Phase Change Ink Jet Technology

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Phase change, or solid ink, is gaining market acceptance, as a color non-impact printing technology, because of its unique capability to print on nearly any media. In fact, with the right combination of ink base and colorant, it is possible to achieve color quality (as measured by CIE primary color coordinates), that exceeds most other printing technologies for the same substrate.

The principle features of solid ink technology, as embodied in the Tektronix Phaser™ III color printer, will be discussed. The summary will include the composition of the ink and the role of the constituents in meeting the requirements for jetability using a piezo electric driven ink jet device as well as color quality and image durability. The ink jet device and the unique relationships among fluidic geometry, drive wave form and system thermodynamics that result in reliable, high quality drop ejection will also be described. The practical embodiment of these features, in a manufacturable device, will also be covered. Finally, the issue of fixing the image to the media, and achieving acceptable transparency quality, will be discussed.

Introduction

Phase change ink has the unique quality, among non impact printing technologies, of producing brilliant color printing nearly regardless of the substrate. Since the material solidifies on contact with the media, very little spreading and absorption occurs so that the colorant re-

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mains on the surface. This feature has long been a design objective of the ink jet ink developers[1].

The development of phase change ink jet technology was probably initiated at Teletype Corporation in the late 1960's, for continuous ink jet devices. The later application to drop-on-demand devices occurred at several companies (both U.S. and International). Data Products was the first company to commercialize the technology for monochrome printing through a joint development with Exxon. Later, Howtek first introduced a color printer which employed solid ink together with a unique arrangement of ink jet devices spinning inside a cylindrical paper hold down device. Today, color printer products based upon the technology are offered by Data Products, Brother/Spectra and Tektronix. The intent of this paper is to describe the technology embodied in the Tektronix Phaser™ III color printer. The main features of this printer are listed in Table I.

Table I. Tektronix Phaser‘ III Pxi Color Printer

Ink:	Phase Change
Print Head:	96 nozzle drop-on-demand ink jet comprising 48 black and 16 each yellow, magenta and cyan
Print Speed:	2 minutes per letter size page
Media:	4" x 6" card to 12" x 18" bond paper (0.003 in. to 0.011 inches thick) overhead transparency
Controller:	Adobe Level II postscript

Printing Process

Tektronix phase change ink has a melting temperature of about 90°C and physical properties suitable for jetting above 130°C. Accordingly, the ink is first melted, then elevated to above 130°C and ejected as droplets toward the substrate using a piezo-electric driven ink jet device. The ink solidifies on contact with the substrate surface. A cold pressure fusing device fixes the ink to the substrate and improves transparency projection. This sequence is illustrated in Figure 1.

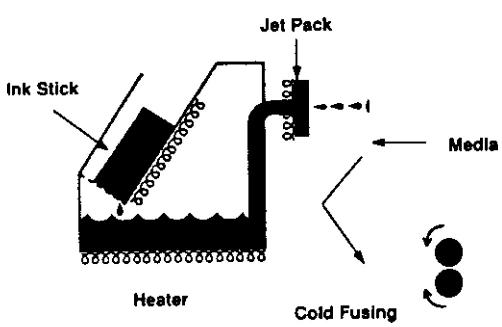

Figure 1. Phase change printing process

Phase Change Ink

The first design objective for color inks is to produce prints that achieve the full spectral capacity of the colorants. This means the base or carrier materials must be as transparent as possible and must hold the colorant at the surface of the substrate. The later requirement is achieved by materials that solidify with little spreading or absorption on contact. It is also necessary that the printed image be durable, and this property is governed by the mechanical properties of the ink material and its adhesion to the substrate. Compatibility with the print head materials and jetability (i.e., physical properties that allow good drop formation are also important). Another desirable property is that the liquid to solid phase change occurs over a narrow temperature range. With these requirements in mind, the following properties were established:

Table II. Properties of a Phase Change Ink[2]

- Non toxic
- Transparent in the solid phase
- Melting point of 100 to 130 °C
- Single melting transition by DSC
- Viscosity <20 CPS at 130 °C
- Gardner number 2+
- Capable of dissolving printing process color dyes
- Stable to long term heating in air and in contact with print head materials
- No offset transfer (Blocking) of finished prints at 70°C or below
- Good adhesion to overhead transparency materials
- Flexibility towards bending when printed on paper and transparency

We have achieved the properties listed in Table II through the use of a blend of synthetic waxes, a tackifier, antioxidant and plasticizer according to the formulation listed in Table III[3]. The colorants used are dyes for cyan, yellow, magenta and black inks. Prints made with these inks, and the Phaser III printing mechanism, produce the color coordinates shown in Figure 2. As the figure shows, these phase change inks produce a color gamut as good as or better than other non-impact printing technologies considered.

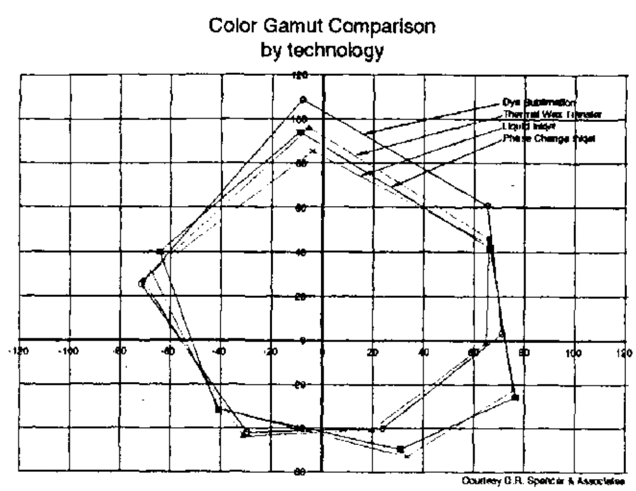

Figure 2. Color gamut of phase change ink compared to other non-impact printing technologies

Table III. Tektronix Phase Change Ink Composition[3]

	Weight %
Tetra-Amide	10-50
Mono-Amide	30-80
Plasticizer	0-25
Tackifier	0-25
Viscosity Modifier	0-10
Colorant (Dye)	<5

Array Ink Jet

Generally, the ink jet devices suitable for aqueous and solvent based inks are also suitable for phase change inks, with a few exceptions. First, the materials used must be compatible with long term exposure to the ink at temperatures greater than 100°C. Second, the pumping method must be compatible with the type of ink being used. For example, thermal ink jet devices require inks having a volatile carrier in order to achieve rapid vapor bubble formation. Since phase change thermal inks are not yet well developed, available commercial devices rely upon piezo-electric pumping mechanisms.

Inks of the type described in Table III must be heated to greater than 100°C in order to achieve viscosity low enough for good drop formation up to 8-10 KHz. This thermodynamic requirement, together with operational sensitivity to changing viscosity (e.g., drop velocity and volume), require tight control of the thermal environment of the print head along with materials compatibility at elevated temperatures. Another design constraint arises from the capacity of phase change inks, and hydrocarbons in general, to dissolve relatively large amounts of air. The high air solubility can result in performance degradation due to a phenomenon of bubble growth called rectified diffusion[4]. According to the theory, small bubbles exposed to sound waves grow by mass diffusion fed by the dissolved air as the bubble wall vibrates.

We addressed the materials compatibility issues by using a stainless steel laminated structure for the jet array along with a solid state bonding process[5]. The architecture of the device is illustrated in Figure 3. The chemically-milled stainless steel plates are designed so that the bonded stack produces 96 individual pressure chambers with outlet passageways to separate drop forming apertures. Other large features connect these devices to ink inlet ports connected to the main reservoir shown in Figure 1.

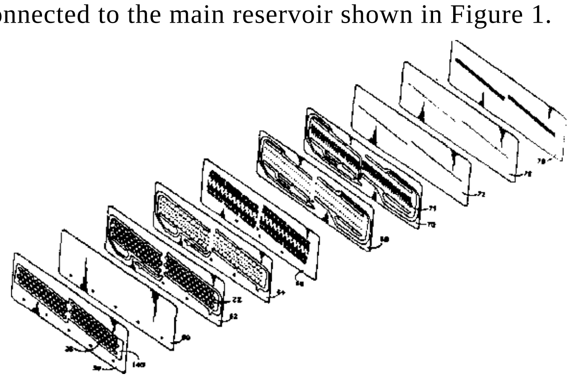

Figure 3. Jet stack architecture[9]

The rectified diffusion problem was addressed through drive wave form tailoring[6], i.e., the wave form was tuned so that the device operates below the threshold of bubble growth due to this phenomenon. A drive wave form having this property for the device shown in Figure 3 is presented in Figure 4.

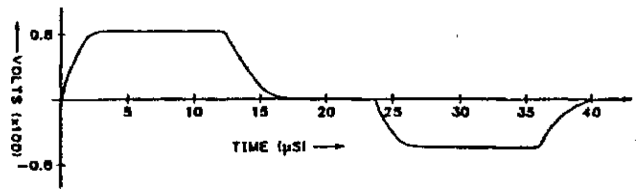

Figure 4. Drive wave form for bubble growth prevention.[6]

Fixing the Image

The ink property that rapid solidification occurs on contact with the substrate results in the formation of spherical lenslets on overhead transparency materials. These lenslets defract the light passing through the transparency material such that some of the color light does not reach the projector lens, resulting in a gray toned image. Some improvement of the projected image can be achieved by re-heating the ink, allowing it to flow, then rapidly quenching in order to re-freeze the ink in a more favorable geometry[7]. We chose instead to use a cold fusing apparatus to flatten the lenslates at pressures up to 3000 psi thereby improving the rectilinear light transmission.

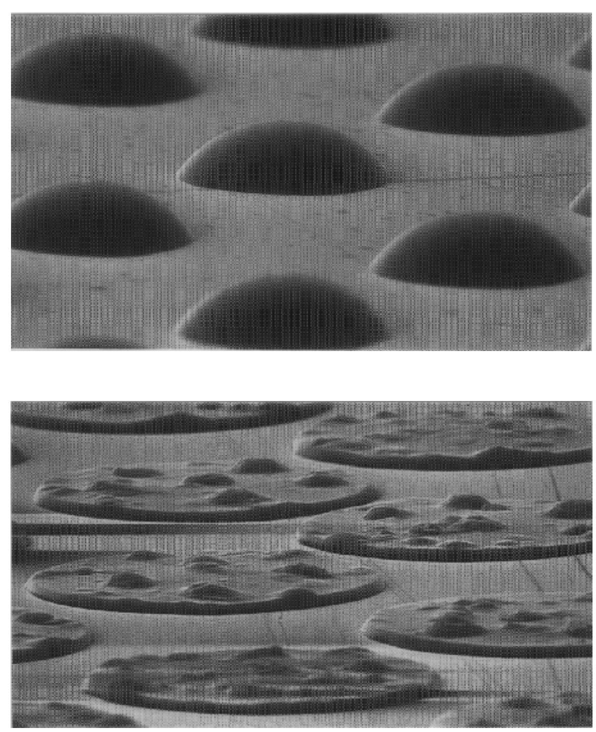

Figure 5. Ink geometry before (top) and after (bottom) cold pressure fusing.

SEM photographs of ink dots before and after fusing are shown in Figure 5. This fusing process also improves the durability and flattens the images printed on paper. In order to enable printing on a variety of paper substrates including thin bond papers as well as thick papers and card stock, we developed a unique fuser roller that is comprised of a composite of plastic and elastomeric materials surrounding a steel core.

The deformation of this roller adjusts for substrate geometry and stiffness so that a wide range of materials can be fused without wrinkling (both longitudinal and transverse).

Summary

Phase change ink jet technology has long been known as a viable means to achieve brilliant color printing regardless of substrate material. The Tektronix embodiment of this technology includes a unique ink formulation that maximizes the color gamut on paper substrates, a print head design and drive wave form that accommodates the physical properties of the ink, and a cold fuser that enables overhead transparency projection as well as durable prints for a wide variety of substrate physical properties.

Acknowledgments

This paper represents a summary of results achieved through the efforts of a number of scientists, engineers and technicians at Tektronix, including those whose publications were cited. This group was known internally as the Phaser Jet team.

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* Phaser is a trademark of Tektronix.