, the designer of injection molded optics is left with very few materials but with freedom of form. However, in order to utilize fully the potential of free and aspherical forms optical tooling needs to be at a level such that these forms can be manufactured. In addition to advanced optical tooling, the whole variety of mold design and tooling is described. This ranges from prototype molding to multi-cavity series molds.

In Chapter 4 an overview of current state-of-the-art metrology is given. As in all of the other chapters the subtleties of injection molding are emphasized. A few generic metrology technologies are discussed and the conflict between these generic methods and custom metrology setups is described. Also the need for high-volume inspection is discussed.

Chapter 5 is devoted to materials. If currently or in the future there is one area that is or will be important for injection molded optics, then it is materials. At present it is very difficult to get reliable and coherent data on optical plastics. In the chapter an attempt is made to provide these data for the most common optical polymers. The most relevant properties of many optical plastics are listed and described. This chapter can serve as a reference for properties like refractive index, Abbe number, thermal expansion, etc.

Chapter 6 deals with coatings on polymers. Proper coatings can add value to injection molded optics. Besides that, coatings can enlarge the areas of application of polymer optics. Coatings can be used not only to enhance the optical performance of injection molded components but also make them more able to withstand a larger range of environments. In this way some of the traditional shortcomings of injection molded optics can be compensated for. The chapter gives an overview of the current state-of-the-art of coatings on plastics. Also, the challenges of working with plastics are illustrated.

Chapter 7 is devoted to injection-molding equipment and processes. Besides proper design and tooling, suitable processes for the parts at hand are necessary as well. The processes used go mostly together with the injection-molding equipment available. Therefore, Chapter 7 gives a good overview on both: some of the most common equipment and on injection molding processes. Since processes are usually a core competence of the injection molding companies, this chapter gives an overview on basic principles; not recipes to follow.

A reoccurring topic in injection molding is costs. When it is cost effective to start molding? What are initial costs involved? These are only two of several common questions asked. Chapter 8 shines some light on cost modeling for injection molding. The chapter gives a review on several of the most important parameters that determine the cost of injection molding parts and products. As the other chapters of the book, this chapter can also be used and read from various perspectives: engineer, purchasing, and general interest.

The last chapter that was added to the second revision is a chapter on Applications. Sometimes in can be very useful and illustrative to see, how certain problems have been solved and how some of the solutions look like. In Chapter 9, several authors of companies and institutes have been willing to lift the tip of the veil and share their solutions with the reader. This chapter is intended more as an inspiration and food for thoughts on what is possible using injection-molded optics.