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Insight into the Dielectric Breakdown of Elastomers

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Abstract

Nowadays, dielectric elastomers are used in many different fields, such as: dielectric or transport layers, modern devices or flexible electronics. To test dielectric elastomer stability in electric field, dielectric breakdown measurements are used. These measurements have been used over many years and still gaining on importance, however, fundamentals behind the electrical breakdown of thin and elastic films are still not fully understood. There are only few theoretical models that assess the physical processes occurring during a breakdown phenomenon, for example: the hole-induced breakdown model, the electron-trapping breakdown model, the resonant-tunneling-induced breakdown model and the filamentary model. In all these theories, electrons movements from electrode to polymer film samples are considered. Other theory is the, so-called, electro-mechanical model, which implies that polymer films are not always smooth, and when an electric field is applied, the force gets bigger at the thinnest spot of the film, which causes the deformation of a film. Subsequently, when electric strength is reached at the thinnest spot - breakdown occurs. This is also referred to electro-mechanical instability (EMI) and has been extensively studied by modelling. In this work, microscopic processes taking place during the dielectric breakdown were captured using high-speed camera, to verify if the time-scale and behavior of the electrical breakdown can elucidate the underlying behavior.

Keywords: dielectric elastomers, electrical breakdown, high-speed camera.

Experimental

Materials

ELASTOSIL®FILM 2030 250/50, Wacker Chemie AG;
ELASTOSIL®LR 3043/50, Wacker Chemie AG;
Filler: **AEROXIDE®STX501 TiO2/SiO2 filler**, Evonik Industries.
BET surface area 35±10 (m2/g).

Measurement

Polymer film (52-60µm thickness) was cut and placed on the plastic frame, which subsequently was placed into breakdown instrument between the electrodes (Fig. 1). The gap between the electrodes was fixed to be the same as the thickness of the film sample. Voltage (100V/s, room temperature and room humidity) was applied until polymer film broke down. In the meantime, breakdown process was recorded with high-speed camera system (FASTCAM Mini UX100–Photron, 125fps).

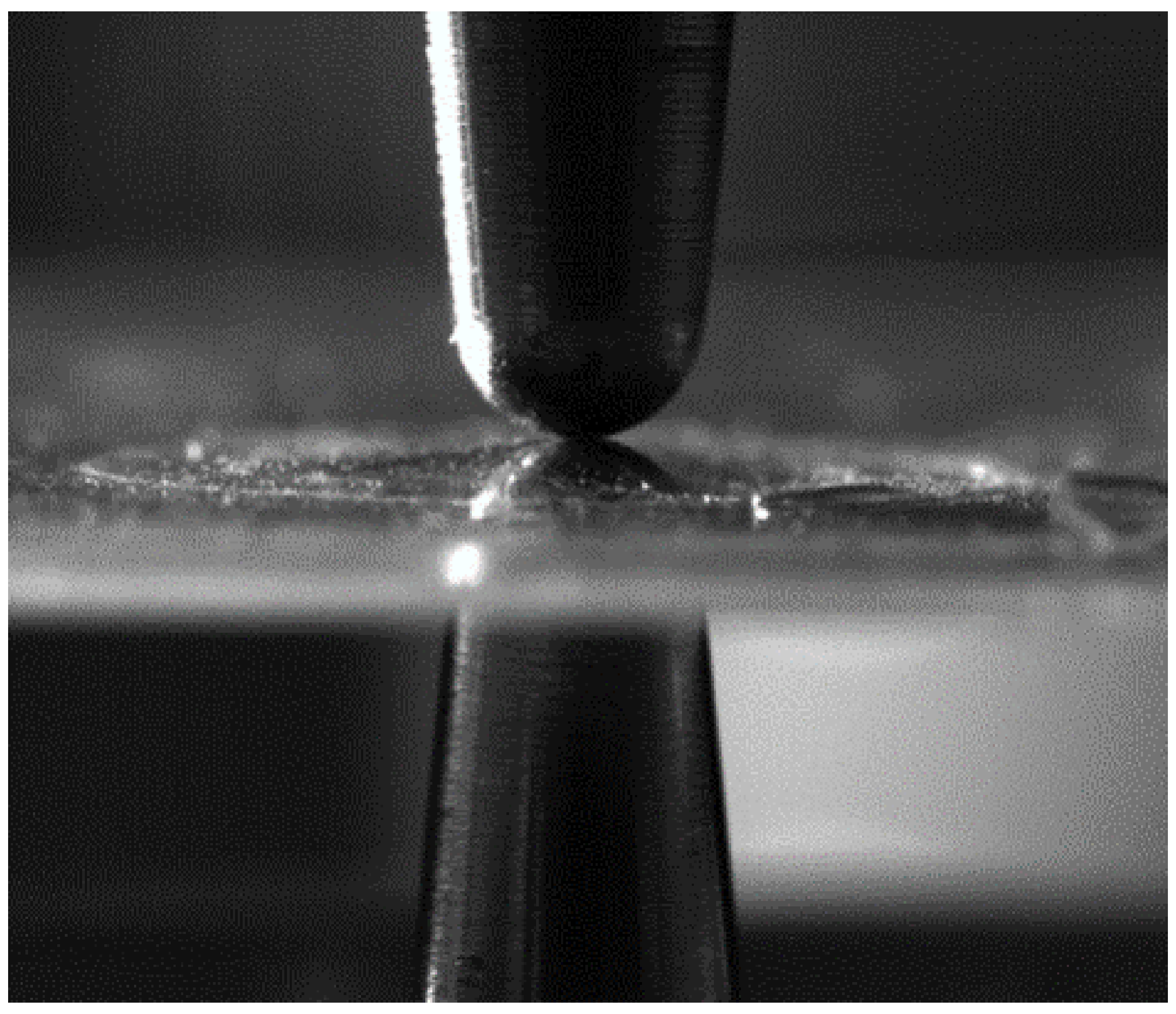


Fig. 1. Film sample between two small (Φ = 2mm) electrodes.

Results

Sample actuation:

A. **Film stretching (Fig. 2A):** When the voltage is applied, film starts to stretch and surrounds the lower electrode. This film movement can be observed in almost all experiments. This movement is happening just before B and C movements starts to show.
B. **Bubble structure (Fig 2B):** When the voltage is applied, film starts to move upwards, bend and form bubbles.
C. **Ring shape structure (Fig 2C):** When the voltage is applied some smaller bubbles connect and encircle the electrodes.

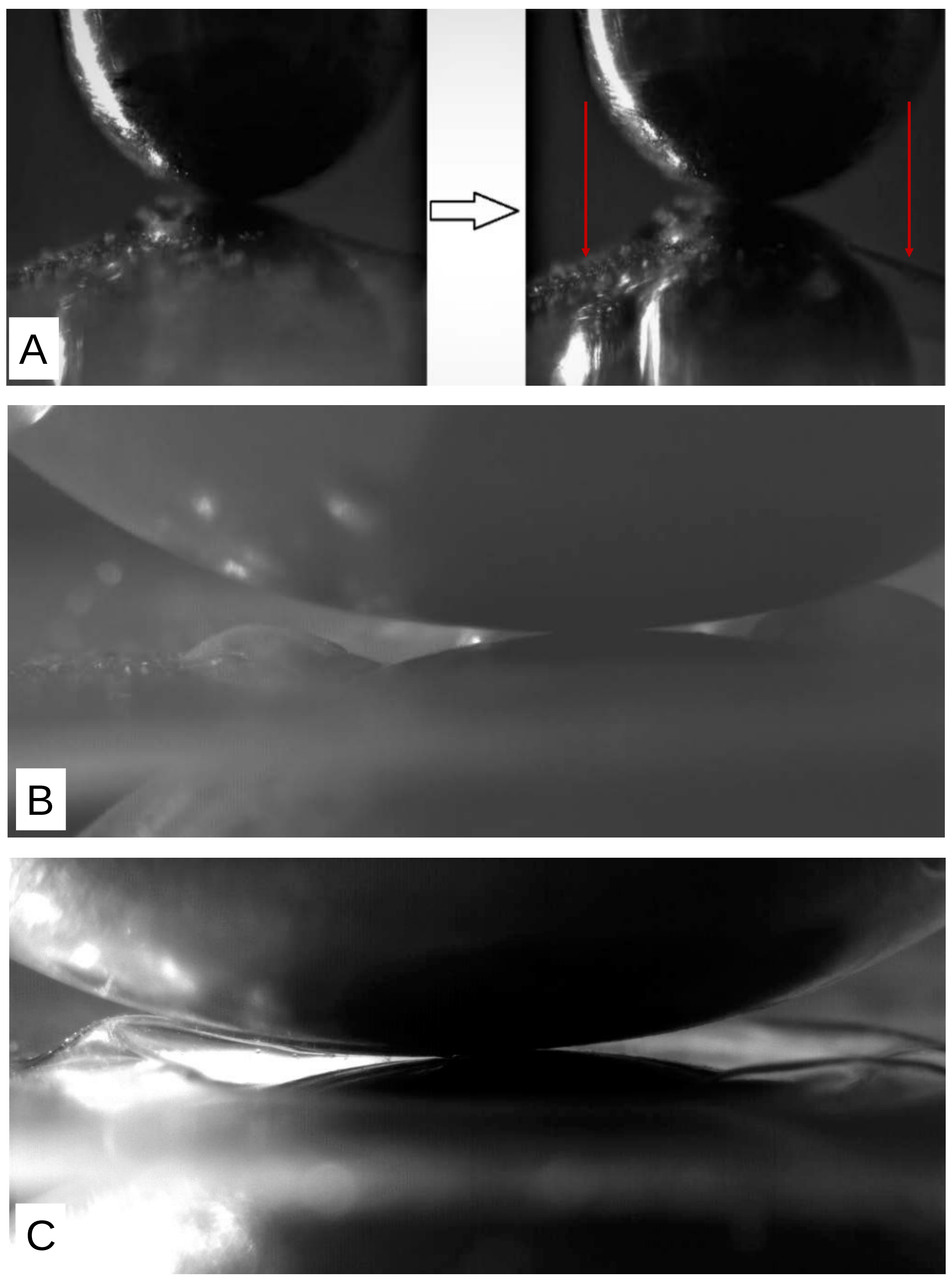


Fig. 2. Examples of a film activation: A - film stretching on small (Φ = 2mm) electrode. B - bubble structures on big electrode (Φ = 20mm). C - ring shape structures on big electrode (Φ = 20mm).

Breakdown:

Breakdown is an instantaneous process and when it occurs, it can be spotted with high-speed camera, in a shape of electrical discharge (**Fig. 3**).

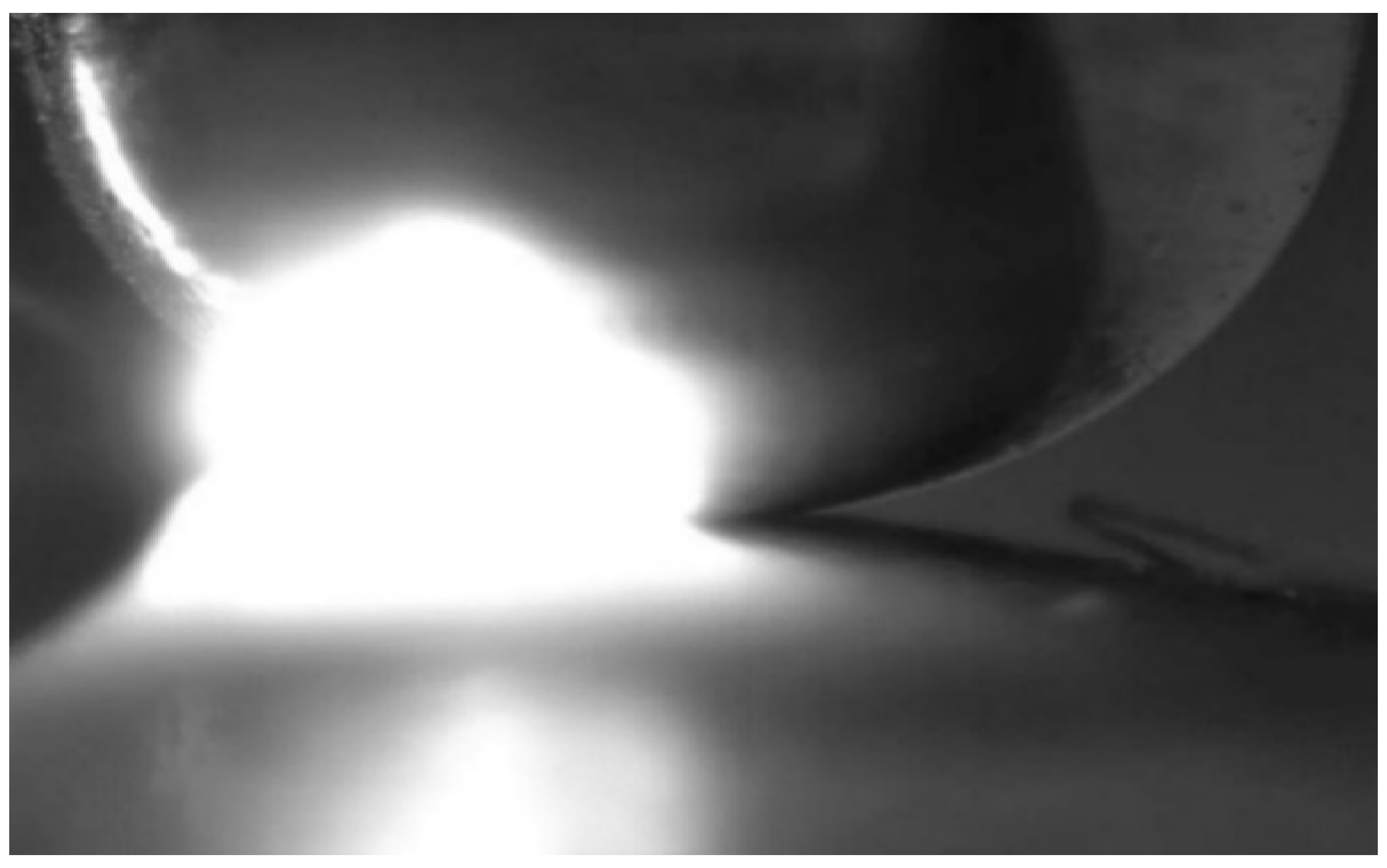


Fig. 3. Film sample during breakdown on small electrode (Φ = 2mm).

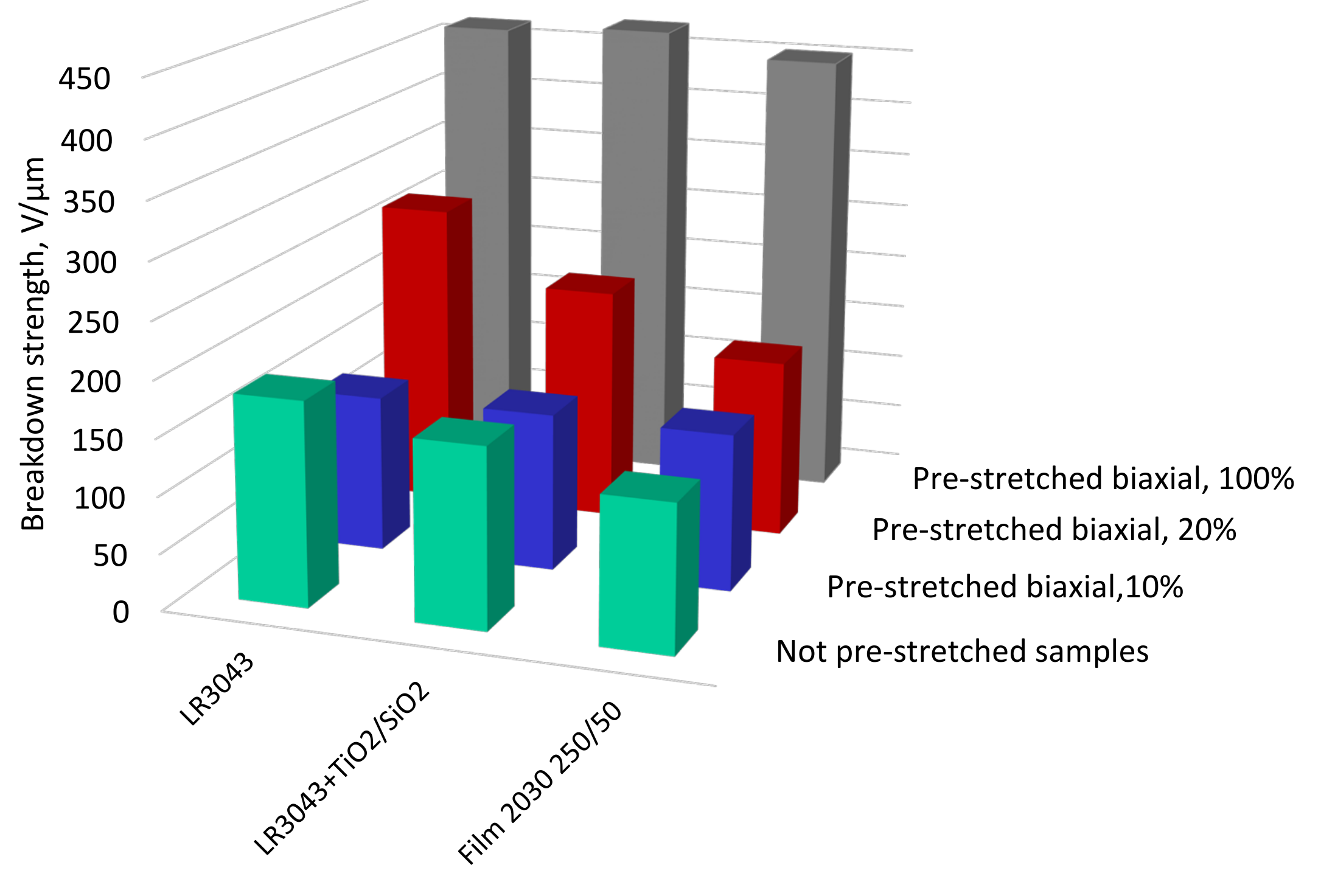
Breakdown lasts until film sample breaks and a hole on the film sample appears (**Fig.4**). Hole varies in size from few micrometers to a few millimeters and the broken structure shape does not change over time.

Fig. 4. Film sample after breakdown, with a hole (marked with red circle). Electrode diameter: 2mm.

Pre-stretched samples:

Samples were pre-stretched **uniaxial** and **biaxial**, with pre-stretch of **10%**, **20%** and **100%**.

It was noticed that when samples are pre-stretched, sample activation is small, the pinhole after breakdown is much smaller and located directly under the upper electrode. However, breakdown strength increase by increasing the pre-stretch rate (**Fig. 5**).



	LR3043	LR3043+TiO2/SiO2	Film 2030 250/50
🟩 Not pre-stretched samples	181	159	129
🟦 Pre-stretched biaxial,10%	139	140	139
🟥 Pre-stretched biaxial, 20%	272	209	159
⬛ Pre-stretched biaxial, 100%	416	422	402

Conclusion

Breakdown is widely used to state the quality of a given dielectric elastomer, however the breakdown phenomenon has not been thoroughly studied. From our results, there are many different processes, as film wrinkling movements, happening during breakdown. Therefore, this method needs further investigation and experimentation until it is fully understood. With the underlying mechanisms and phenomena elucidated, a design guideline towards more electrically robust dielectric elastomers can be made.

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