DC resistance in thin films having cracks

by

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Overview

Flexible electronic products are made using polymer-supported thin metal films. While flexing these products, microscopic cracks develop in the metal film which results in an electrical degradation from the increase in DC electrical resistance.

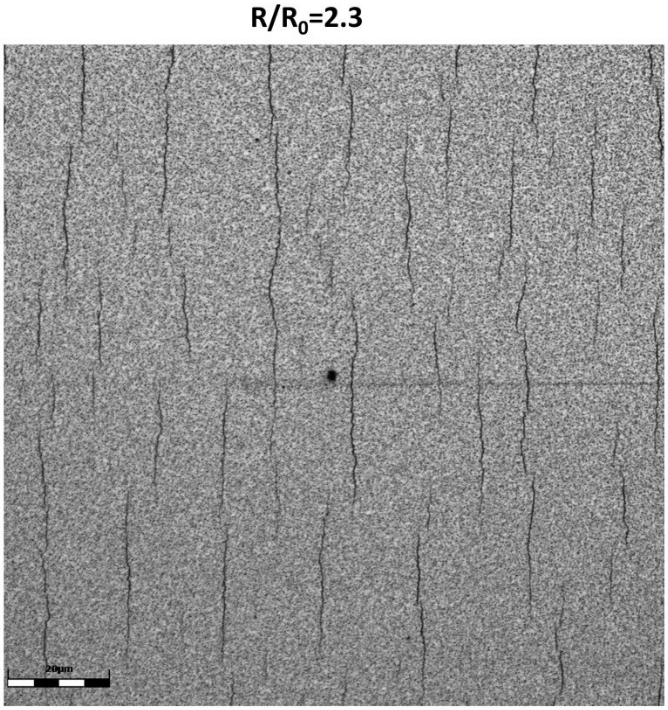

Fig 1. Microscopic image of the surface of a thin conductive film with cracks. The increase in resistance after the cracks developed was measured to be R/R_0=2.3.

For reliability testing, the electrical resistance of thin conductive films can be measured during mechanical loading; the growth of resistance with the applied strain or cycle number can be attributed to induced cracks. However there is currently no understanding of the quantitative relationships between the parameters of crack pattern and electrical resistance growth.

This paper describes a way to determine the electrical resistance directly from crack patterns using the finite element method. For a systematic investigation fine-grid models containing hundreds of cracks with pre-defined parameters should be evaluated. But before addressing the actual model, a simpler model for illustration purposes will be used here to describe the modeling concepts involved.

An illustrative model

To illustrate the concepts in the analysis a simpler model with coarse elements will first be used. This finite element model is built using the LISA (www.lisafea.com) software. Fig 2 shows a coarse mesh of a conductive material without any cracks. The material properties needed for each element is its electric conductivity and thickness. The edges highlighted with green represent the current entering (source) and leaving (drain).

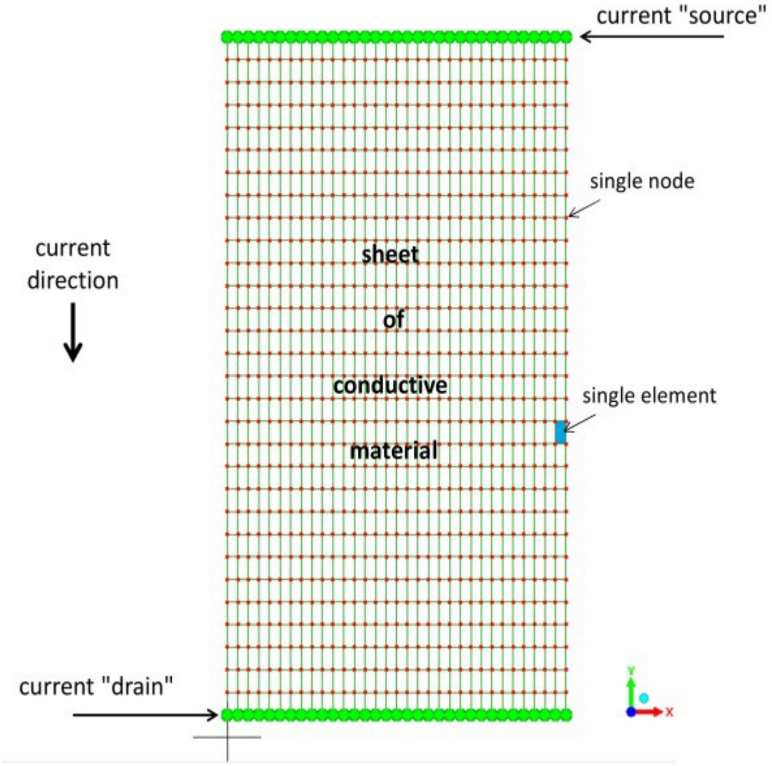

Fig. 2. General view of the DC current flow model in LISA.

The solution of the model gives the distributions of current, electric field, electric potential and energy density. Fig 3 shows the potential difference across the model, $\Delta U_0 = U_{max} - U_{min} = 6.46E+07$.

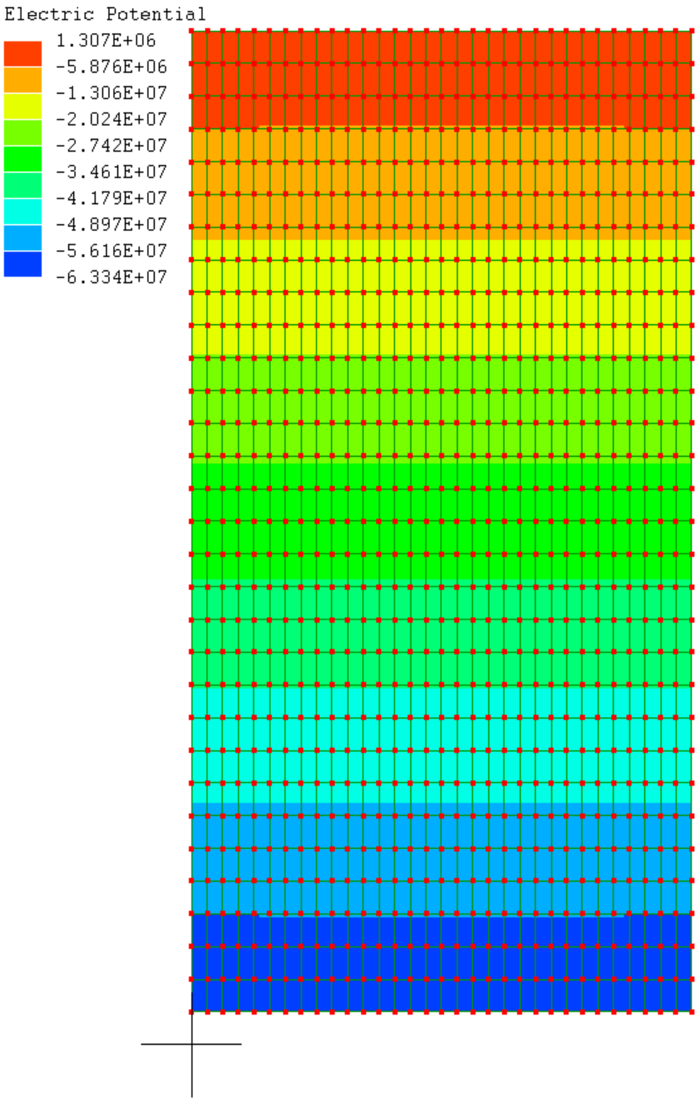

Fig. 3. The distribution of the electric potential in a conductive material with no cracks.

For this illustration the size of the cracks will be exaggerated by deleting the coarse elements along a straight line as shown in Fig 4.

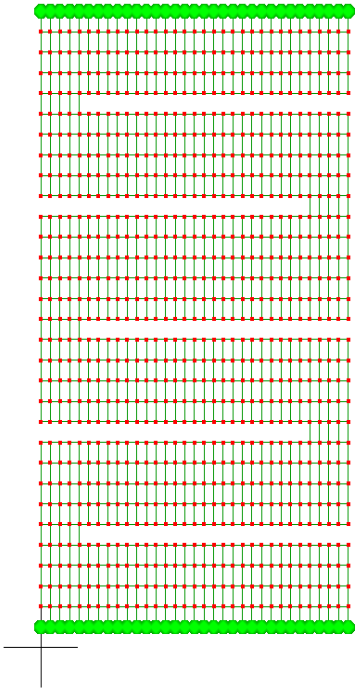

Fig. 4. The model with cracks. Missing elements have zero electric conductivity.

In the actual models used later, the crack patterns will be generated randomly.

The distribution of the electric potential is as shown in Fig. 5a. The potential drop across the model is now $\Delta U = U_{max} - U_{min} = 78.2E+07$. As the applied current remains constant in both the models, the increase in electrical resistance is simply the increase of the electric potential drop (Ohm's law):

$R = \Delta U / I$; $R_0 = \Delta U_0 / I$ => $R/R_0 = \Delta U / \Delta U_0$

Which is $R/R_0 = \Delta U / \Delta U_0 = 12.1$

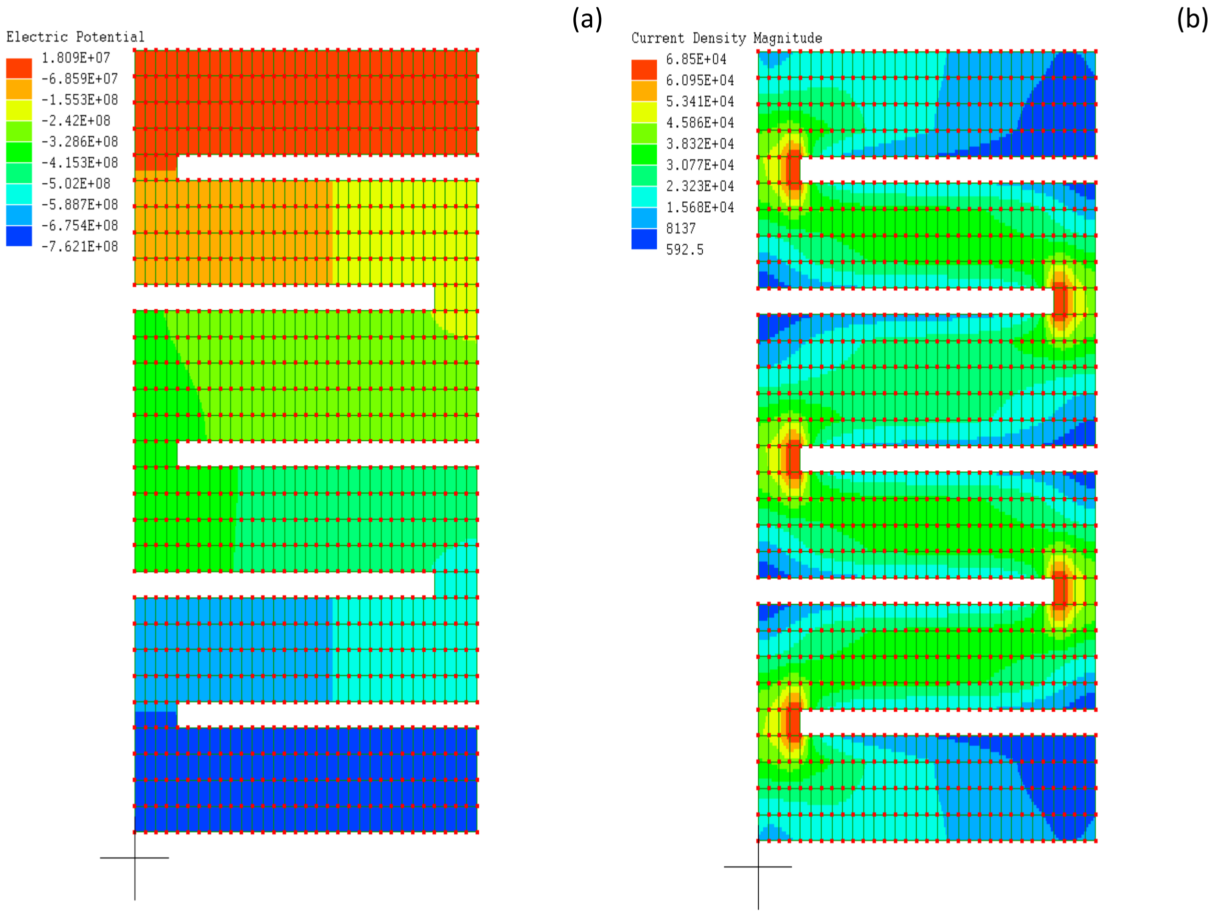

Fig. 5. Solution of the model with exaggerated cracks. (a) shows the electric potential and (b) shows the current density distribution.

Verification model

This section describes a laboratory controlled test of a polymer-supported copper film of thickness 600 nm, length 20 mm and width 5mm. Cuts were made in the film (Fig 6a) and their lengths measured using an optical microscope. The resistance of the film was measured before and after the cuts were introduced. The results of the finite element model before the cracks was 0.116 ohm which was within 4% of the measured value of 0.121 ohm.

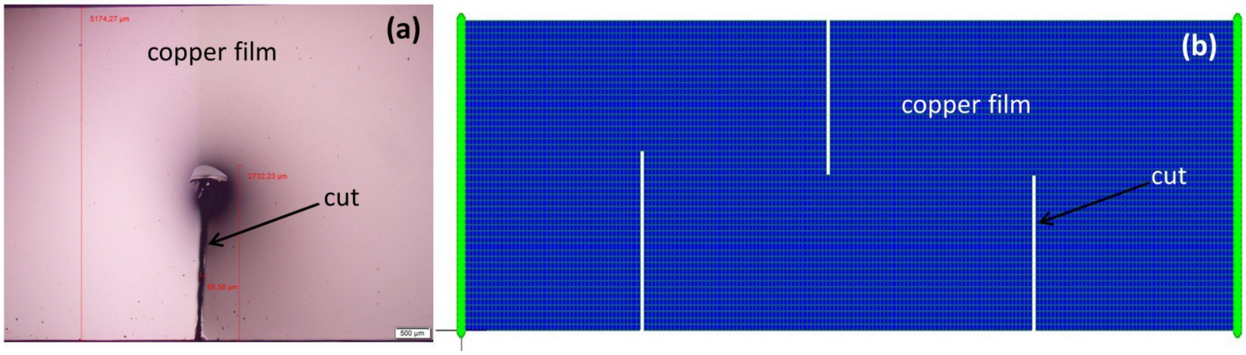

Fig. 6. Verification of the model. (a) Optical image of a copper sample with cut. (b) FEA model copper film with three cuts. The current flows in the horizontal direction.

The finite element model with the cracks is as shown in Fig. 6b. The blue area corresponds to copper with a conductivity of 5.5E7 S/m which is slightly lower than the bulk value due to the thin film geometry and small grain size.

For statistical validity, multiple specimens were tested and modeled, the results for two of them are shown in Fig 7. As can be seen the differences between the measured and simulated values are negligible.

Fig. 7. Comparison of experimental and simulated resistance growth depending on the number of cuts.