Contact mechanics of a flexible imprinter for photocured nanoimprint lithography

G.M. McClelland*a, C.T. Rettnera, M.W. Harta, K.R. Cartera,c, M.I. Sancheza, M.E. Bestb and B.D. Terriss

aIBM Research Division, Almaden Research Center, 650 Harry Road, San Jose, CA 95120, USA
bHitachi Global Storage Technologies, San Jose Research Center, San Jose, CA 95120, USA
cDepartment of Polymer Science and Engineering, University of Massachusetts, 01003

Received 26 August 2004; accepted 16 January 2005

A flexible imprinter can be used to accommodate substrate or template roughness in nanoimprint lithography. The contact mechanics of a multi-layer imprinter incorporating bending and local deformation is described. With the right combination of dimensions, moduli, and viscosity, the imprinter can transfer a pattern evenly to a non-flat substrate. These concepts have been used to pattern magnetic media for high density information storage.

KEY WORDS: imprint, nanoimprint, lithography, contact mechanics

1. Introduction

In imprint lithography, the principle of transferring a pattern to a surface is the same as that used to mold vinyl records or CD-ROMs. But in lithography, the pattern is transferred to a resist that can be used in turn to pattern a wide range of underlying materials. The great recent interest in imprint lithography arises largely from its potentially low cost and its very high resolution, which is not limited by an optical wavelength [1].

Possible applications of contact lithography cover a very wide scope, ranging from changing macroscopic optical properties by texturing, to replacing optical lithography in microelectronic manufacturing. Our group has explored using imprint lithography to pattern magnetic films for high-density information storage. In this work, we used a compliant imprinter to accommodate curvature and roughness of the disk substrate [2]. This paper describes issues of contact mechanics and thin film fluid flow which arise in this approach. Our magnetic film patterning work is reviewed briefly.

2. The model

A simple imprinting situation is illustrated in figure 1(a), and some variables are defined in figure 2. The features to be imprinted have a height \( h_f \) and a packing fraction \( F_f \) in an otherwise flat template. Suppose that before contact the resist is evenly distributed at a thickness \( h_r \) over the substrate. After the template is lowered into the resist, the bottom of the template features rest a distance \( h_b \) above the substrate. This base layer thickness is

\[
h_b = h_r - (1 - F_f)h_f.
\]

In most cases the pattern imprinted into the film is transferred to the substrate by etching. Before etching into the material below, the resist base layer must be removed between the features. Next, an etch (normally with a different etchant) removes the substrate material below (figure 1). In terms of the etch rate of the substrate and resist, the height of the etched features can be no greater than \( h_f R_s / R_r \).

If the base layer is uneven across the sample surface due to uneven deposition of the resist or non-flatness of the sample or imprinter, uneven transfer of the template features to the substrate can result. Consider the usual condition, in which the resist is to act in a binary fashion: the template has high (H) and low (L) levels (with respect to the substrate), corresponding to thick and thin areas to be protected and etched respectively. A minimal condition for transferring the pattern is that the resist formed at the H regions is always thicker than the resist formed at the L levels. If etches were always completely vertical, and the two etches were perfectly selective for the resist and the substrate, the template pattern could then be transferred faithfully. But in practice, the substrate etch will also etch the resist, degrading the resist features as it does. If the base layer is uneven, then to remove the base layer everywhere will reduce the height of some of the resist features, degrading their shape and limiting the height that can be transferred. Achieving a uniform base layer in the imprint process is thus essential to achieving good lithography.

If the template and substrate are both rigid and flat (aside from the desired features) a uniform base layer is achieved as long as there is not an overall angle between

---

*To whom correspondence should be addressed.
E-mail: mclell@almaden.ibm.com

DOI: 10.1007/s11249-005-4265-6
the imprinter and substrate (figure 1(a)). In fact, if the imprinter and substrate can be in contact long enough, an uneven distribution in the resist thickness will be pressed out by contact.

There has been a great deal of progress recently in photocured nanoimprinting using rigid imprinters and substrates [3]. In a variant termed “step and flash imprint lithography”, a bilayer resist scheme enables patterning with high aspect ratios, and affords a little tolerance to non-flat substrates [4]. Colburn et al. have analyzed the process by which pL to nL resist droplets can be deposited across a wafer [5]. This method allows a much more efficient use of resist [5] than does spin-coating. Using this method, the volume of dispensed resist can be varied across the die, to compensate for varying density of imprinter features.

In our work on patterning magnetic media, we needed to pattern features <50 nm in diameter into glass substrates which were far from flat. For this purpose we used a flexible imprinter (figure 1(b)) [6,7] and a viscous resist [2]. With the correct geometrical and mechanical parameters, the imprinter conforms to the local curvature of the substrate, and an even base layer is achieved. This approach can also compensate for non-flatness of the imprinter itself.

One approach to achieving good contact is the multilayer imprinter of figure 3. Long range compliance is achieved by a bending backing plate (figure 3(a)) [6]. A cushion applies an even pressure to the backing plate. Since bending and stretching stiffness vary as the third and first power of the thickness, by reducing the thickness, significant bending compliance can be achieved over long distances while keeping good lateral stability. But because the compliance varies as the third