MicroFab Technote 99-01
Background on Ink-Jet Technology

Continuous Mode Ink-Jet Technology

The phenomena of uniform drop formation from a stream of liquid issuing from an orifice were noted as early as 1833 by Savart[1] and described mathematically by Lord Rayleigh[2,3] and Weber.[4] In the type of system that is based on their observations, fluid under pressure issues from an orifice, typically 50-80µm in diameter, and breaks up into uniform drops by the amplification of capillary waves induced onto the jet, usually by an electromechanical device that causes pressure oscillations to propagate through the fluid. The drops break off from the jet in the presence of an electrostatic field, referred to as the charging field, and thus acquire an electrostatic charge. The charged drops are directed to their desired location, either the catcher or one of several locations on the substrate, by another electrostatic field, the deflection field. This type of system is generally referred to as "continuous" because drops are continuously produced and their trajectories are varied by the amount of charge applied. Theoretical and experimental analysis of continuous type devices, particularly the process of disturbance growth on the jet that leads to drop formation, has been fairly extensive.[5,6] Continuous mode ink-jet printing systems produce droplets that are approximately twice the orifice diameter of the droplet generator. Droplet generation rates for commercially available continuous mode ink-jet systems are usually in the 80-100kHz range, but systems with operating frequencies up to 1MHz are in use. Droplet sizes can be as small as 20µm in a continuous system, but 150µm is typical. MicroFab has built systems that produce droplets as large as 1mm (~0.5µl) and as small as 6µm (10fl).

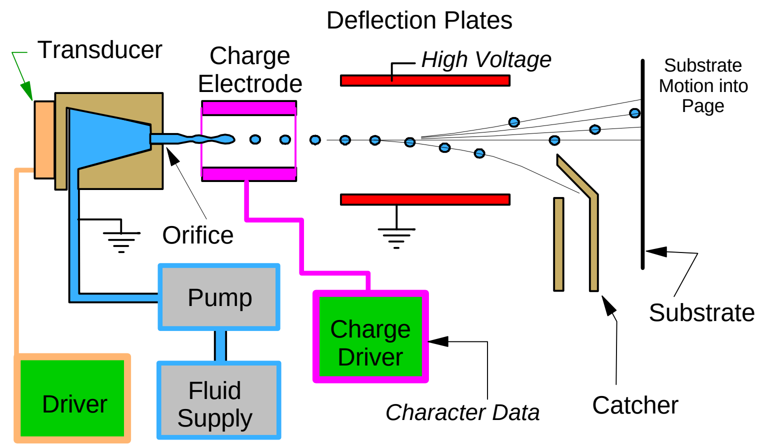

***Figure 1**: Schematic of a continuous type ink-jet printing system.*

Figure 1 shows a schematic of this type of ink-jet printing system, and **Figure 2** shows a photomicrograph of a 50µm diameter jet of water issuing from a MicroFab droplet generator device and breaking up due to Rayleigh instability (continuous mode) into 100:m diameter droplets at 20,000 per second.

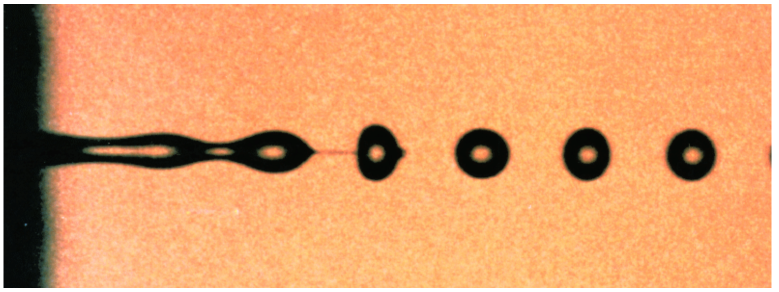

***Figure 2**: A 50:m jet of water breaking up due to Rayleigh instability into 100:m droplets at 20kHz.*

Dmand Mode Ink-Jet Technology

In the 1950's, the production of drops by electromechanically induced pressure waves was observed by Hansell.[7] In this type of system, a volumetric change in the fluid is induced by the application of a voltage pulse to a piezoelectric material that is coupled, directly or indirectly, to the fluid. This volumetric change causes pressure/velocity transients to occur in the fluid and these are directed so as to produce a drop that issues from an orifice.[8,9,10] Since the voltage is applied only when a drop is desired, these types of systems are referred to as drop-on-demand, or "demand mode."

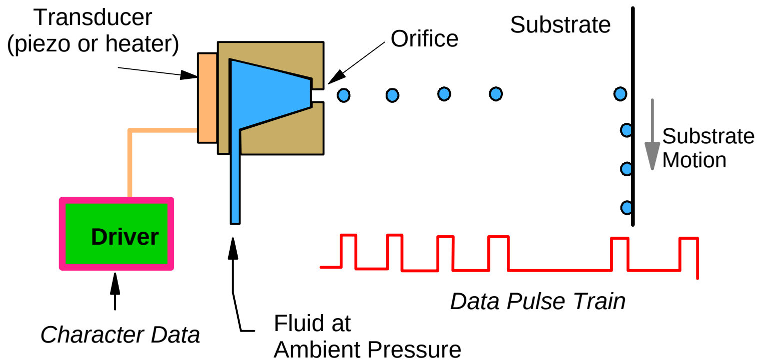

***Figure 3**: Schematic of a drop-on-demand ink-jet printing system*

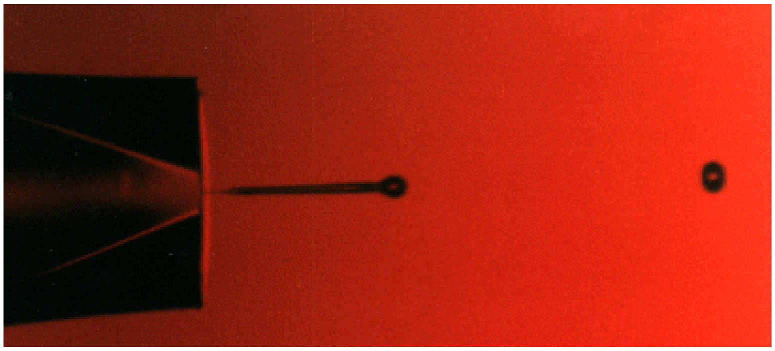

***Figure 4**: Drop-on-demand type ink-jet device generating 50 : m diameter drops at 2kHz.*

A recent demand mode droplet gen eration technology uses focused acoustic energy to cause a droplet to be emitted from a free surface. This type of technology has been employed in industrial processes for adhesive coating, and in NASA's liquid metal droplet free form fabrication efforts.[11]

In many commercially available ink-jet printing systems today, a thin film resistor is substituted for the piezoelectric drive transducer. When a high current is passed through this resistor, the ink in contact with it is vaporized, forming a vapor bubble over the resistor. This vapor bubble serves the same functional purpose as the piezoelectric transducer.[12] This type of printer is usually referred to as a thermal ink-jet printer.

Figure 3 shows a schematic of a drop-on-demand type ink-jet system, and **Figure 4** shows a MicroFab drop-on-demand type ink-jet device generating 50µm diameter drops of ethylene glycol from a device with a 50µm orifice at 2,000 per second. Demand mode ink-jet printing systems produce droplets that are approximately equal to the orifice diameter of the droplet generator.[13] As **Figure 3** indicates, demand mode systems are conceptually far less complex than continuous mode systems. On the other hand, demand mode droplet generation requires the transducer to deliver three or more orders of magnitude greater energy to produce a droplet, compared to continuous mode, and there are many "elegant' (i.e., complex) array demand mode printhead designs.[14]

Characteristics & Applications of Ink-Jet Systems

One of the characteristics of ink-jet printing technology that makes it attractive as a precision fluid microdispensing technology is the repeatability of process. The images of droplets shown in **Figure 2** and **Figure 4** were made by illuminating the droplets with an LED that was pulsed at the droplet generation frequency. The exposure time of the camera was ~1 second, so that the images represent thousands of events superimposed on each other. The repeatability of the process results in an extremely clear image of the droplets, making it appear to be a high speed photograph. To further illustrate this point, **Figure 5** shows two 60µm diameter jets of water breaking up into 120µm diameter droplets streams at 20,000 per second, and being caused to merge into a single droplet stream. Again, this image was created using a "strobed" LED and a ~1 second exposure time. Not only is the droplet formation process so repeatable that the image of the droplets is sharp, but when the droplets are caused to merge, the formation of the highly contorted merged droplets is seen to be just as repeatable.

Continuous mode ink-jet systems are currently in widespread use in the industrial market, principally for product labeling of food and medicines. They have high through-put capabilities, especially array continuous mode systems, and are best suited for high duty cycle applications. Few continuous mode ink-jet systems are multicolor, but two color systems are in use. Continuous mode ink-jet systems require the unused drops to be recirculated or wasted.

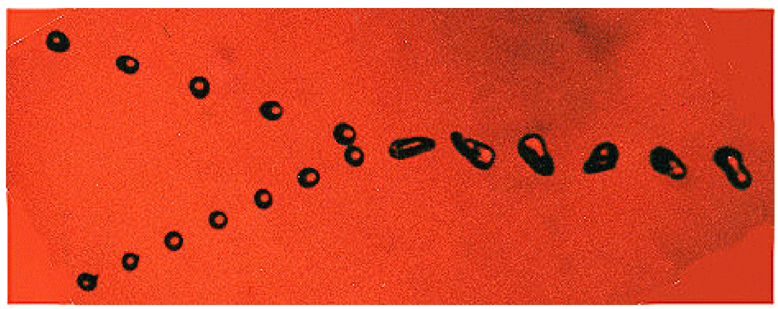

***Figure 5**: Two streams of 120 µm water droplets merging into a single droplet stream at 20kHz.*

Drop-on-demand ink-jet systems have been used primarily in the office printer market and have come to dominate the low-end printer market (HP's DeskJets, Cannon's Bubble Jets, and Epson's Stylus). Demand mode ink-jet systems have no fluid recirculation requirement, and this makes their use as a general fluid microdispensing technology more straightforward than continuous mode technology. Thermal demand mode ink-jet technology systems can achieve extremely high fluid dispensing performance at a very low cost. However, this performance/cost has been achieved by highly tailoring the ink: thermal ink-jet systems are restricted to fluids that can be vaporized (without igniting the fluid) by the heater element and their performance/life can be degraded drastically if other fluids are used. In practice, thermal ink-jet systems are limited to use with aqueous fluids.

As a non-contact printing process, the accuracy of ink-jet dispensing is not affected by how the fluid wets a substrate as is the case when positive displacement or pin transfer systems "touching off" the fluid onto the substrate during the dispensing event. In addition, fluid source cannot be contaminated by substrate, or contamination on the substrate, in a non-contact dispensing process. Finally, the ability to free-fly the droplets of fluid over a millimeter of more allows fluids to be dispensed into wells or other substrate features (e.g., features that are created to control wetting and spreading).

References

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