Evonik provides an extensive range of modifiers for use in the electrical and electronic industry and related industries.

Modifying epoxy resins with core-shell materials (ALBIDUR®)
- Improved fracture toughness
- No reduction in the glass transition temperature (Tg)
- Excellent electrical properties

Modifying epoxy resins with nanoparticles (NANOPOX® E)
- Improved fracture toughness
- Enables high filler contents
- Increase in the modulus

Nanocomposites for UV-curing formulations (NANOCRYL® A)
- Reduced shrinkage upon cure
- Improved wear properties
- Reduced thermal expansion

Flexible epoxy-silicone-copolymer-based formulations (ALBIFLEX®)
- Formulation of flexible compounds
- Excellent electrical properties
Modifying epoxy resins with core-shell materials

- Improved fracture toughness
- No reduction in the glass transition temperature (Tg)
- Excellent electrical properties

Product overview

<table>
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<th>Technical data (no specification)</th>
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<td><strong>Product name</strong></td>
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<tr>
<td>ALBIDUR® EP 2240 A</td>
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<td>ALBIDUR® EP 5340</td>
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Improvements to properties
With ALBIDUR®, the impact strength of an epoxy resin formulation can be improved without decreasing modulus and glass transition temperature (Tg) and without significantly increasing the viscosity of the formulation.

Figure 1 shows the dependence of the fracture toughness and energy depending on the silicone content of the formulation (bisphenol A epoxy-based formulation, cured with anhydride), which reveals significant improvements. For best performance, we recommend 3 – 5 % silicone elastomer in the total formulation (without fillers), because this is usually sufficient for a significant improvement in fracture toughness without decreasing the modulus. (Please note: ALBIDUR® contains 40 % silicone elastomer.)
ALBIDUR® products consist of an epoxy resin in which silicone elastomer particles of a defined size (0.1 – 3 µm) are finely distributed. The silicone elastomer particles have an organic shell structure comprising reactive groups (Figure 3). These particles are able to chemically link into the epoxy matrix. If a mechanical load is applied to the cured resin, it can be dissipated uniformly in all directions when interfering with a rubber domain. If a tear has already occurred, it is prevented from propagating, because the elastomer particles stretch perpendicular to the direction of tear and are not torn out, as they are chemically bound into the matrix. Figure 4 shows the finely distributed silicone elastomer particles in the epoxy matrix.

Further advantages besides the low viscosity are the high thermal stability of the silicone elastomer (up to 200 °C) as well as the excellent electrical properties, as can be seen in Figure 2.

In addition, the shrinkage upon cure of a formulation modified with ALBIDUR® can be influenced very favourably, as the silicone elastomer particles expand at increased temperatures during the curing and hence counterbalance the shrinkage.

Dielectric properties of a formulation based on a cycloaliphatic epoxy resin with ALBIDUR® (Fig.2)

![Figure 4: Scanning electron microscope image of an epoxy resin modified with ALBIDUR®](image)
Modifying epoxy resins with nanoparticles

- Improved fracture toughness
- Enables high filler contents
- Increase in the modulus

Product overview

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<tr>
<td>NANOPOX® E 500</td>
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<tr>
<td>NANOPOX® E 600</td>
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**Improvements to properties**

Under the brand name NANOPOX® E we are producing a number of colloidal silica sols in various epoxy resins which are highly suitable for modifying epoxy resins. Important properties can be significantly improved in epoxy formulations by using NANOPOX® E:

- Lower viscosity of the formulation in comparison to conventional reinforced fillers
- No sedimentation
- Increase in the fracture toughness, impact resistance and modulus
- Improved scratch and abrasion resistance
- Reduction of shrinkage and thermal expansion

NANOPOX® E is used in applications where the above improvements of properties are desired or necessary, without compromising the processability by an excessive increase in viscosity (known from fumed silica). Application examples are encapsulation materials and coatings. It is important to emphasize the excellent impregnation properties of NANOPOX® E due to the small particle size and the absence of agglomerates. This also enables the complete impregnation of electronic components which are difficult to seal otherwise.
**How it works**

NANOPOX® E is a colloidal silica sol in an epoxy resin matrix. The disperse phase consists of surface-modified, spherically shaped SiO₂-nanoparticles with diameters below 50 nm and an extremely narrow particle size distribution (Fig. 6).

These spheres, only a few nanometers in size, are distributed agglomerate-free in the resin matrix (Fig. 7). This produces a very low viscosity of the dispersion with SiO₂-contents of up to 40 wt %.

The nanoparticles are chemically synthesized from aqueous sodium silicate solution. In this unique process the binding agent is not damaged, in contrast to processes in which powdered fillers are dispersed with dissolvers or other equipment using high shear energy.

**Development of fracture toughness (\(K_{IC}\)) and modulus with increasing nano SiO₂-content (Fig. 5)**

![Graph showing the development of fracture toughness (KIC) and modulus with increasing nano SiO₂-content.](image)

Figure 5 shows the improvement of the fracture toughness (\(K_{IC}\)) and the modulus as a function of the silica content. The system shown is based on NANOPOX® E 500 cured with anhydride. A significant increase in the fracture toughness is discernible with an accompanying increase in the modulus.

**Particle size distribution (Fig. 6)**

(Determined by SANS)

![Graph showing the particle size distribution.](image)
Application remarks

In existing formulations, NANOPOX® E can be used to replace part or all of the epoxy resin contained and cured as usual. Generally, the curing system should be selected as required by the application.

The total silica content required in the ready formulation is dependent on the desired product properties and can range from only a few percent (for fracture toughness improvement) up to the maximum nanoparticle content possible (for scratch and abrasion resistance improvement). To address the application problem an adjustment of the formulation may be required.

If necessary, additional reinforcing fillers can be used. With increasing total filler content, structural reinforcements unattainable with conventional fillers alone can be achieved.

Figure 7: TEM – images of a cured NANOPOX® sample with 5 % SiO₂-nanoparticles
Nanocomposites for UV-curing formulations

- Reduced shrinkage upon cure
- Improved wear properties
- Reduced thermal expansion

Product overview

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**Note:** Further NANOCRYL® A products and mixtures for special applications are available on request. Please contact our application specialists.
**Improvements to properties**

The nanocomposites described in chapter 2 can also be used in UV-curing systems for the electronics industry. The use of NANOCRYL® A or of NANOPOX® E 600 (listed in chapter 2) in the formulation enable a whole range of material properties to be significantly improved.

The products are highly transparent, low viscous and do not show any sedimentation, i.e. the processability remains essentially unchanged in comparison to the respective base resin. This way, the individual advantages of organic and inorganic materials can be combined almost perfectly.

Important material properties which can be improved by the use of NANOCRYL® A are:

- No reduction in the transparency despite high filler content
- Reduction of shrinkage upon cure
- Reduced thermal expansion and internal stresses
- Barrier effect against gases, water vapour and solvents
- Increased weather resistance and inhibited thermal aging
- Greatly improved scratch and abrasion resistance
- Increase in tear resistance, fracture toughness and modulus
- Improved adhesion on numerous inorganic substrates (e.g. glass, aluminum)
- Improvement in a number of other desired properties, such as: thermal stability, stain-resistance, heat conductivity, dielectric properties

NANOCRYL® A is used in applications where the above improvements to properties are desired or necessary, without compromising processability by an excessive viscosity increase (as known from e.g. fumed silica). The fact that this is possible without the loss of optical clearness makes NANOCRYL® A particularly suitable for transparent formulations. Application examples are: highly scratch-resistant coatings for fiber optic cables, conformal coatings, UV curing adhesives for printed circuit boards (PCBs).

**Application remarks**

To ensure optimum compatibility, we recommend premixing all other recipe components and adding the NANOCRYL® A to this mixture while stirring. NANOCRYL® A products are compatible with most acrylate monomers, oligomers and polymerization initiators. Nevertheless, compatibility with the individual formulation components should be tested prior to recipe development. Nanoparticles tend to form agglomerates if their stabilization is influenced by unsuitable components. This affects, above all, highly hydrophobic oligomers and certain performance additives (e.g. several lubricants, UV stabilizers and amine co-initiators).

A list of suitable commercial additives can be obtained from Evonik (Technical Information: "Suitable Additives for NANOCRYL® Formulations").

NANOCRYL® A can be used alone or as an additive in formulations and cured by free radical polymerization using standard process technology (in addition to radiation curing, peroxide curing is also possible). The total silica content required in the ready formulation is dependent on the desired product properties. In general, the above-listed effects increase proportionally to the solids content. As a result, a silica content as high as possible is recommended (≥ 20 wt%, corresponding to e.g. ≥ 40 % NANOCRYL® A 210) for first screening tests. The optimal content should then be determined through systematic tests.

If necessary, additional conventional fillers (Al₂O₃, glass micro-pearls, etc.) can be used. The nanoparticles then fill the space between the micro particles. This enables the formulator to increase the total content of reinforcing fillers, thus optimizing the material properties.
Flexible epoxy-silicone-copolymer-based formulations

- Formulation of flexible compounds
- Excellent electrical properties

Product overview

**Technical data (no specification)**

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<th>EEW [g/equiv]</th>
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<td>DGEBA / Acrylate</td>
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</table>
**How it works**

All ALBIFLEX® products have a common chemical base structure, which can be represented as follows:

The basic principle is a linear block copolymer which consists of alternating blocks or segments of hard polyepoxides and soft polysiloxanes. Reactive epoxy blocks are located at both chain ends. Due to the morphology created by phase separation between the polysiloxane and polyepoxide segments, the property profile of the end product does not simply correspond to a plain mixture of epoxy and silicone properties. In general, the epoxy resin character predominates in the property profile.

**Improvements to properties**

ALBIFLEX® combines the normally incompatible polymer types “epoxy resin” and “silicone” into a unique copolymer, in which the advantageous properties of the two main polymers are united:

- From epoxy resin, the tremendous peel strength on a large number of substrates, the high mechanical strength and the good chemical resistance
- From silicone, the high elasticity, even at very low temperatures, the good thermal and aging resistance as well as the excellent dielectric properties

This product profile makes the use of ALBIFLEX® particularly useful in flexible encapsulation materials, coatings and adhesives in electronic applications.

**Application remarks**

ALBIFLEX® has been developed as a base polymer for the formulation of elastic adhesive and sealing materials, encapsulation materials, coatings and similar products. Due to the high silicone content of the copolymers, miscibility with epoxy resins is limited and should be tested separately (with all liquid components of the formulation, but without fillers).

ALBIFLEX® 712 is a product modification with acrylic end groups. This enables the product for free radical polymerization and therefore for use in UV-curing applications.
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(May 2008)