1. Publishable summary

Summary description of project context and objectives

First main objective is development, formulation and feasibility assessment of several lower-cost alternatives for Silver nano-particle based conductive inks.
Second major objective is to develop optimised ink dispersions for printing and curing for a number of processes including screen print, flexography printing, and aerosol-jet and ink jet.
The third main objective is to optimise the inks towards large area printing technology and towards techniques, which enable higher resolutions than in screen-printing. We realised during the project that the way of sintering is not only important to reduce the cost of large area printing, is strongly connected to the applicability of certain low cost alternatives of silver nano particles to realize the high conductivity but is also part of the total cost due to the investment in specific equipment.
The last major objective is the realisation of the demonstrators based on these inks.
During the project we learned there will be no unique solution for a low cost conductive ink as the final cost of the application will not only depend on the cost of the ink itself, but also on the volume and resolution of printing, the availability of printing and curing technology (or investment level in case of investment in new technologies) and the cost and printability of low cost substrates. As we look for specific solutions for SME´s we have to take in mind all these parameters and this will result in a low cost total process rather than low cost ink.
It was also impossible to work out different ink compositions for every combination of printing and curing technology mainly because of insufficient oxidation resistance of developed and commercially available micro copper components.
We had to limit the number of ink composition variants to specific combinations of printing and curing technologies taking in mind a total low cost process and probably resulting in specific resolution targets for the selected combinations.
Recent studies have indicated that conductive inks are on of the 3 most lucrative businesses for Printed Electronics in the short term. There are many areas of applications, which can benefit from a lower cost for conductive tracks such as OPV (the bus bars and fingers), fractal antennas in automotiveé

Description of work performed and main results

Specific stabilized and solvent based mono-modal nano-silver particle components were worked out by USC/Nanogap to be used in ink compositions for screen, flexography and ink-jet inks. Bimodal and trimodal silver nano particles were made to proof the cost benefits of these particle distributions in ink-jet inks.
Copper nano particles made by wet processing were supplied by USC to be tested in ink-jet and Aerosol jet .
A process for silver coated copper nano particles was worked out by USC, first trials were supplied to make thermal curable ink-jet inks.
Sub micron size copper micro flakes for ink-jet formulations were made by AVL. It was not possible to reproduce the first trials to make silver coated copper micro flakes because of insufficient oxidation stability of these components in ink compositions and during thermal curing. Commercial available silver coated copper micro flakes proved also to be not stable enough for making inks.

Optimised, low cost screen and flexography ink composition were developed by PRA for combination of screen, flexography printing and photonic curing based on micro copper flakes and silver nano/ copper nano particles. The screen ink compositions were successfully printed on different substrates at ACREO and photonic cured at IML. Flexography ink compositions need several consecutive layers to result in sufficient conductivity. The quality of printed flexography inks on paper substrates is good, but printing on PET is still a problem. Further optimisation of these ink compositions to improve surface resistance will be done during in-line printing and curing trials.
Based on stabilized solvent-based silver nano particles, ink-jet inks were prepared and tested at SIRRIS and KTH. Procedures for filtration of small ink-jet ink samples till 0.2-micron mesh size were worked out. After filtration, these inks could be printed and thermally cured on paper substrates. For printing on PET substrates surface treatment of the film and additional wetting agents in the ink were necessary to get good wetting of the ink on the PET film. Bimodal and trimodal nano-silver based inks were printed and thermally cured, but because of interactions with filtering no definitive result on the cost benefit of these inks could be proved.
Anyway the surface resistance of the printed ink compositions was lower than the commercial available

reference ink.
First test on Aerosol-jet printing and in-line laser curing of nano silver and copper inks showed exceptional low conductivities close to the specific resistivity of the pure metal. Micro copper Inks based on original micro copper flakes could not yet be printed with AJP.
Contacts were initiated to test in-line and alternative photo curing processes.

Because of default of a project partner, alternative demonstrators have to be proposed for every printing technology.
A HAZOP study of metal nano particles was made, a report on recommendations for handling in production, transport and packaging of nano particles is in preparation.
We started with making dissemination and exploitation plan that will be further worked out and implemented during the last period of the project.

Expected final results and their potential impact and use.

Although WP1 and WP2 financing period is closed some important component, ink and printing tests will be finalized in the last year of the project:

-Further trials to prove the cost benefits of bi- and trimodal nano silver based ink-jet inks will be continued by SIRRIS

-Silver coated copper nano particles will be tested further in ink-jet ink compositions by SIRRIS and KTH.

-SIRRIS will continue to improve the process for silver coated copper flakes and AVL will try to coat copper flakes during the milling process.

-Ink compositions made with these new and improved components will be further tested in screen, offset, ink and AJP printing processes to improve the resolution of printed lines, the surface resistance, wetting on and adhesion to substrates.

-The photo curing process has to be further optimised; composition of inks has probably been modified to improve surface resistance.

-The sub-micro size copper flakes of AVL will be further tested in ink-jet and AJP printers.

The process of in-line photo curing of developed screen inks will be tested at Holst Centre in collaboration with FP7/LOTUS project.

The main task of the last project period is the making and testing of demonstrators based on the developed inks and printing processes, so the real benefits of the developed inks and printing processes can be proved in practice. Some demonstrators can be printed and tested by the project partners themselves, but others have to be made and tested in collaboration with external partners.

The dissemination and exploitation plan has to be worked out and implemented. Project partners at coming planned Conferences will give presentations of project results. A joint workshop on final project results is proposed in collaboration with FP7/LOTUS project.

Recent studies results from 2012 have indicated that conductive inks are on of the 3 most lucrative businesses for Printed Electronics in the short term. There are many areas of applications, which can benefit from a lower cost for conductive tracks. The major drop of pricing in production could make it possible to have such application for a large buying population. Metallic flake inks for bus bars and fingers in PV ï rapid increase in the past five years to a multi billion-dollar market for conductive ink. Nano particle ink will increasingly be adopted. What is clear that printed Electronics is not going to replace something in a complete different way. What Printed Electronics and conductive printing is all about making items simple, make production more efficient, less energy depending, avoid rare and expensive materials. The first applications will only be produced for 30% by printing and only 6% of this production is done on rigid materials. Non-impact printing such as inkjet and AJP will gain importance because many of the developments of new applications are on fragile thin materials and non-flat substrates.