FACULTY OF ELECTRICAL ENGINEERING
UNIVERSITY OF WEST BOHEMIA

RICE

Faculty of Electrical Engineering
University of West Bohemia, Pilsen, Czech Republic

Nanostructured Potting Compounds with Enhanced Material Properties

17. 3. 2021 – ViF Strategic Grant: 21930061

Jaroslav Hornak

MINISTRY OF EDUCATION, YOUTH AND SPORTS
EUROPEAN UNION
EUROPEAN REGIONAL DEVELOPMENT FUND
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Table of Contents

History of Nanodielectrics

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Nano- definitions:

- **Nanotechnology –** „*Methods that create materials or structures with designed features in the 1–100nm size range“.* (Niemeyer, 2002; Whitesides et al., 1991).

- **Nanotechnology –** „*The creation and use of structures, devices, and systems that have novel properties and functions because of their small size“.* (U.S. Environmental Protection Agency (EPA))

- **Nanotechnology -** „*The understanding and control of matter at dimensions between approximately 1 and 100 nm, where unique phenomena enable novel applications“.* (The National Nanotechnology Initiative (NNI, 2010))

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History of Nanodielectrics

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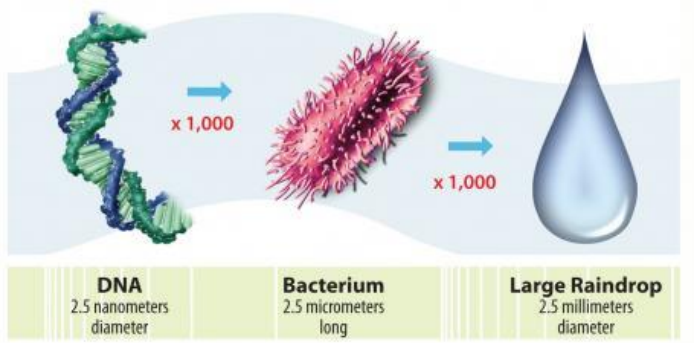

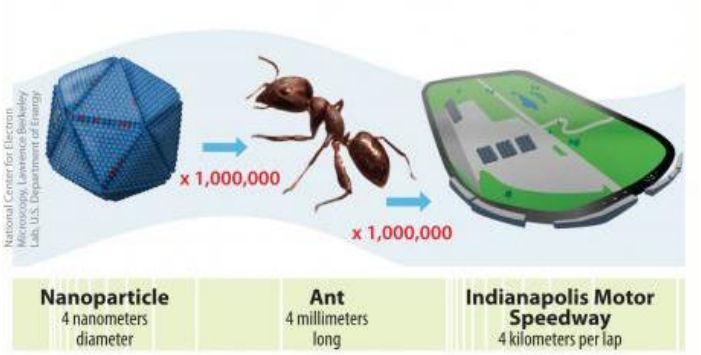

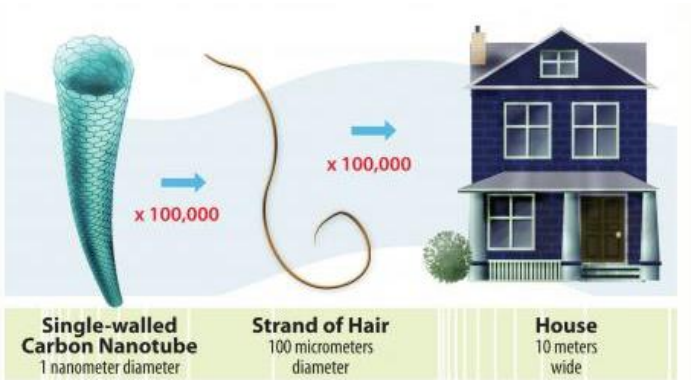

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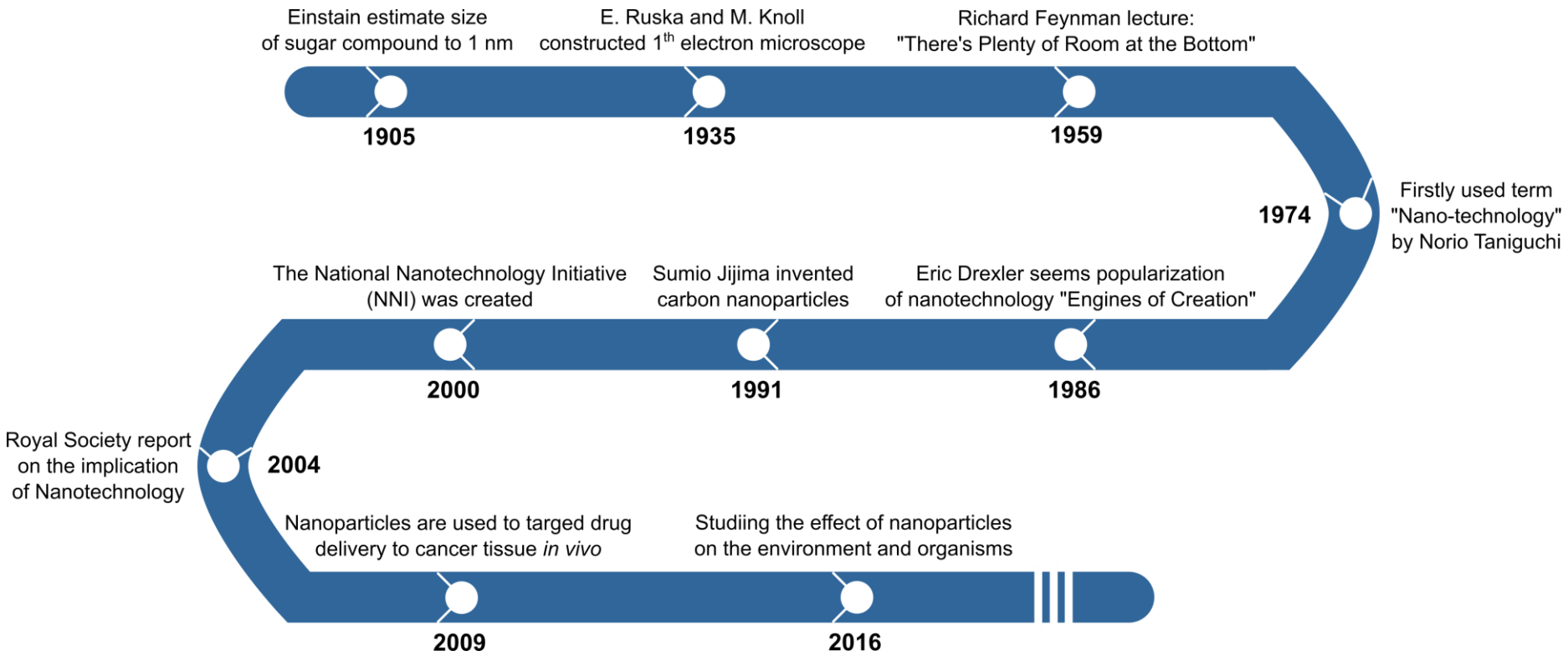
History of Nanodielectrics

Nano- evolution



Based on: Niska, et. al., Metal nanoparticles in dermatology and cosmetology: Interactions with human skin cells, Chemico-biological Interactions 295, 2017.

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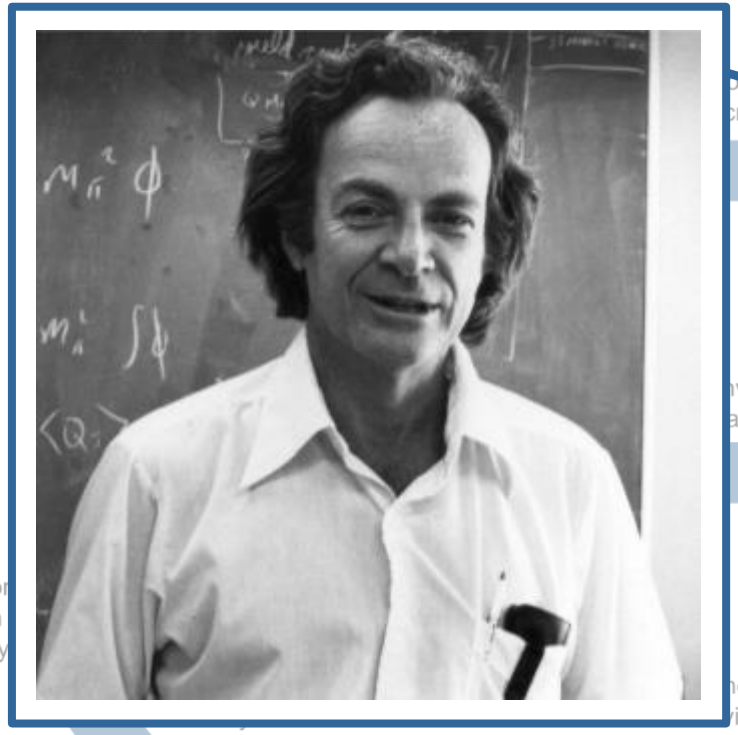

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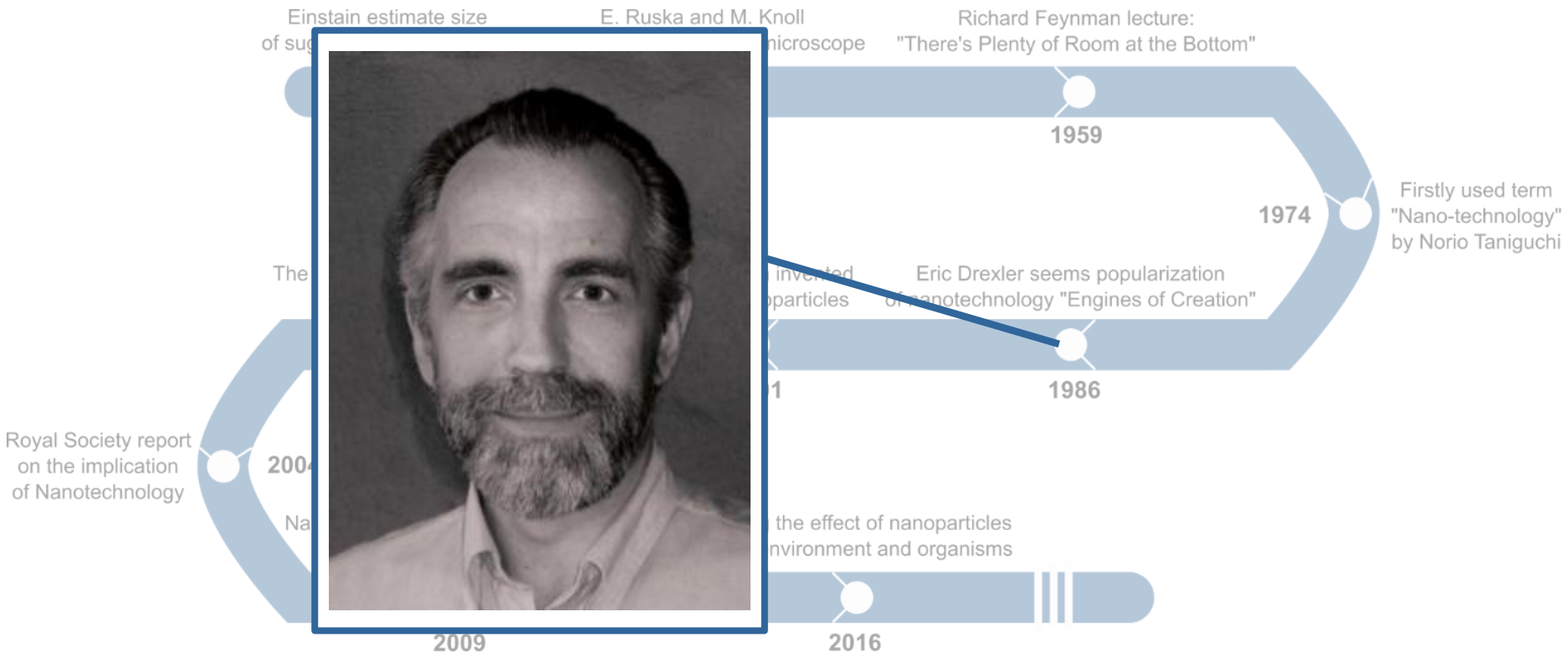

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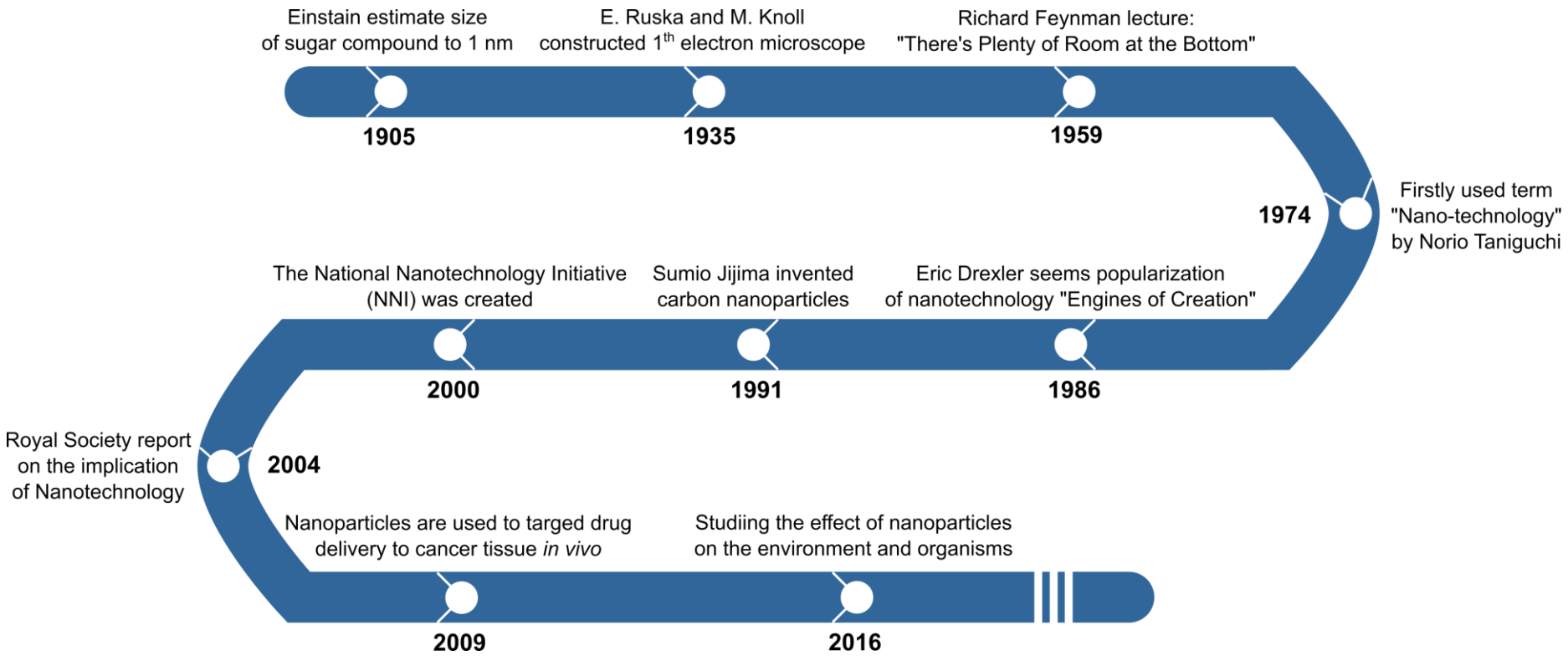

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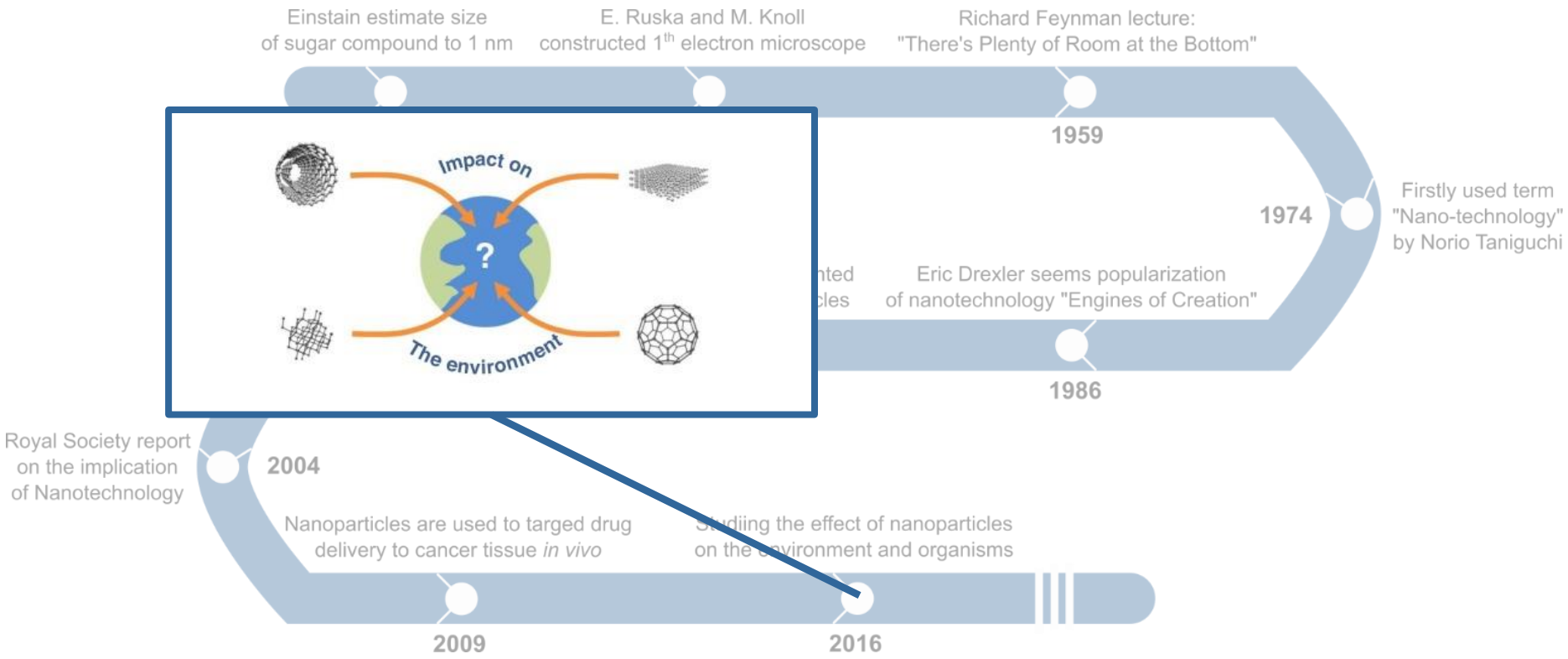


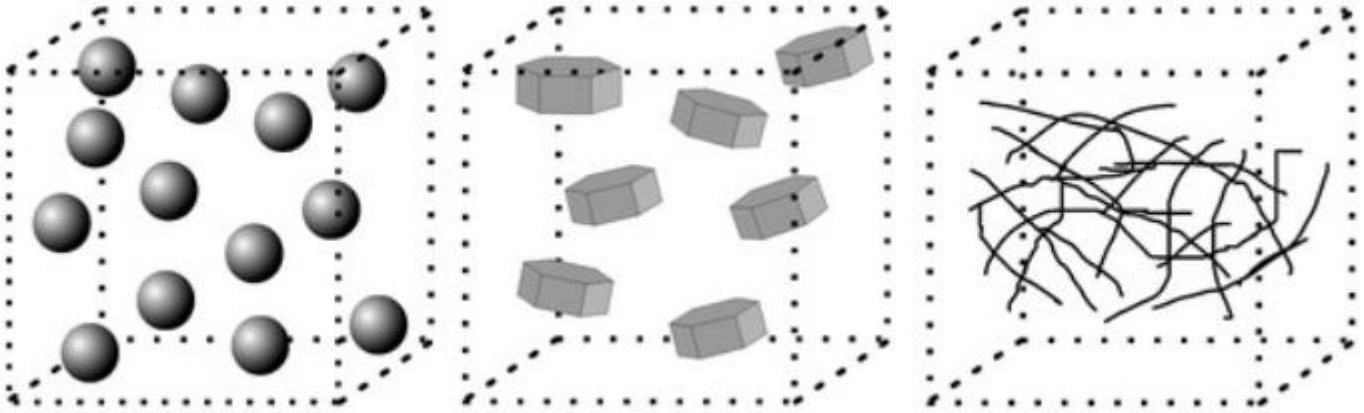
Reprint from: Mottier, et. al., Environmental impact of engineered carbon nanoparticles: from releases to effects on the aquatic biota, Current Option in Biotechnology, 46, 2017.

History of Nanodielectrics

Nanodielectrics

- **Dielectrics –** „*Materials that can be polarized in interaction with an external electric field*“.

- **Nanodielectrics** – „*Dielectric material that contain dispersed nanofiller in their structure*“.



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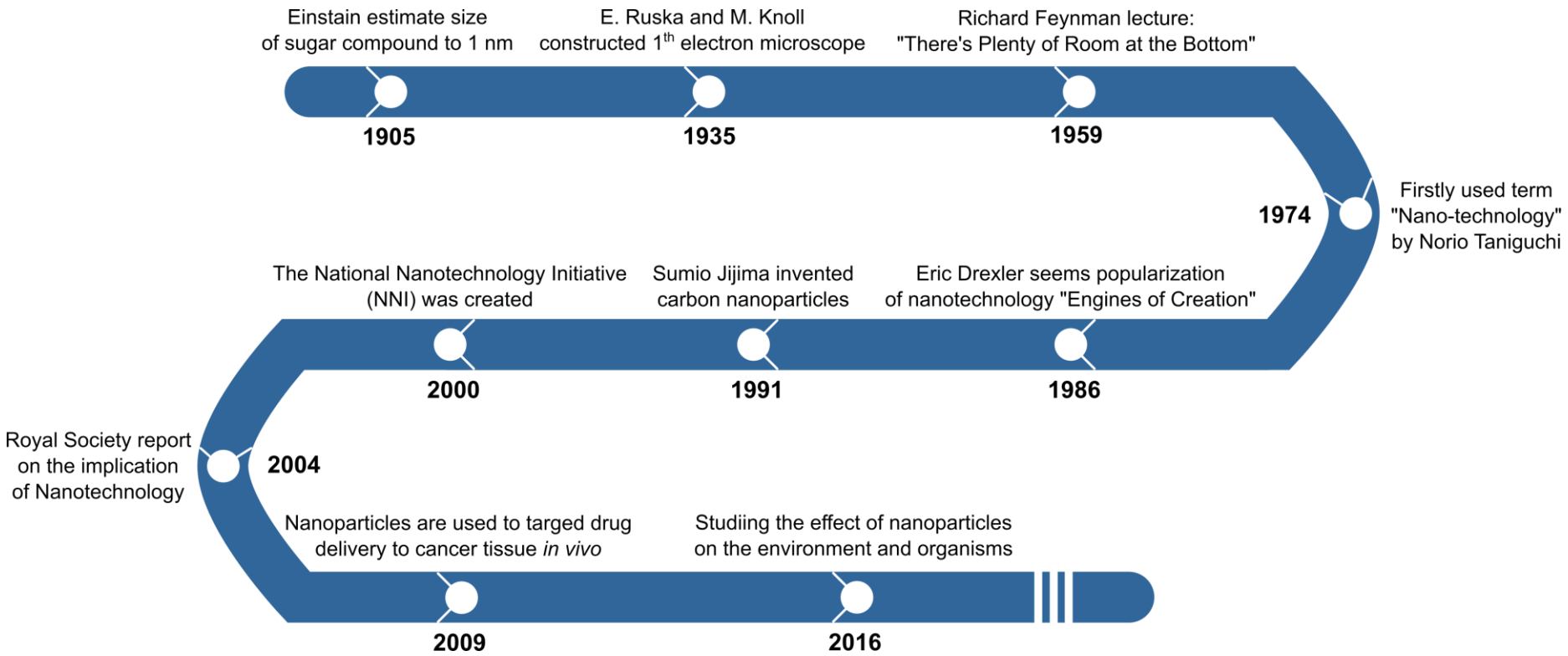

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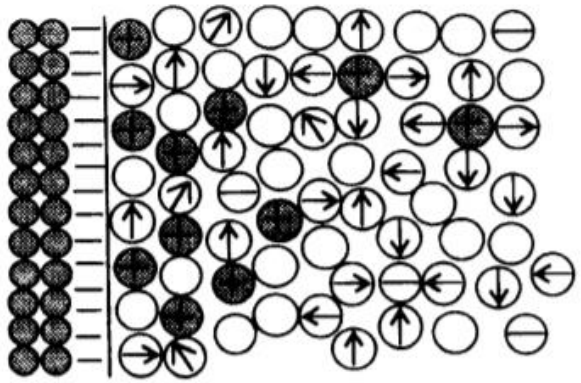

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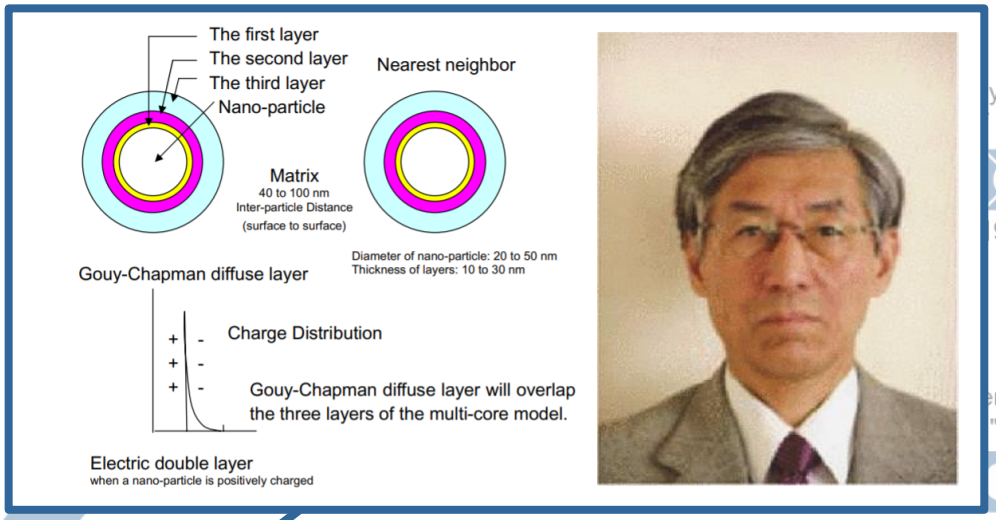

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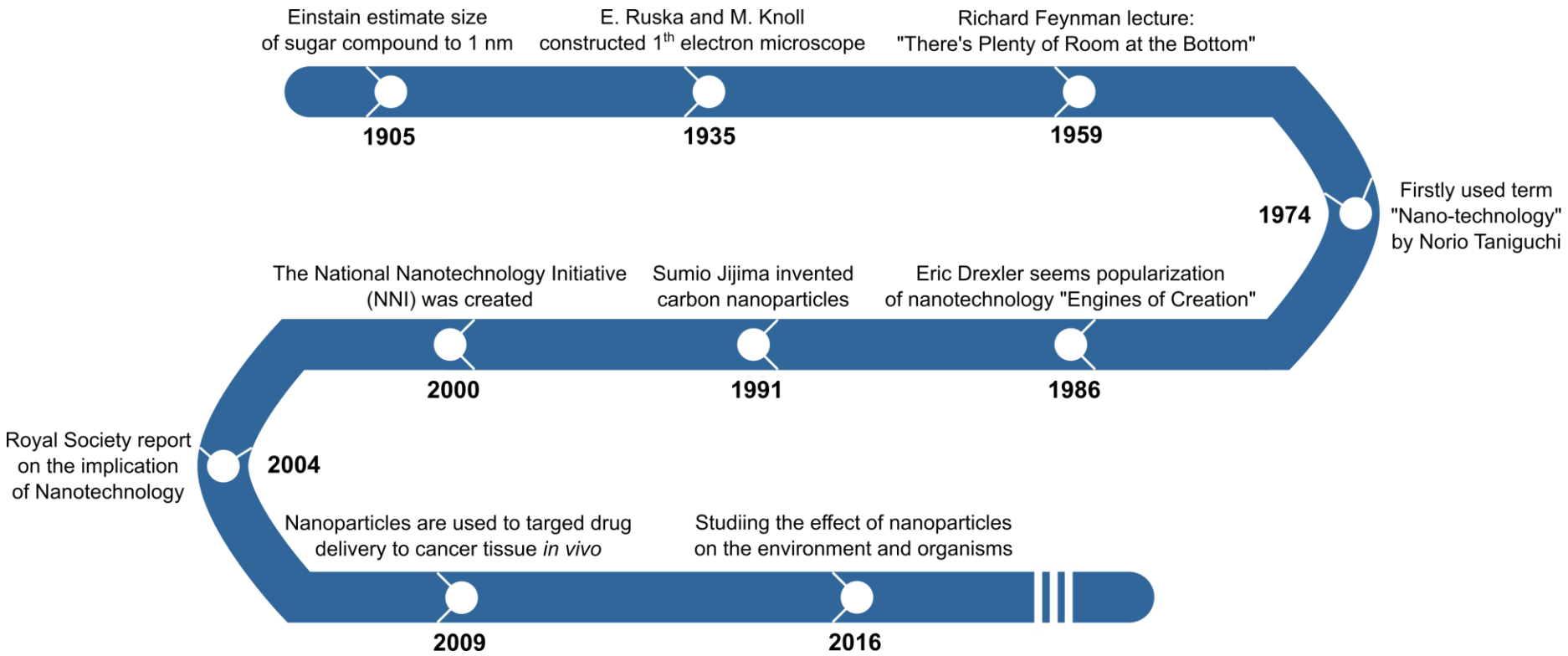

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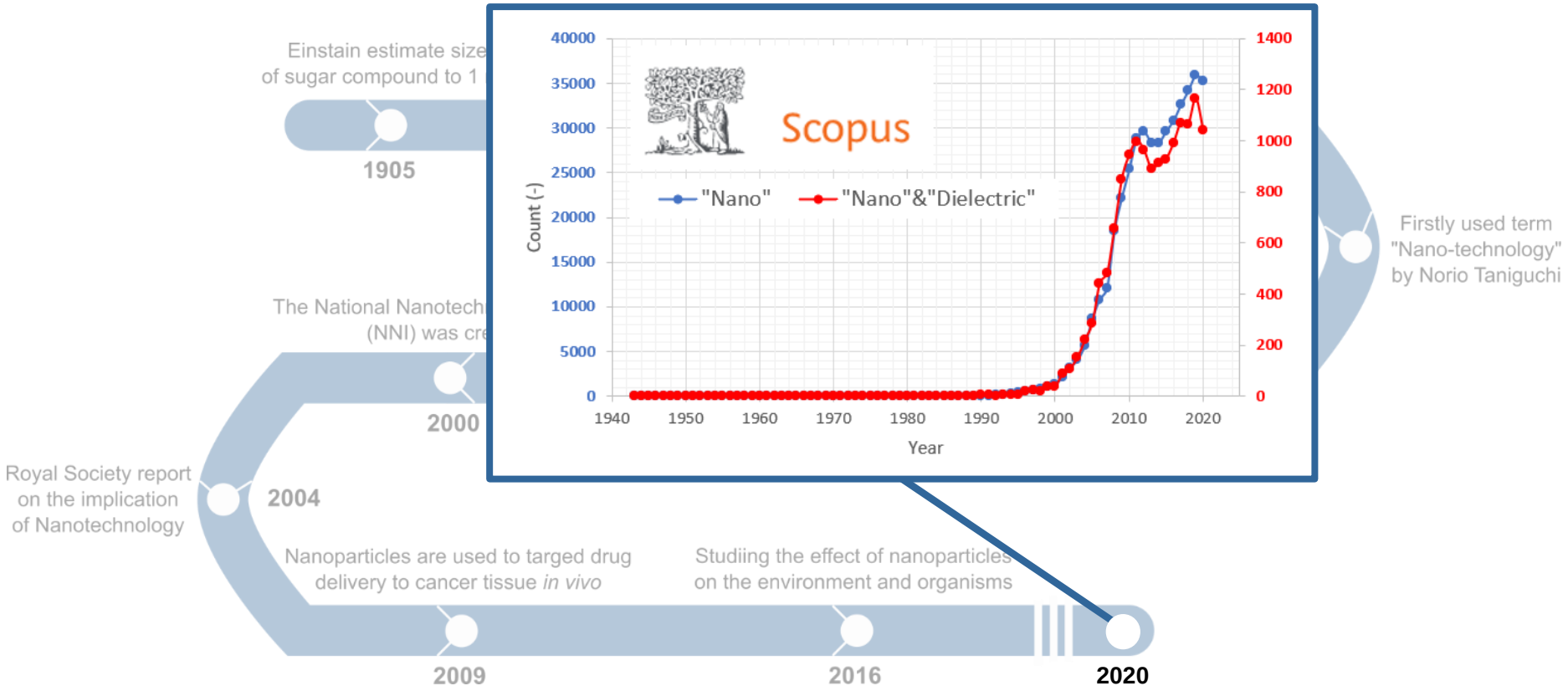


Based on data from Scopus.com.

Cold-Curing Potting Compounds

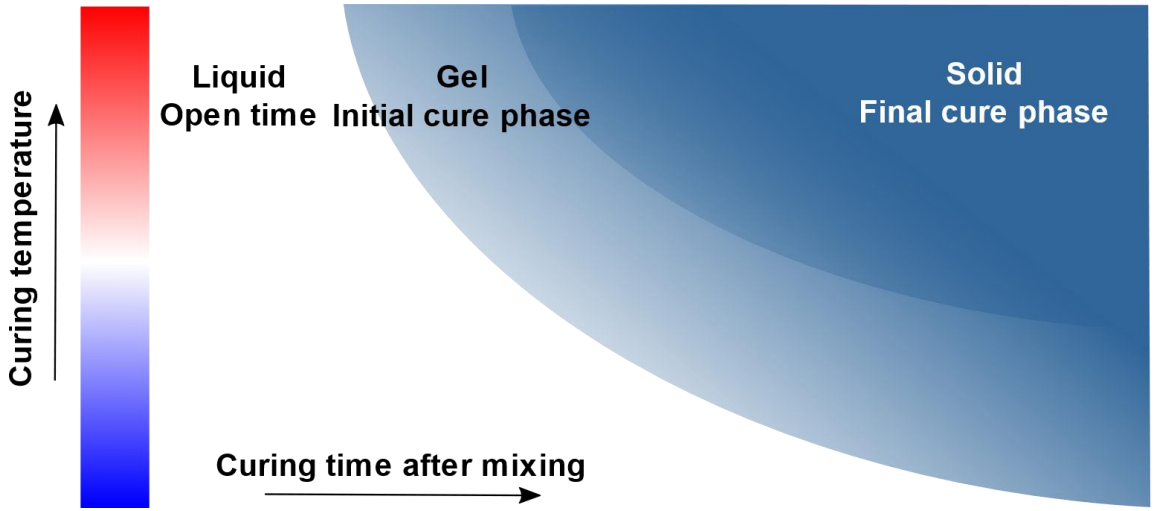
Cold-Curing Potting Compounds

Definitions:

- **Cold-curing –** Crosslinking reaction due to the addition of hardener without additional heat exposure.

Examples:

- **Epoxy**
- **Polyurethane**
- **Silicon**



Based on: https://entropyresins.com/how-to/resin-and-hardener-basic-instructions/

Cold-Curing Potting Compounds

Definitions:

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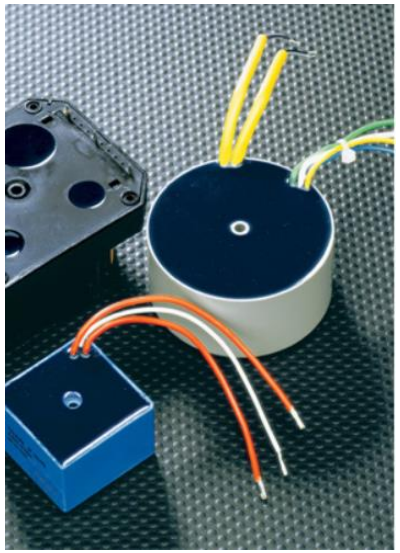
Cable joints

PCBs

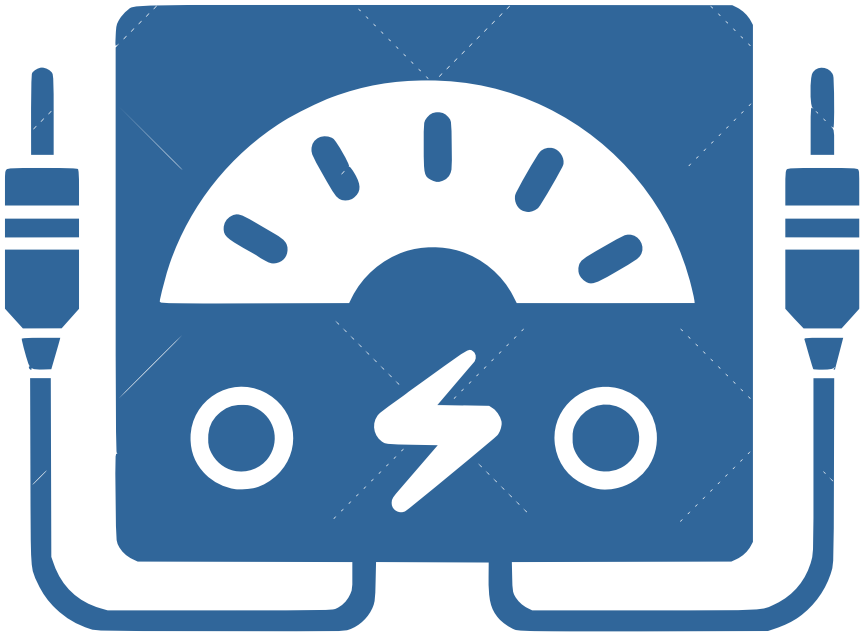
Transformers



Reprint from: https://www.contragent.com/; https://www.indiamart.com/; https://www.elantas.com/

Experiment I

Improvement of dielectric and mechanical properties



Experiment I

Motivation:

- Verify the effect of different nanostructured fillers on dielectric and mechanical properties of epoxy potting compound.

Requirements on raw materials:

- Particular morphology
- Similar size of filler (≤ 30 nm)
- No additional surface treatment

- Cold-curing resin
- Transparent

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Experiment I

Epoxy resin

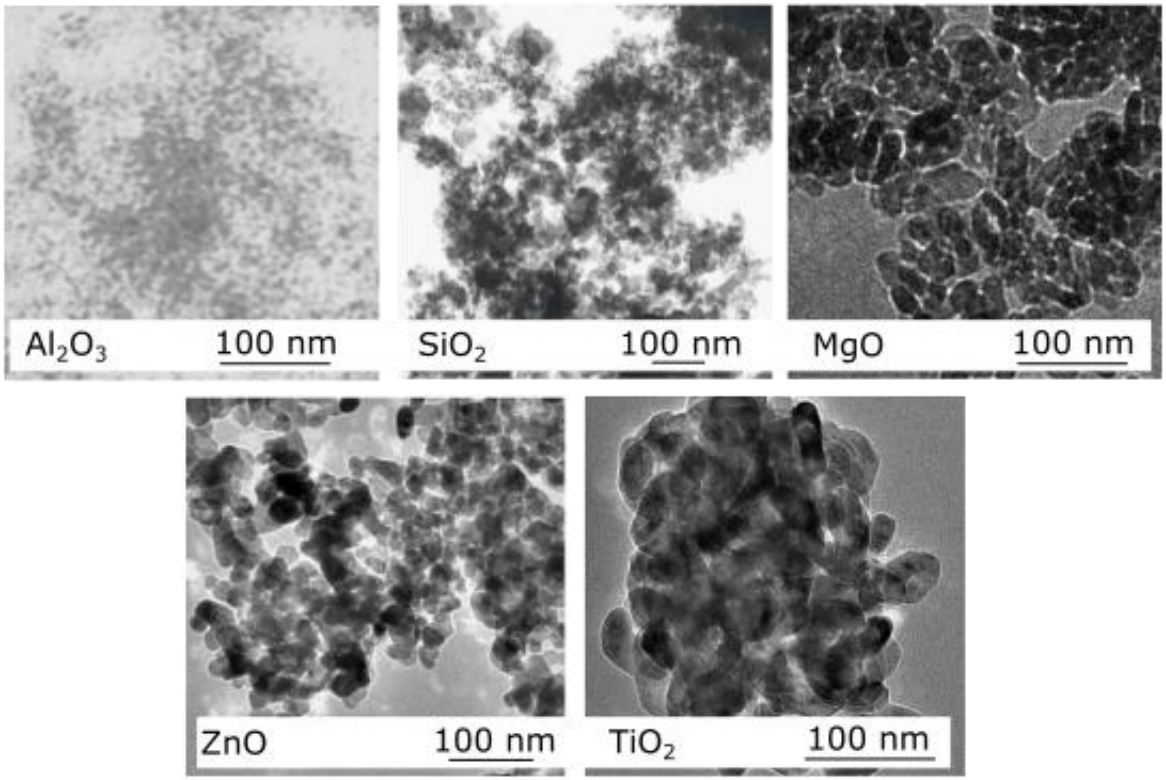
- Cold-curing epoxy resin based on Bisphenol A + Epichlorohydrin
- Amine hardener
- Mixing ration 1:0.45

Nanoparticles

Material	Size (nm)	Purity (%)	Morphology
SiO_2	20	99+	Spherical
Al_2O_3	20-30	99+	Almost spherical
MgO	20	99+	Spherical, ellipsoidal
ZnO	20	99+	Spherical
TiO_2	20	99+	Spherical, ellipsoidal

Experiment I

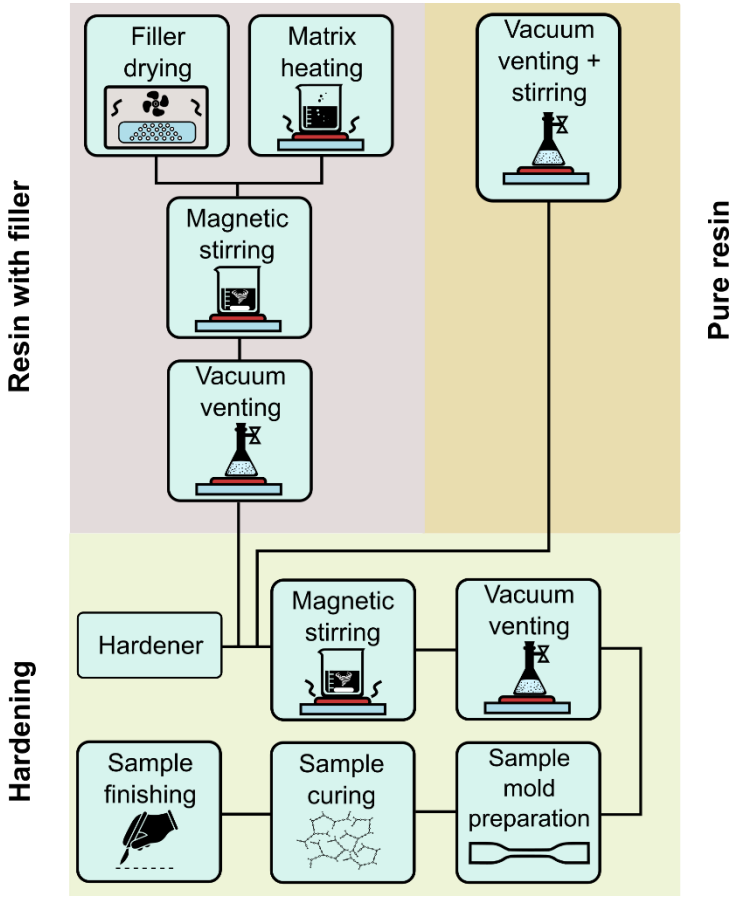
Nanoparticles

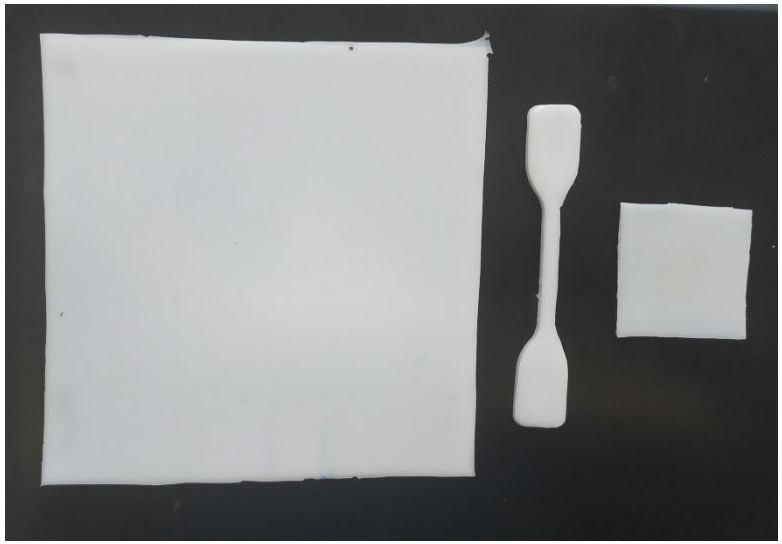


Reprint from: Nanostructured & Amorphous Materials Inc. Products: Nanoscale elements, oxides, carbides & nitrides, accesed from: https://www.nanoamor.com/products.

Experiment I

Mixture and Sample Preparation





Experiment I

Broadband Dielectric Spectroscopy

- Relative permittivity and loss factor
- 10 mHz to 10 MHz; 25 °C; 1 V_{RMS}

Absorption Characteristics

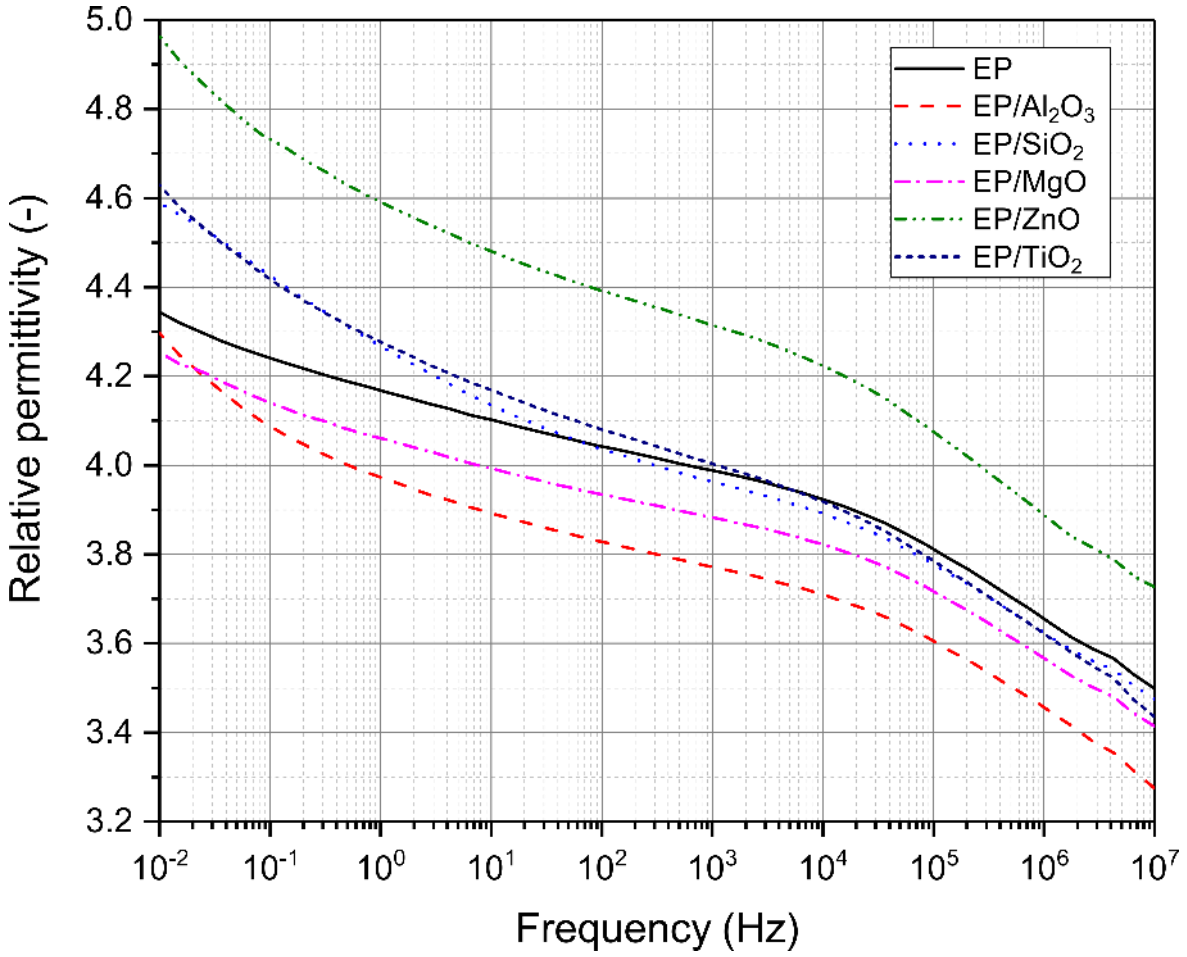
- Volume resistivity and 1 min. polarisation index
- 1000 V DC; 3600 s
- IEC 62631-3-1:2016

Mechanical Properties

- Tensile strenght and elongation
- ISO 527-1 and ISO 527-2

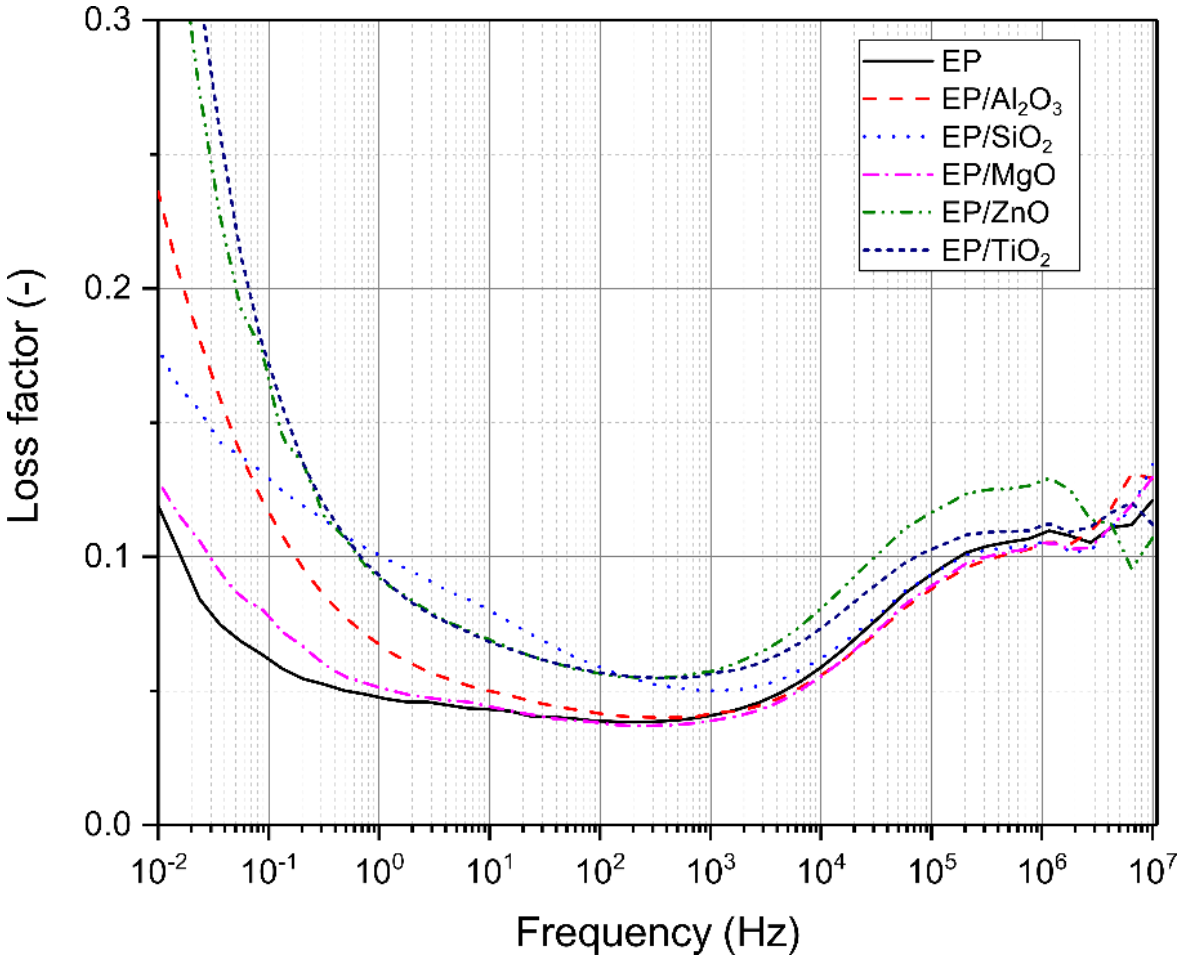
Experiment I

Relative permittivity



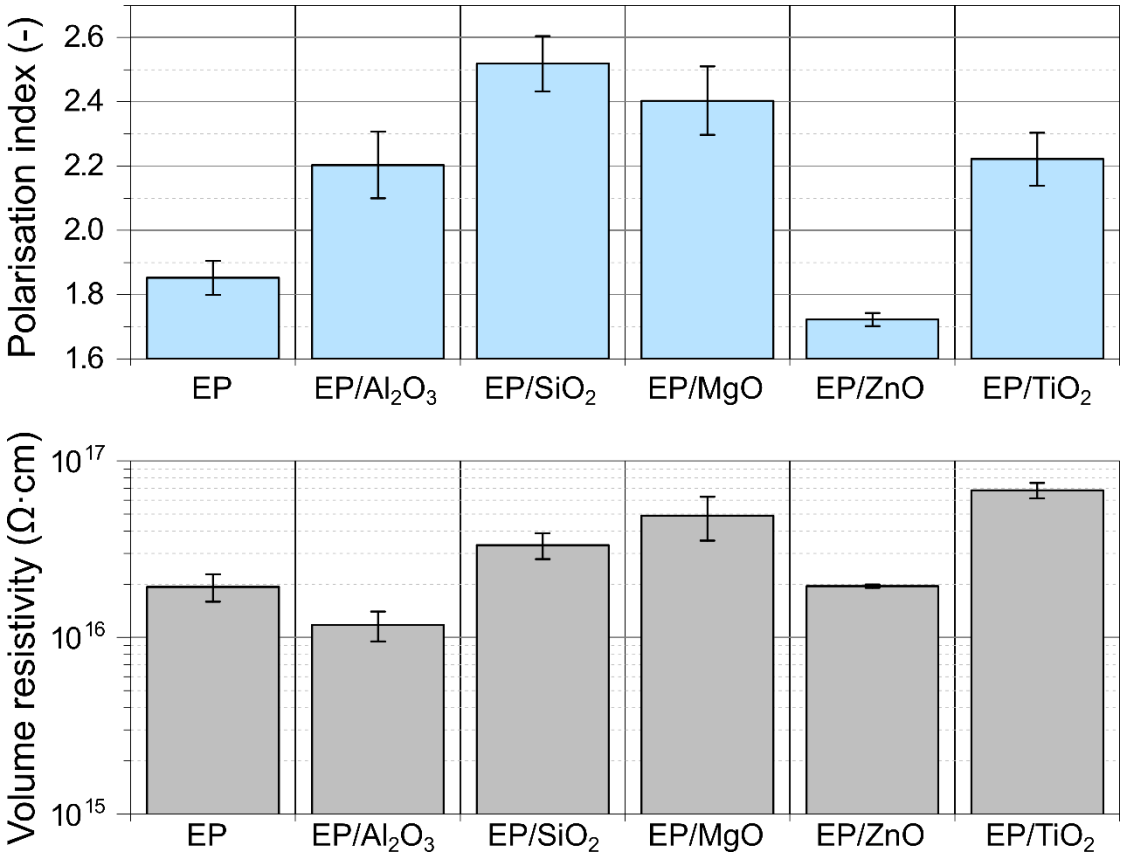
Experiment I

Loss factor



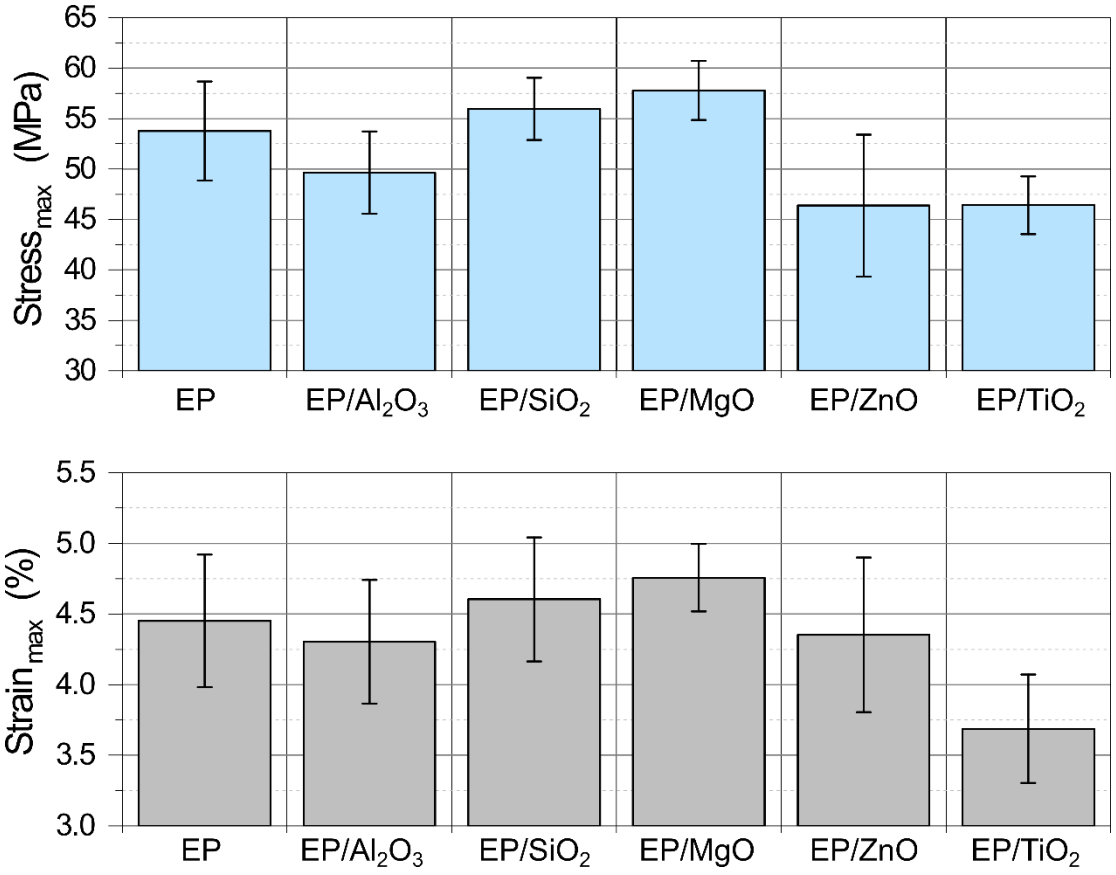
Experiment I

Absorption characteristics



Experiment I

Mechanical properties



Experiment I

Conclusions

- Magnesium oxide shows the most promising results of investigated material properties.
- Elimination of ultrasonic mixing did not result in a significant deterioration in volume resistivity of EP filled with single metal oxides in comparison with pure EP.
- The level of cross-linking of the internal structure of investigated composites has not been negatively affected by adding them.

------ Other observations ------

- Higher filling concentrations no longer lead to significant improvements. On the contrary, in some cases, there is a significant deterioration of the observed properties.

Experiment II

Improvement of fire retardancy properties

Experiment II

Motivation:

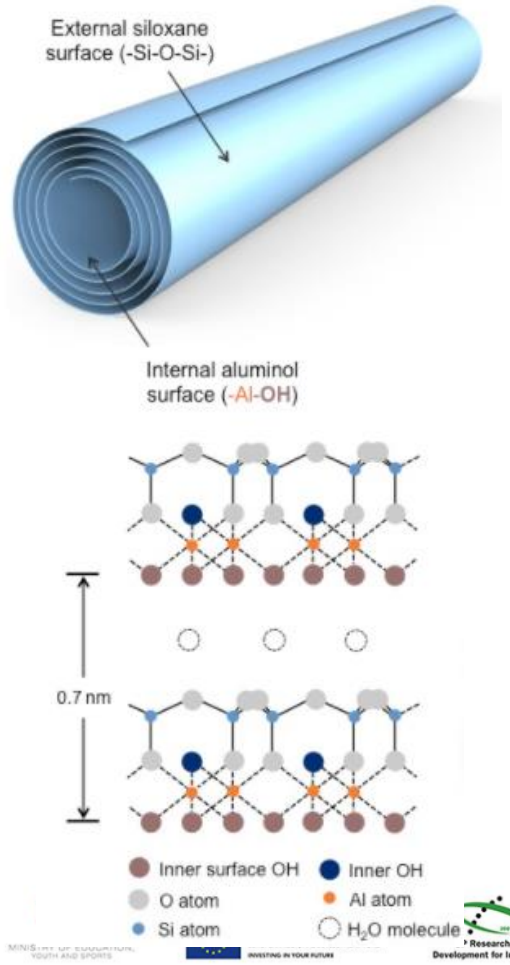
- Verify the fire retardancy effect of Halloysite dispersed in cold-curing epoxy resin.

Halloysite nanotubes:

- Clay mineral $Si_2Al_2O_2(OH)_2 \cdot 2H_2O$ in tubular form
- Wide range of applications (medicine, agriculture,…)
- Unique crystal structure and charge distribution
- Easily dispersible

Resin:

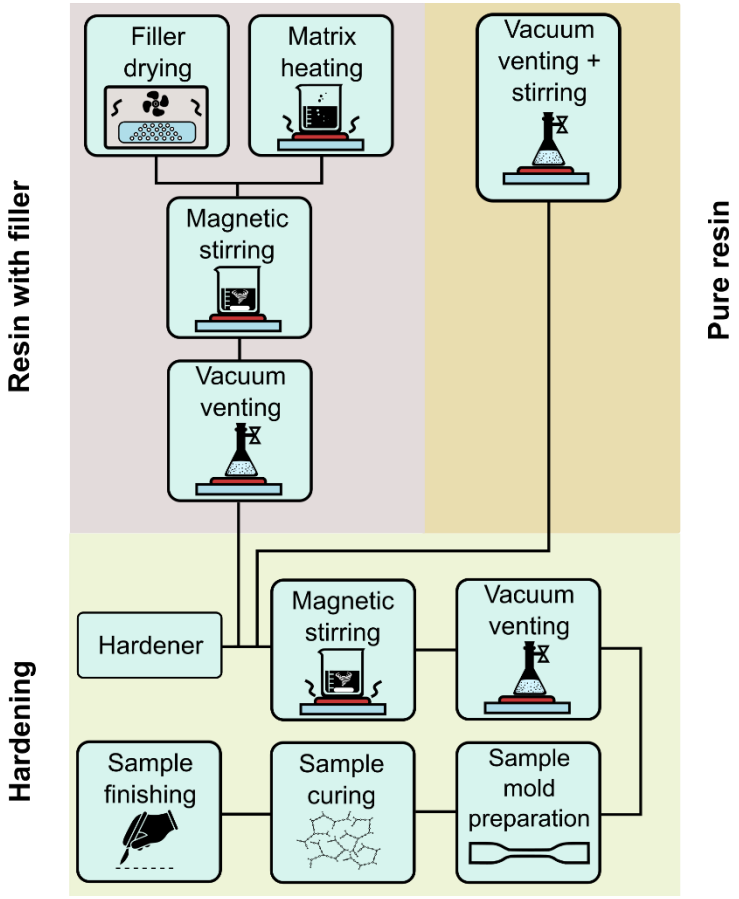
- Bisphenol A + Epichlorohydrin + amine hardener



Reprint from: https://phantomplastics.com/functional-fillers/halloysite/

Experiment II

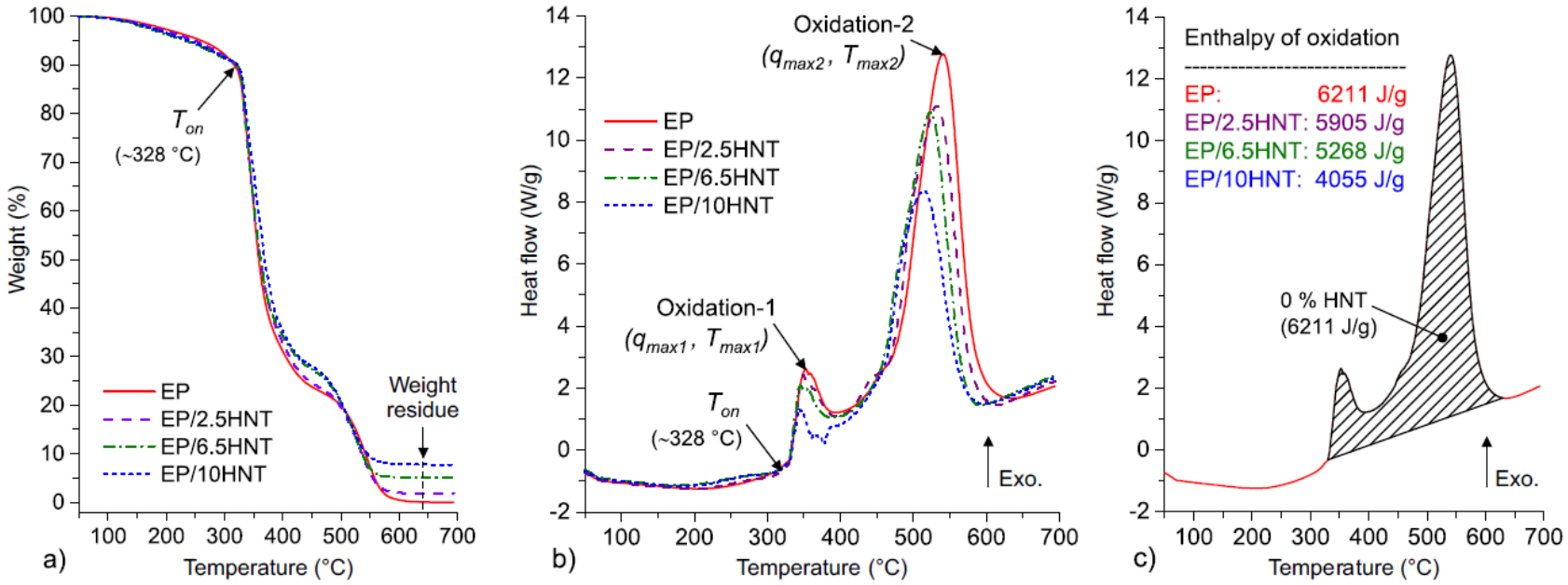
Mixture and Sample Preparation



Experiment II

Simultaneous Thermal Analysis

- Sample weight of 9.0±0.2 mg
- Air atmosphere with volume flow rate 10 mL/min
- Temperature interval 25 – 700 °C



Reprint from: Hornak, et al. Halloysite Nanotubes as an Additive to Ensure Enhanced Characteristics of Cold-Curing Epoxy Resins under Fire Conditions. *Polymers*, 12, 2020.

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Experiment II

Conclusions

- Decrease in the heat flow maximum of the primary thermo-oxidation process and a decrease in the specific enthalpy.

- The glass transition temperature decreases by several degrees Celsius with increasing concentrations of HNT filler up to 6.5% HNTs.

------ Other observations ------

- Slightly increasing trend in the values of the dielectric constant and an insignificant difference in the values of the loss factor as a measure of dielectric losses.
- A slight decrease in volume resistivity with increasing concentrations of HNT filler is also observed.
- The addition of HNTs into the EP matrix also affects the mechanical properties of the resulting composite, where the tensile stress at break significantly decreases, and the strain at break increases.

Chance for Contribution

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Guest Editors

Dr. Jaroslav Hornak, Dr. Pavel Trnka

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Fax: +420 377 634 002

Email: jhornak@fel.zcu.cz

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