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Conductive UV Curable Adhesives for Printed RFID Antenna Structures

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Summary: For the use as RFID antennas conductive adhesives were developed and investigated which are UV curable and could be applied with printing methods like offset printing or flexography. Further investigated aspects of the materials have been the range of the distance between emitter and receiver. The resulting formulations which are based on acrylates filled with silver pigments for the conductivity allow to cure layers with a thickness of up to 50 μm with a maximal volume resistance of 1.6×10^{-5} Ω/cm.

Keywords: electrical conductivity; flexography; offset printing; RFID; UV

Introduction

Conductive adhesives are an enabling technology for a growing number of electronic applications; one of them is the RFID (radio frequency identification) technology. Although a lot of research and development in this field has been done next generations of these products should be improved in manufacturing and properties. Limiting factors for the manufacturing of RFID antennas with conductive adhesives are the slow thermal curing process and the application by dispensing. In commercial smard cards used antennas are based on copper or etched aluminium, which have disadvantages in manufacturing process.[1]

On that score the development of a formulation was started that fulfils the main topics:

- High electric conductivity.
- Printable with very fast and low cost printing techniques like offset printing or flexography during the production process of packaging or smart cards.
- Curable with UV for less temperature entry to the substrate (e.g. paper) and a fast overall manufacturing process.

Using this strategy the possibility is given to use new substrate materials with lower thermal stability, higher process speeds to save costs and energy and at least the possibility for introduction of the RFID technique in new (low cost) product markets.

Typically dynamic viscosity ranges between 40–100 Pa*s for offset printing and 0.05–5 Pa*s for flexography.[2] Typically layer thickness is around 0.5–2.5 μm with these printing techniques. Both topics are detrimental for a system which is highly filled with silver powder for a good performance in electric conductivity. Further properties to be considered during development are the sedimentation, curing through the complete adhesive layer, which is hindered due to the metal content and homogeneous distribution of the silver pigment in the cured adhesive layer. Due to the different viscosity between offset printing and flexography two different formulations are needed.

Results and Discussion

The basic resin for the formulation is based on 2-hydroxyethyl methacrylate (from Panacol-Elosol, Vitralit Y391135) which

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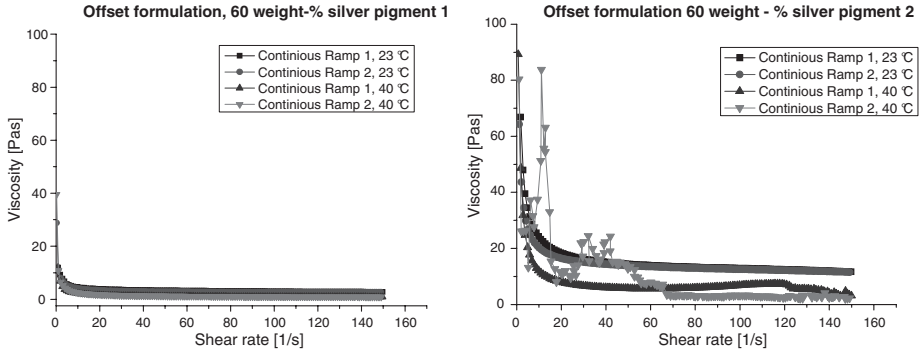

Figure 1.
Viscosity measurements of the offset printing formulation with silver pigment 1 and 2 at 23 °C and 40 °C with 60 weight % silver.

require a curing time of 5 seconds for the unfilled resin (measured as described in PE norm P001, UV (UV-A60mW/cm^2 with layer thickness of 1 mm). For the flexography formulation a reactive thinner was used to reach the lower viscosity. Two different silver pigments were used, one with an average size of 0.5 μm (silver pigment 1), the other with nano sized primary particles (silver pigment 2). Three different filling grades were used, 60-, 70- and 80 weight % silver filling grade. The viscosity was proved at room temperature and at 40 °C which represents the maximum temperature during offset printing. The results for the offset printing formulation with 60 weight % are pictured in Figure 1; the results of the 70 and 80 weight % measurements are similar and not shown.

The offset printing formulation with silver pigment 1 is stable over the examined shear rate range at both temperatures,

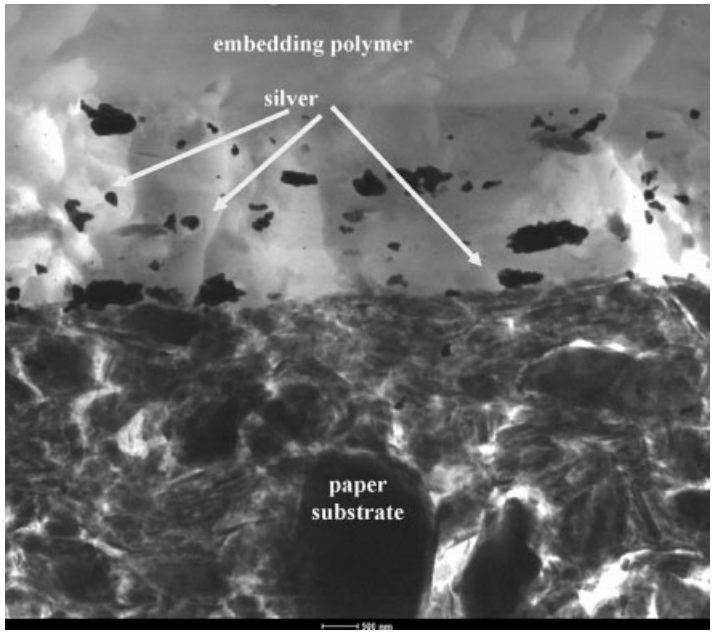

Figure 2.
TEM image of offset printing formulation with 60% silver pigment 2.

whereas the formulation based on silver pigment 2 shows at higher temperature a non uniform behaviour which indicates an agglomeration due to shear during measurement. This results in structures of the cured layer after printing as demonstrated in Figure 2, which shows the Transmission Electron Microscopy (TEM) image of the offset formulation with silver pigment 2. It is to assume, that during offset printing process an agglomeration of the pigment occurs, the agglomerated pigments are not longer transported in the printing process (at least over twenty rollers during printing process) and a massive decrease of pigment content in the cured layer was observed.

This printed structures show nearly no conductivity, while the same formulation applied as 10 μm thick layer with a squeegee shows a conductivity of 1.8×10^{-3} Ohm/cm. Silver distribution of formulations with silver pigment 1 is similar if offset printed structures and applied with a squeegee structures are compared, as shown in Figure 3. But also here an about one decade less conductivity was observed for printed structures. It is to assume that the thinner layer caused the lower conductivity by skips which are in relation to layer thickness larger. Such a strong influence of the silver amount (60, 70, 80 weight %) could not be found, which indicates that a silver pigment amount of 60 weight % should be enough, if homogeneously distributed.

The curing behaviour of the formulations was investigated by FT-IR spectroscopy in ATR technique. For these experiments curing was carried out on the ATR crystal with a point source and after defined time periods the measurements were carried out. With this measurement protocol it is possible to measure the curing progress at the ''bottom'' of the layer, as schematically drawn in Figure 4.

For curing progress the decrease of –C=C– double bonds was evaluated, typical spectra of a non-cured and cured formulation are shown in Figure 5. Overall, all investigated formulations showed no residual double bonds after 30 second radiation.

For flexography the viscosity should lower, therefore the offset printing formulation was diluted with a reactive thinner. The resulting rheological properties are shown in Figure 6 for a formulation with 60 weight % silver pigment 1.

Examples for printed antenna structures are shown in Figure 7. The upper structure was used for the measurement of the electric conductivity, the other for measurement

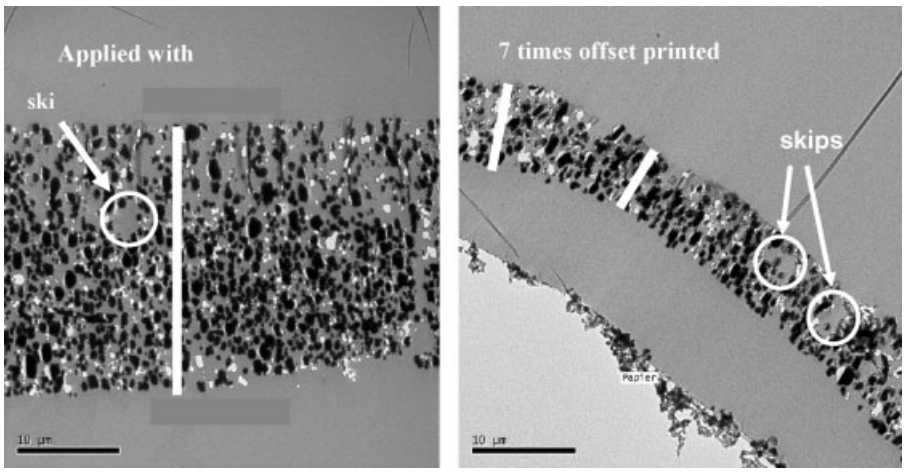

Figure 3.
TEM analysis of offset printed and squeegee applied structures of offset printing formulation with silver pigment 1.

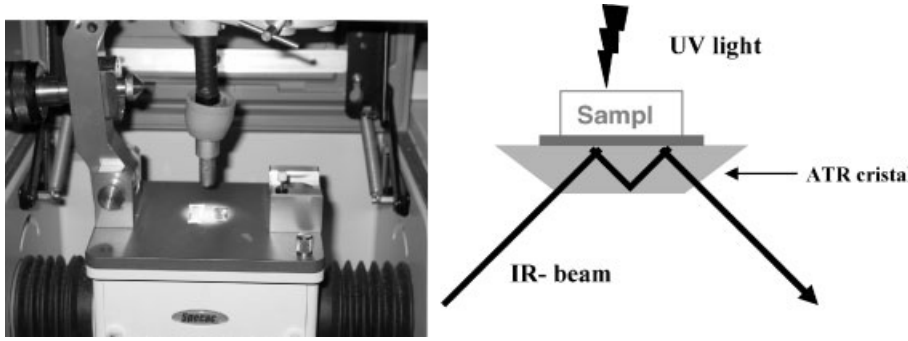

Figure 4.
Set up for FT-IR measurements to investigate the curing progress.

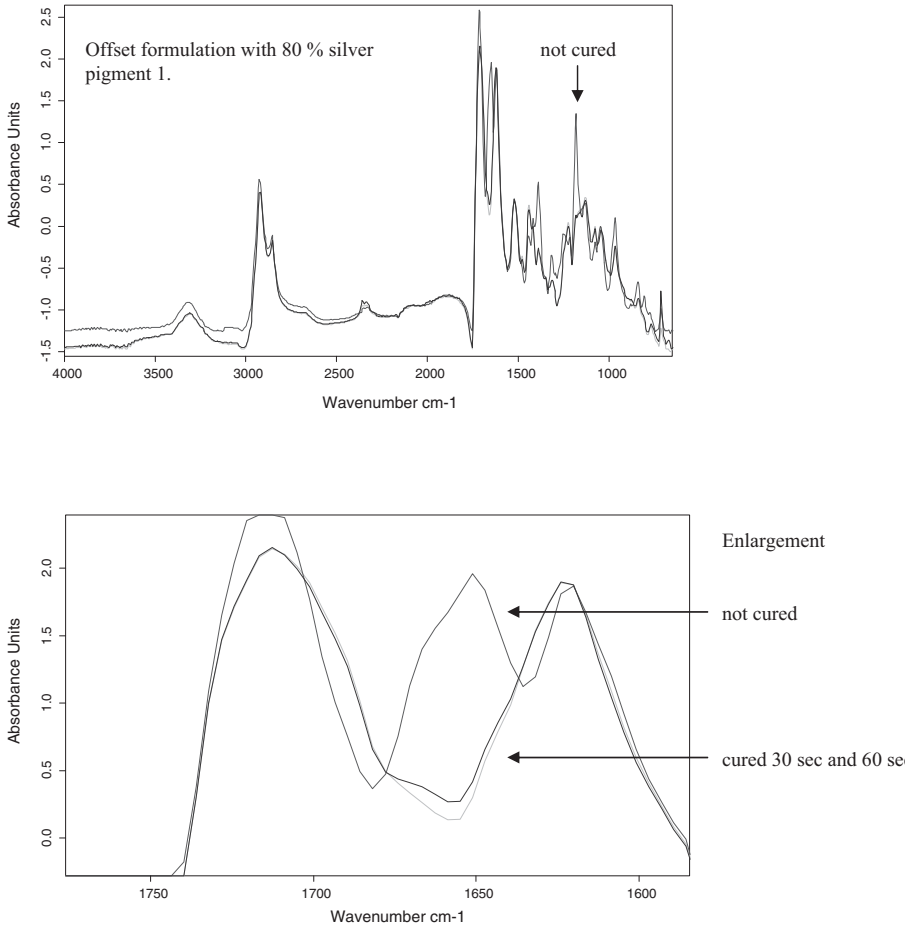

Figure 5.
Example FT-IR spectra of offset printing formulation with 80 weight % silver pigment 1 for the evaluation of the curing progress.

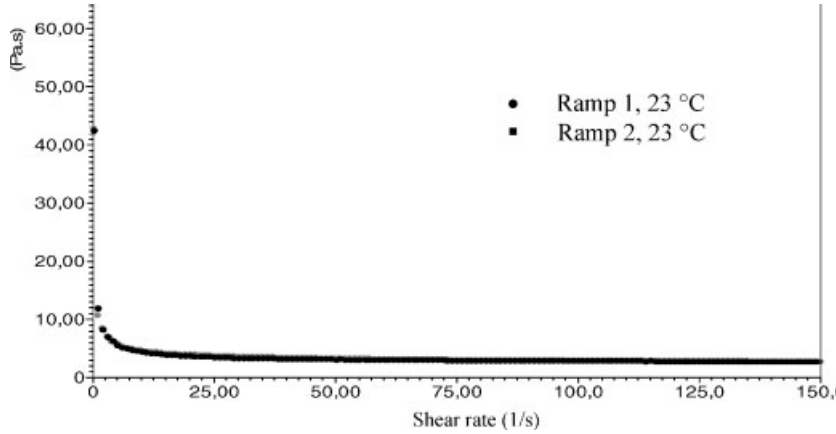

Figure 6.
Viscosity of the flexography formulation with 60 weight % silver pigment 1 at 23 °C.

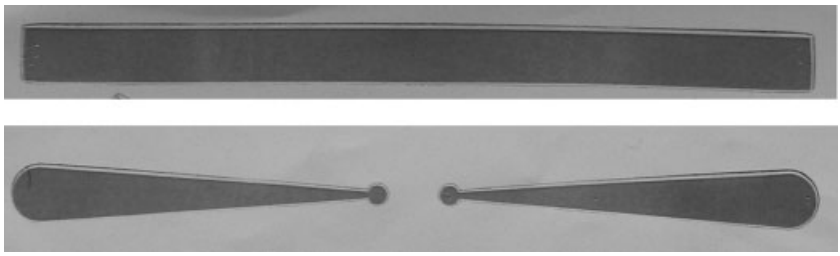

Figure 7.
Flexography printed structures of a formulation with 60 weight % silver pigment 1. Upper structure for electric conductivity measurements, lower half structure for measurement of the maximal emitter/receiver distance.

of the resulting maximum distance between potential emitter/receiver devices.

With this kind of formulation and printing process it was possible to observe a volume resistance of as less as 5×10^{-4} Ohm/cm. This means that a maximum distance between emitter and receiver of 0.86 m is possible. With an optimised antenna design a distance of 4 m was realised.

Conclusions

Based on 2-hydroxyethyl methacrylate resins formulations were developed, which could be used for the application as RFID antenna structures. For a very fast and low cost manufacturing of these antenna structures, the process should be an offset printing or flexography printing process with an integrated curing process, here UV curing. Necessary for the antenna properties is the conductivity as high as possible. It was shown that silver filled formulations were developed, which could be fully cured by UV light and processed with offset printing and flexography. The in the offset printing process produced skips in the layer reduced the observable volume resistance to such a low value that no antenna properties could be observed, although the layers produced with a squeegee showed volume resistance up to 10^{-3} Ohm/cm.

The flexography produced antenna structures showed a quite good volume resistance from $5^{*}10^{-4}$ Ohm, which means a maximum distance between emitter and receiver devices of 0.86 m. The presented

formulations together with the printing processes make a cheaper and quicker production of the RFID antennas possible and therefore a big step for a broader application of this technology is done.

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[1] Finkenzeller Klaus, *RFID – Handbuch*, 3. akt. Auflage.
[2] ''Offset Printing'' *Encyclopædia Britannica*, Retrieved March 22, 2004.

