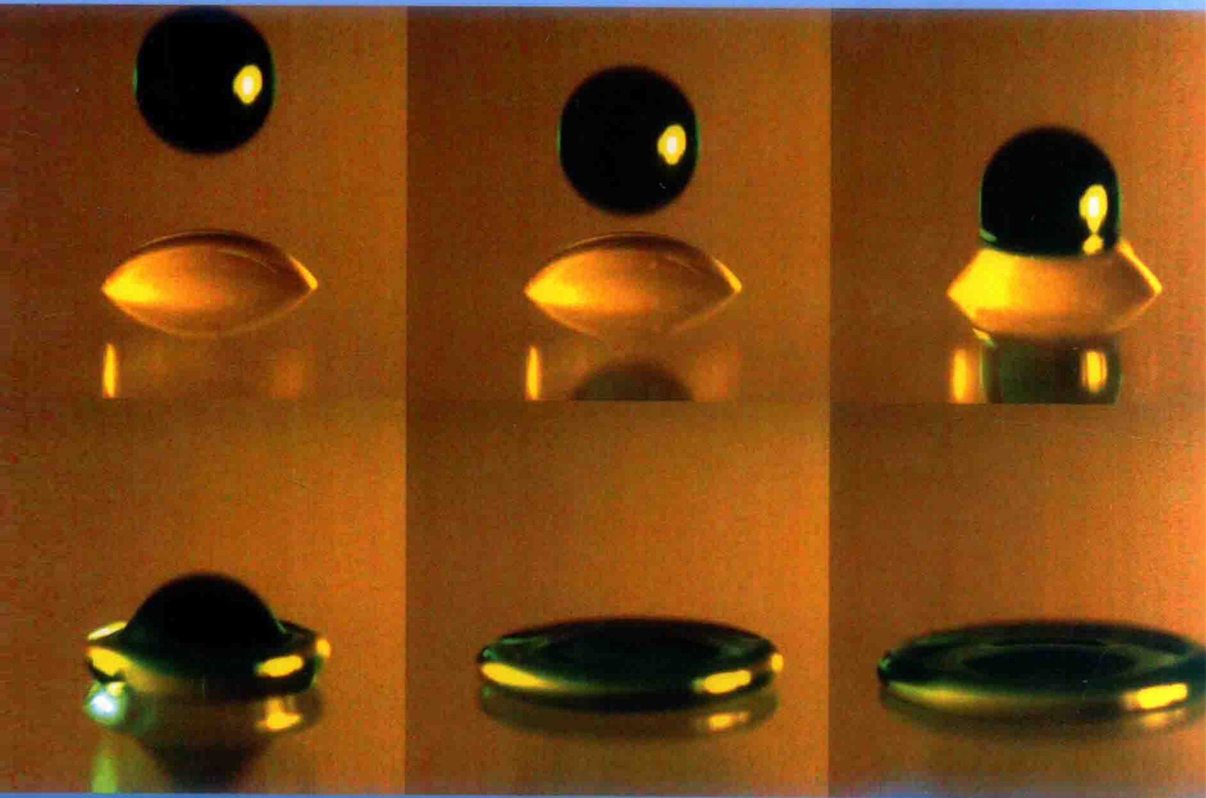
EDITORS | IAN M. HUTCHINGS | GRAHAM D. MARTIN

INKJET TECHNOLOGY
FOR DIGITAL FABRICATION



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Inkjet Technology for Digital Fabrication

Edited by

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Inkjet Technology for Digital Fabrication

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Ian M. Hutchings has been GKN Professor of Manufacturing Engineering at the University of Cambridge since 2001, working in the Institute for Manufacturing which is part of the Department of Engineering. Previously, he was Reader in Tribology at the Department of Materials Science and Metallurgy. His research interests are interdisciplinary, crossing the boundaries between engineering, materials science and applied physics. He established the Inkjet Research Centre at Cambridge in 2005 with support from the UK Engineering and Physical Sciences Research Council and several academic and industrial collaborators.

Graham D. Martin has been Director of the Inkjet Research Centre at the Institute for Manufacturing, University of Cambridge since 2005. He has a PhD in solid state physics and has worked in inkjet-related research, consultancy and product development for many years. The companies he has worked for include Cambridge Consultants Ltd (Non Impact Printing Systems group leader), Elmjet (Technical Director) and Videojet (Director of Technology).

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Introduction to Inkjet Printing for Manufacturing

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1.1 Introduction

The basic principles of conventional printing have remained the same for hundreds of years: the various different printing processes which we take for granted all involve the repeated reproduction of the same image or text many times. Usually, this is achieved by transferring a pattern of liquid or semi-liquid ink from some master pattern to the paper or other substrate through direct contact. Changes to the printed product can be achieved only by changing the master pattern, which involves making physical changes within the printing machine.

In contrast, the inkjet printer which is now ubiquitous in the modern home and office works on a fundamentally different principle. Each small droplet of ink, typically 10–100 μm in diameter, is created and deposited under digital control, so that each pattern printed in a sequence can just as readily be different from the others as it can be the same. The principles of inkjet printing were first developed commercially during the 1970s and 1980s, with the practical applications of marking products with dates and bar codes, and addressing bulk mail. As indicated in Figure 1.1, the technology used for these purposes, which demand high operating speeds but can tolerate quite low resolution in the printed text, is now fully mature: these printers, which use continuous inkjet (CIJ) technology, are widely used as standard equipment on production lines worldwide. The next development, from the mid-1980s onwards, involved drop-on-demand (DOD) printing which is capable of much higher resolution than the early coders and placed the

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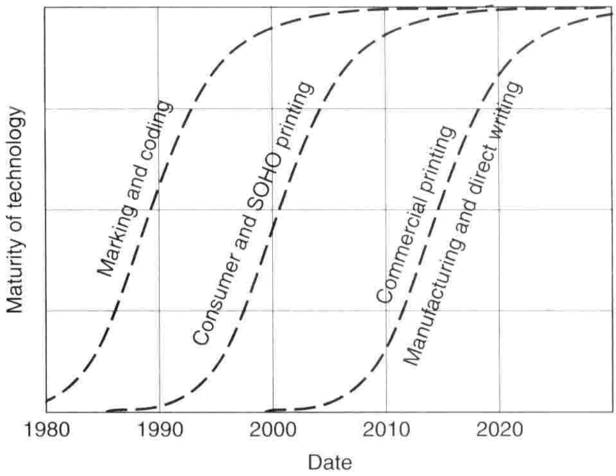

Figure 1.1 *The applications of inkjet technology have developed in three waves: initially for marking and coding, followed by desktop printing of text and graphics in the home and small office environment and, currently, increasing use in commercial printing and manufacturing.*

capability for digital reproduction of text and images, at low cost, into the domestic and small office environment. The principles of both the CIJ and DOD printing technologies are described in Chapter 2.

The subject of this book is the third wave of technology development shown in Figure 1.1; the use of inkjet printing as a manufacturing process. This advance, which is occurring in parallel with the use of inkjet for commercial printing in direct competition with such processes as offset lithography, employs the same basic principles of drop generation as the earlier applications, but with an emphasis on the features of reliability, accuracy, flexibility and robustness which are essential for successful industrial application. Many of the applications discussed in this volume are still under development, and there is undoubted scope for further innovation. Several features of inkjet printing make it particularly attractive for manufacturing.

Firstly, it is a digital process. The location of each droplet of 'ink' (i.e. the material being deposited) can be predetermined on a two-dimensional grid. If necessary the location can be changed in real time, for example to adjust for distortion or misalignment of the substrate, or to ensure that a certain height of final deposit is achieved. Because it is a digital process, each product in a sequence can easily be made different from every other, in small or even in major ways; bespoke products are generated just as readily as multiple replicas of the same design. Since the pattern to be printed is held in the form of digital data, there may be significant cost savings over processes which involve the use of a physical mask or template.

Secondly, it is a non-contact method; the only forces which are applied to the substrate result from the impact of very small liquid drops. Thus fragile substrates can be processed which would not survive more conventional printing methods. The substrate need not even be solid: we shall see examples in Chapter 13 where materials are printed into a liquid bath, and in Chapter 14 where the substrate is a bed of powder. Material can be deposited onto non-planar (rough or textured) substrates, since the process can be operated with a stand-off distance between the print-head and substrate of at least 1 mm. In conventional contact-based printing, the printed material may also be transferred by accidental contact, potentially causing poor quality or contamination; such problems are avoided in a non-contact process.

Thirdly, a wide range of materials can be deposited. By selection of an appropriate print-head, liquids with viscosities from 1 to 50 mPa s or higher can be printed. Several different methods can be used to generate printed structures. Multiple combinations of materials can be used, and inkjet printing can also be combined with other process steps, so that in principle complex heterogeneous and composite structures can be produced, with different materials distributed in all three dimensions.

A further benefit is that inkjet printing is modular and scalable. Multiple print-heads can be assembled to print in tandem, for example by placing them side-by-side to print a wider pattern, or one after the other to print different materials in sequence. These concepts are standard for graphical printing, where four or more colours are commonly used, but can also be readily extended to the manufacturing context.

In this introductory chapter, we shall briefly review the range of materials which can be deposited by inkjet printing and the various methods by which inkjet processes can be used for both additive and subtractive fabrication in manufacturing. The processes of jet and droplet formation, and the various types of print-heads, are introduced in Chapter 2. Later chapters describe the formulation of printable fluids and examine particular applications of inkjet printing in much more detail.

1.2 Materials and Their Deposition by Inkjet Printing

1.2.1 General Remarks

Inkjet technology has been used to deposit a very wide range of materials, including metals, ceramics and polymers, for many different applications. Biological materials, including living cells, have also been successfully printed; they are the subject of Chapters 12 and 13, and we shall not consider them further here. The most important restriction is that the substance being printed must be in liquid form (or contain small solid particles in a liquid medium) with appropriate rheological properties at the point of printing. As discussed in Section 1.3, the material which is printed need not be the same as the final material required: there are several process routes in which a precursor material is deposited, followed by other steps to achieve the final product.

1.2.2 Deposition of Metals

Figure 1.2 illustrates several routes by which inkjet printing can be used to form metallic deposits. These involve direct printing from a melt, printing a suspension of metallic particles which are then sintered to bond them together, printing a metal compound which is then chemically reduced to form the metal and printing a suitable catalyst followed by electroless plating to deposit the metal. Any of these processes can also be combined with one or more secondary electroless plating or electro-plating steps to produce a thicker metallic deposit, which can even be of a different metal.