Gravure printing is the preferred method for printing high quality, fine dimension graphics using high-speed roll-to-roll or sheet fed presses. Gravure printing typically employs flexible and compressible substrates such as various papers and polymer films. In electronics, glass substrates are a common, if not preferred, substrate in many applications, particularly displays and photovoltaics. In combining printing with glass substrates, challenges exist in adapting contact-based printing methods such as gravure to the mechanical properties of the more rigid substrates. In this work, sheet-fed gravure printing has been successfully used to print silver-based conductive inks on glass substrates. Various features were designed and printed to evaluate conductive layers in terms of their printability and electrical performance. The independent variables include gravure cell dimensions, trace orientation with respect to printing direction, and ink type. Results from this work provide an insight into the science of gravure printing on glass by correlating the independent variables to printed feature quality and electrical performance.

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Printing design (Fig. 1) - set of meander line resistors that were used for both printability evaluation and DC resistance testing. Test structure line (trace) widths were designed to range from 50 µm to 500 µm. In order to evaluate directionality effects of gravure printing, traces were designed at three different angles with respect to the print direction (0°, 45° and 90°). For the evaluation of printed gaps, a group of 500 µm wide lines with different spacing was included.

Gravure cylinder preparation - indirect laser method - laser ablation of a protective mask on the cylinder is chromium plated and finished using traditional methods.

Substrate - Glass substrates were supplied by Corning Incorporated (Corning, NY). Dimensions of were 110 mm x 310 mm and 0.7 mm thick. A UV curable acrylate coating (>10um thick) was applied to the substrate surface to ensure ink adhesion (Ra roughness = 1 nm, Surface energy = 50 mN/m).

The nanosilver ink tends to spread more resulting in wider lines than silver flake ink (Fig. 10). This was supported by line width, line thickness, and resistance measurements.

If moat surrounding the pattern to be printed is connected to the main gravure cells, improved printability can be achieved as opposed to when the moat is separated from the main cells. The highest line spreading was found for 90° then for 45° lines, and the narrowest lines were printed at 0° to the print direction (Fig. 5).

Among printed and measurable gaps, the narrowest gaps printed with nanosilver ink on glass were measured as 36 ± 8 µm. Silver flake ink consistently provided lower DC resistance values than nanosilver ink (Fig. 8). When considering the thickness of printed lines, nanosilver ink has better applicability since it printed more than 4 times thinner and smoother ink film than silver flake ink (Fig. 10).