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Inkjet printing of highly reliable nanoporous silver films for flexible applications

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Introduction

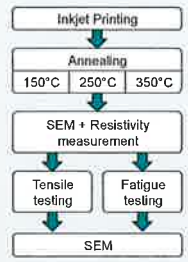
The preparation of flexible electronics on compliant substrates offers a wide range of possible applications such as flexible displays, flexible batteries or electronic skins. Inkjet printing is a promising technology for the preparation of such devices due to its low cost, high throughput and high substrate compatibility.

Compared with conventional vacuum processes, inkjet printed films show a considerably lower film quality concerning roughness and porosity. Generally, this is regarded as a severe drawback because of the lower electrical conductivity and local stress concentration during mechanical deformation, leading to earlier failure.

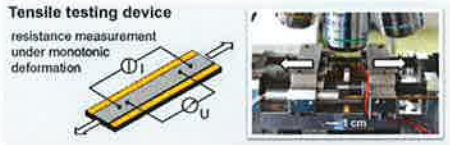
This publication covers the process development for inkjet printing of flexible silver electrodes. By choosing the right annealing conditions films with high conductivity and superior fatigue were achieved.

Experimental

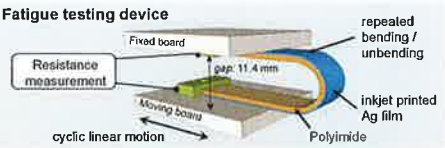
Process chain



Tensile testing device

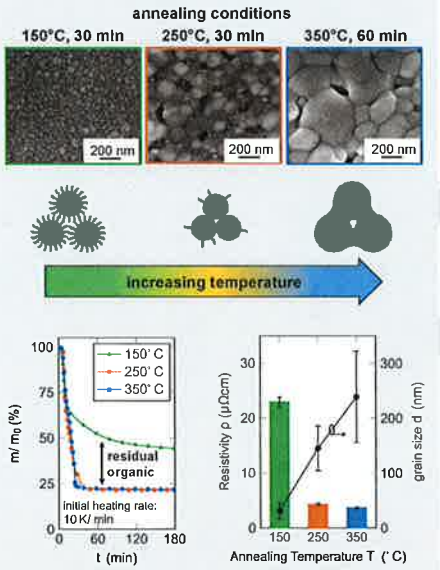


Fatigue testing device



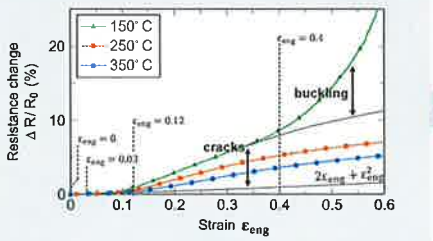
Film properties and failure behavior

Initial film properties

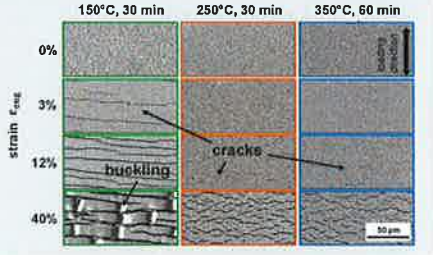


Tensile testing

Failure condition: $\Delta R/R_0 > 1.05 \times (2\varepsilon_{eng} + \varepsilon_{eng}^2)$

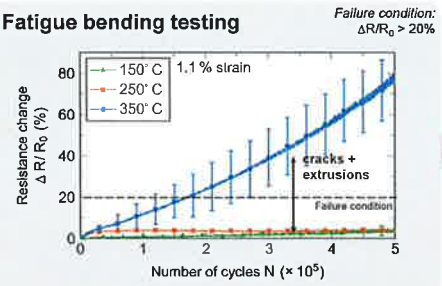


Failure behavior

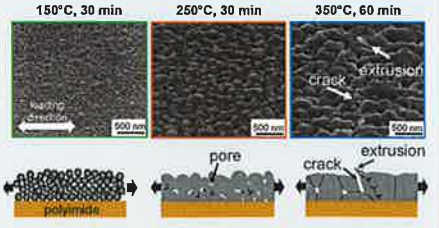


Fatigue bending testing

Failure condition: $\Delta R/R_0 > 20\%$

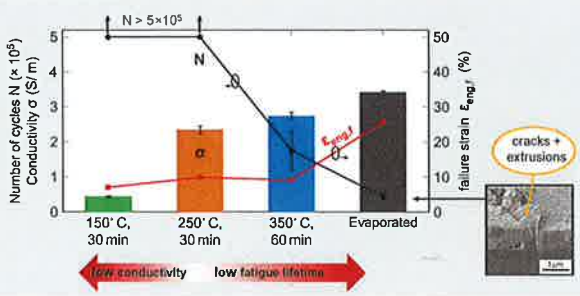


Failure behavior (after 5×10^5 cycles)



Conclusions

Conclusion chart



A nanoparticle silver ink was printed on polyimide substrates and annealed at different temperatures.

For annealing at 250°C and above the films show a high conductivity of 2.3–2.7 S/m, very close to the value of conventional evaporated films. Tensile testing showed a failure strain of 7–10 % for all printed samples. A strong resistance change with deformation was only visible for the sample annealed at 150°C due to the weak particle interconnections in this case. Fatigue bending testing showed a resistivity change of less than 5% after 5×10^5 cycles for the samples annealed at 250°C and below. This is a superior fatigue behavior compared to evaporated films which showed an overall fatigue lifetime, which was more than one order of magnitude less.

The investigations show that a good conductivity and a high reliability can be achieved by optimizing the nanostructure of inkjet printed Ag-films.