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Adhesives in the Electronics Industry

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I. INTRODUCTION

Although the application of adhesives in the electronics industry is widespread, the production of printed circuit boards (PCBs) creates a demand for a wide spectrum of properties. Technical progress by research and development leads to more miniaturization of components and circuits, to a higher level of integration of printed circuits, and therefore to higher electrical power evolved per square unit. This trend continues. A lot of problems arising from this development could be solved by using special adhesives, sealants, or laminating resins only.

The aim of this short overview is to define the requirements of the electronics industry for adhesives, to derive their profile of properties, and to describe the state of the art. Additionally, encapsulating and sealing materials as well as binders for laminates are treated if there are analogous requirements regarding their properties. One well-known example of this situation is FR4-based material for PCBs, where the epoxy resin acts simultaneously as an adhesive for the copper foil and as a binder for the laminate. The primary fields for application of adhesives in the production of electronic circuits are adhesives for surface-mounted devices (SMDs), binders for laminates and/or adhesives for PCB base material, encapsulating and sealing materials for separate electronic components or complete circuits, and adhesive tapes used, for example, for flexible keyboards, feeding tapes, and covering materials. A variety of products are commercially available for all these applications.

II. REQUIREMENTS OF THE ELECTRONICS INDUSTRY ON ADHESIVES

As stated earlier, the main requirements for adhesives in the electronics industry result from the increasing miniaturization of the electronic devices, which is manifested in an increasing number of pins with decreasing distance between them. Therefore, both the number of leads per square unit of the circuit board increases and the conductor width decreases. Additionally, the ‘‘concentration’’ of devices on the board increases. Further requirements on the adhesives arise from the necessity of reaching high production rates using a simple technology with low energy consumption and of dealing with substances

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that are harmless for health and environment. From all these facts the following primary requirements result:

1. Precise casting and dosing of the polymeric material is necessary to ensure electrical insulation between the conducting tracks on a PCB. Additionally, the adhesive should not shrink or creep irreversibly during manufacture of electric circuits (e.g., heating by soldering or curing processes, mechanical stresses by automatic insertion). For these reasons, the thermal expansion coefficients of the adhesives should be in the same range as those of the devices and the PCB.

2. The increasing quantity of power dissipation per square unit as a result of the rising density of devices on PCBs leads to higher operating temperatures. Therefore, the thermal resistance of the applied adhesives has to correspond with the operating temperatures. Furthermore, a low dielectrical constant is essential for the adhesives and/or binders used for laminates because the heat dissipation is a result of dielectrical losses.

3. Up to now the electrical connection of devices and conducting tracks is made by solder processes, and therefore the adhesives have to withstand temperatures of about 260°C for a short time without remarkable losses in their performance. Up to now, conducting adhesives for electrical connections as an alternative have been used in special applications only.

4. The adhesives have to show adjusted rheological behavior. Depending on the application, materials with both high and low viscosity, with and without thixotropy, and with and without yield point are needed.

5. Since electronic circuitries have a filigree structure, they are sensitive against corrosive media. For this reason they must be covered with coatings or sealants of high purity. Alkaline and chloride ions and residual solvents especially have to be avoided.

III. CHEMICAL BASE OF ADHESIVES FOR THE ELECTRONICS INDUSTRY

The chemistry of polymeric materials used for adhesives in the electronics industry does not differ from that of polymers for other applications. Taking into account the requirements mentioned in Section II, it becomes clear that reactive resins evolving no volatile substances during the curing process are of special interest. The following polymeric materials are of particular importance:

1. *Expoxies* [unmodified types of bisphenol A, higher functionalized resins, novolac epoxies, cycloaliphatic resins, heterocyclic resins; one- and two-component systems; curing at room temperature, at elevated temperatures, or by ultraviolet (UV) irradiation], used as mounting adhesives, coverings, and binders for laminates [1,2]
2. *Acrylics* (cyanoacrylates; anaerobic, by heating or UV-irradiation cross-linking acrylates) for mounting adhesives, sealants, and for adhesive tapes [2,3]
3. *Silicone resins* (at room temperature or by heating and by UV-irradiation curing products) mainly for sealings and coverings [4]
4. *Polyimides* as mounting adhesives [1]

Since epoxies and acrylics are the most important base resins for adhesives in the electronics industry, they will be described in more detail.

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A. Epoxy Resins

Examples of the resin components of expoxies are listed in Table 1. Several chemical substances can be used as hardeners for epoxies [5,6]. The two main groups of cross-linking agents used in industry are two or more functionalized amines and anhydrides of carboxylic acids. Cross-linking with amines is possible at room temperature as well as at elevated temperatures, depending on the chemical structure of the amines (Table 2). Anhydrides of carboxylic acids react at elevated temperatures only.

The cross-linking of epoxies by amines follows the addition of a primary amine with two epoxy groups, resulting in a tetrafunctional branching point, as one can see in Fig. 1. For the reaction of anhydrides with epoxy groups, the presence of a small fraction of hydroxyl groups (e.g., secondary hydroxyl groups of oligomeric epoxies) is necessary.

Table 1 Examples of Resin Components of Epoxies

Structural formula	Name
$H_2C-HC-CH_2-O-CH_2-CH_2-CH_2-CH_2-O-CH_2-CH-CH_2$ (each terminal H_2C-HC / $CH-CH_2$ bridged by O)	Butandiol–diglycidyl ether
$H_2C-HC-CH_2-O-C_6H_4-C(CH_3)_2-C_6H_4-O-CH_2-CH-CH_2$ (each terminal H_2C-HC / $CH-CH_2$ bridged by O)	Bisphenol A–diglycidyl ether
$H_2C-HC-CH_2-O-C_6H_4-CH_2-C_6H_4-O-CH_2-CH-CH_2$ (each terminal H_2C-HC / $CH-CH_2$ bridged by O)	Bisphenol F–diglycidyl ether
Phenyl rings linked by CH_2, each ring bearing $O-CH_2-CH-CH_2$ (epoxide, $H_2C-HC-CH_2$ bridged by O)	Novolac–epoxy–resin
Epoxycyclohexyl$-COO-CH_2-CH_2-$epoxycyclohexyl	Cycloaliphatic epoxy resin
Isocyanurate ring (N, C=O) with three N-substituents $H_2C-HC-H_2C-$ / $-CH_2-CH-CH_2$ (epoxide rings bridged by O)	Triglycidyl isocyanurate

Table 2 Reaction Temperatures of Amine-Based Hardeners

Amine	Cross-linking temperature (°C)
Aliphatic	Room temperature
Cycloaliphatic	50–100
Aromatic	80–150

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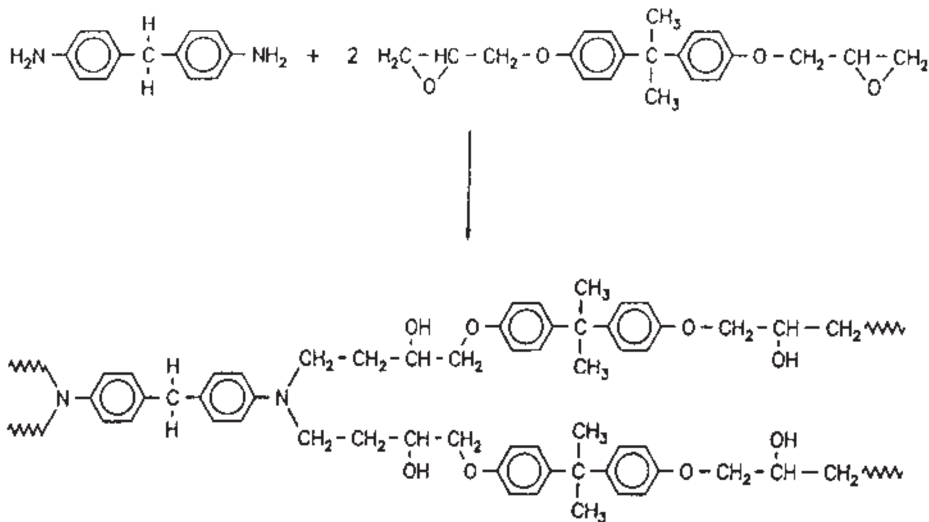

Figure 1 Cross-linking of epoxies by amines (simplified scheme).

At elevated temperatures a hydroxyl group reacts with an anhydride and then the carboxylic group of the resulting half-ester reacts with an epoxy group to get an adduct, as one can see from Fig. 2. Epoxies may be polymerized through cationic polymerization, initiated by UV radiation (Fig. 3).

B. Acrylic Resins

Acrylic resins used as adhesives are formed through radical or anionic polymerization [6]. Radical polymerization can be initiated by UV radiation as well as heat. The two reaction schemes are identical in principle (Fig. 4). Cyanoacrylates are of special interest for systems with very high reaction rates. Their reaction follows an anionic polymerization mechanism. Since the polarity of the cyanoacrylates is very high, water is able to act as an initiator (Fig. 5).

IV. MOUNTING ADHESIVES

Mounting adhesives are needed for the fixation of components in circuit boards during the loading process using surface-mounting technology (SMT) prior to soldering. As an alternative method, electrical-conducting adhesives can be used for the fixation of components. The advantage of this technique is that the soldering process can be avoided. Using SMD components for loading of PCBs, either an adhesive or a solder paste is needed to fix the devices. Which variant is selected for a particular application depends primarily on the board design. If a mixed loading of SMD components together with leaded devices must be used, fixation by an adhesive is the only applicable variant, but by using pure SMD loading, both adhesive and solder paste can be applied. It must be noted that the strength of fixation achievable by adhesives is higher than that achievable by solder pastes. On the other hand, an additional technological process, complete curing of the adhesive, is necessary. This disadvantage can be mitigated by using electrical-conducting adhesives, thus avoiding soldering altogether.

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Figure 2 Cross-linking of epoxies by anhydrides (simplified scheme).

Figure 3 UV-initiated polymerization of epoxies.

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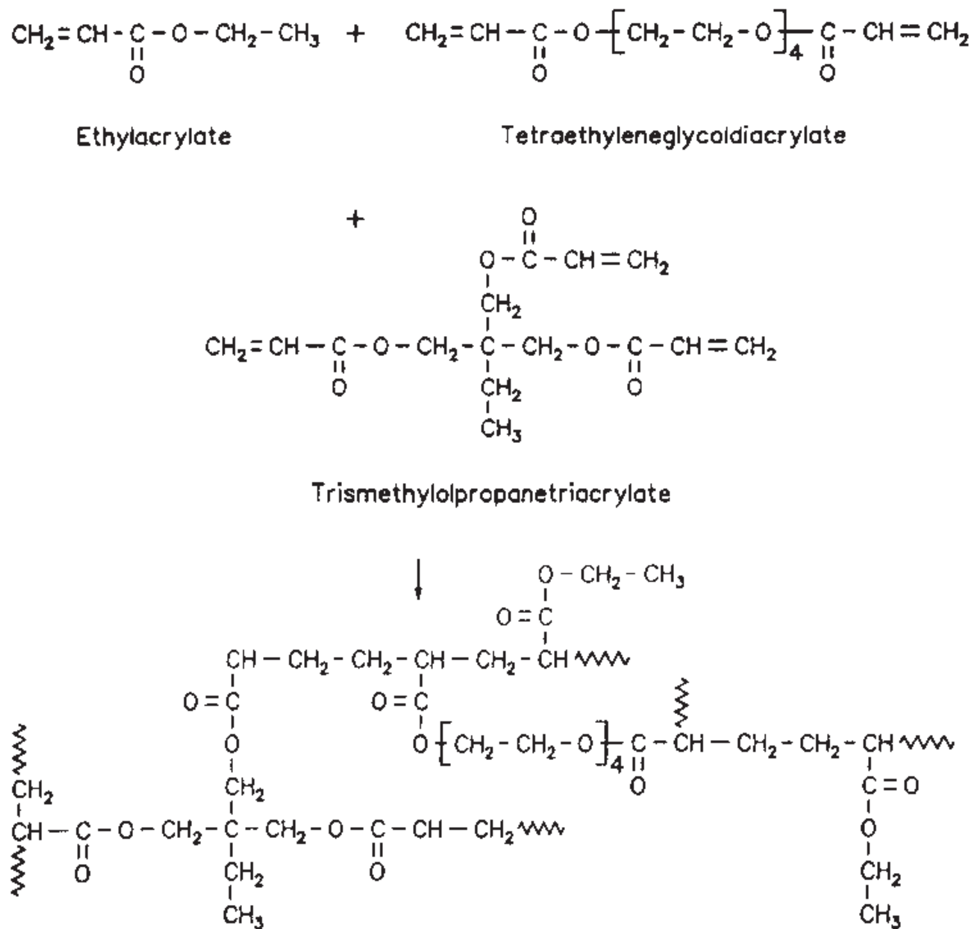

Figure 4 Cross-linking of acrylate resins through radical polymerization (simplified scheme).

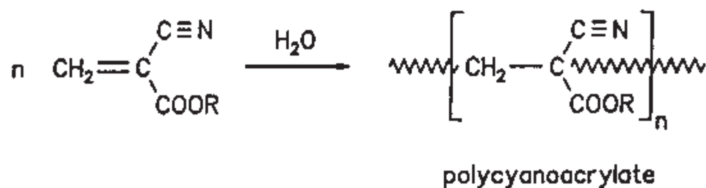

Figure 5 Polymerization of cyanoacrylates.

Requirements of SMD adhesives:

1. High adhesive strength of the uncured resins (wet adhesion) to get exact fixation of the components
2. Sufficient final strength after curing to guarantee the mechanical stability of the PCB
3. High curing rates at low temperatures to minimize the thermal stresses of thermally sensitive components
4. Low dielectrical losses

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5. Processing behavior that meets such technological requirements as:
   a. One-component systems to avoid mixing failures
   b. Homogeneous systems, especially if filled adhesives are used
   c. Sufficiently long pot life
   d. Rheological behavior adjusted to the dosing process used

A. State of the Art

1. *Adhesives*

The most commonly used adhesives in the electronics industry are thermosetting one-component epoxy resins and UV-irradiation cross-linking acrylates [7].

Thermosetting epoxy resins. Generally, thermosetting epoxy resins are mixtures of the following:

Resins	50–80 wt %
Hardeners	20–50 wt %
Accelerators	0–3 wt %
Fillers, dyes, modifiers	0–20 wt %

At this time, thermosetting epoxy resins are the most important adhesive systems used for mounting [2]. One reason for their successful use for a long period is due to the great variability of their properties, which can be adjusted to a lot of requirements. Other advantages are simple processibility and good thermal stability. Furthermore, using modern efficient accelerator systems, the curing temperature of epoxies could be decreased to temperatures lower than 100°C and times shorter than 15 min. In this way, the thermal stressing of temperature-sensitive components can be minimized.

UV-cross-linking acrylate resins. Generally, UV-curing acrylate resins contain [8]:

Reactive oligomers/prepolymers	50–80 wt %
Monomers/reactive thinners	10–40 wt %
Photoinitiators/stabilizers/accelerators	1–5 wt %
Inhibitors/dyes	1–5 wt %

The advantages of UV-curing acrylates are curing times under UV irradiation of only a few seconds and the low energy consumption of UV lamps compared to the thermal energy needed for thermosetting systems. On the other hand, these adhesives cannot be cured completely by UV irradiation. Therefore, postcuring is necessary. Commercially available adhesives (e.g., epoxy acrylates, urethane acrylates, polyester acrylates, silicon acrylates, and methacrylates) contain functional groups, which allow complete hardening. It must be noted that due to the lower glass transition temperature of these polymers than of thermosetting epoxy resins, their maximum operating temperature is limited.

Electrical-and/or thermal-conducting adhesives [1,9]. The epoxies and acrylates described above are filled with metal powders to get electrical-conducting adhesives. For special applications polyimide and silicone adhesives are used also. Since the metallic particles must touch each other inside the resins to reach a sufficient level of conductivity, a metal content of 70 to 80 wt % is necessary. Silver is the metal generally used, since specific resistances of the filled adhesives down to about 10^{-4} Ωcm can be achieved (metallic silver has a specific resistance of 1.6×10^{-6} Ωcm). Using other metals, such as copper or nickel, the accessible electrical conductivity is too small. On the other side, copper-filled resins show good thermal conductivity and are therefore used for such

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applications where heat dissipation is of importance. To reach high heat dissipation levels, ceramic fillers such as aluminum oxide or boron nitride in a quantity of about 60 to 75 wt % are used. The resulting adhesives reach thermal resistances of 5 to 7 K/W. The main advantages of electrical conducting adhesives are (1) better resistance against mechanical stresses, resulting from large temperature variations compared with solder connections, and (2) electrical connections obtained at low temperatures since soldering is not required.

2. Deposition Processes

Adhesives of various rheological properties are available for the usual deposition processes: screen printing, pin transfer, and dispensing [7]. The adhesive droplet must have a definite height and size, which depend on the board design and the type of component, to bridge the distance between the surface of the circuit board and the electronical component. This can be achieved by a specific adjustment of the adhesive rheology, especially thixotropy and yield point. Usually, the adhesive is deposited on the board. If higher distances between board and device have to be bridged, an additional deposition of the adhesive on the underside of the component may be favorable to ensure wetting of both parts to bond and to counteract the drain-away of adhesive by gravitation. Some examples of distances between circuit board and various components are shown in Fig. 6. The usual diameter/height ratio of an adhesive droplet is about 10:1. Commercially available SMD adhesives may have ratios of up to 1:1 (Fig. 7).

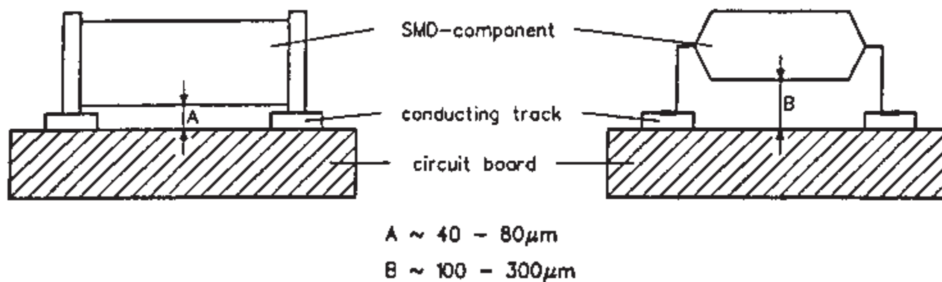

Figure 6 Droplet heights of SMD adhesives.

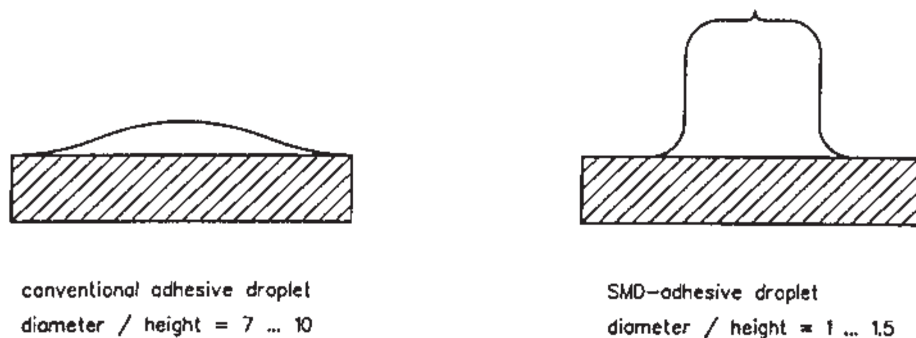

Figure 7 Comparison of droplet heights for conventional and SMD adhesives.

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V. ENCAPSULANTS AND SEALINGS

Protection of components or of the entire circuit board against environmental influences is necessary in many fields of application to ensure proper operation. For this purpose special sealants and encapsulants based on curable epoxies, acrylates, and silicons were developed. Polyurethanes and polyimides are also used as encapsulants and sealings but have only limited importance. Requirements for sealings and encapsulants are:

1. Good wetting of the substrate and sufficient adhesion
2. Resistance against high and low temperatures, moisture, and corrosive media
3. Good processibility
4. Adjusted rheological behavior
5. Good elasticity to withstand mechanical stresses

A. State of the Art

A lot of problems arising from the requirements for encapsulants and sealings can be solved using modified epoxy and acrylate resins [2,10]. Furthermore, silicones became important, which is due to their high heat resistance, good elasticity, maintenance of their electrical properties over a wide range of temperatures and frequencies, and non-flammability [4]. A special type of application of silicones are the silicone gels, which are weakly cross-linked silicone rubbers and behave like elastic liquids. Owing to their good mechanical damping properties, silicon gels are used for encapsulating such components that must be protected against vibrations. On the other hand, encapsulated components are easy to repair since the polymer molecules of these silicones have sufficient mobility for "self-healing."

VI. ADHESIVE TAPES

Two types of tapes are discussed: carrierless adhesive foils (also called transfer adhesives) used, for example, in mounting or laminating processes, and tapes consisting of an adhesive on a carrier tape, used for contact and distance films in foil keypads, covering tapes in galvanizing and solder processes (Fig. 8), and as component supply in insertion installations (Fig. 9). The tape properties required depend, of course, on the type of application. Therefore, the following properties are important for component supply tapes [12]:

1. Constant width of tapes to avoid malfunctions of the handler
2. Sufficient adherence of the components on the tape
3. Stability of the adhesive against aging

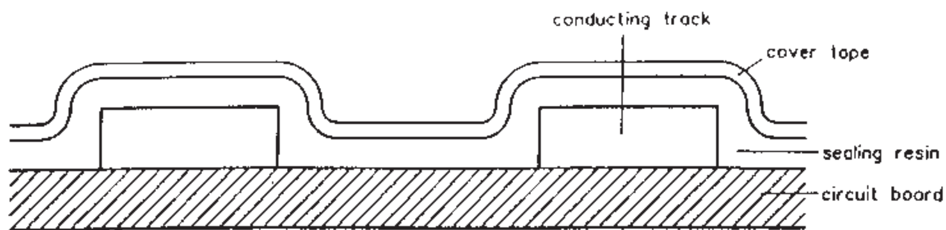

Figure 8 Covering tape with plastic sealing mass. (From Ref. 11.)

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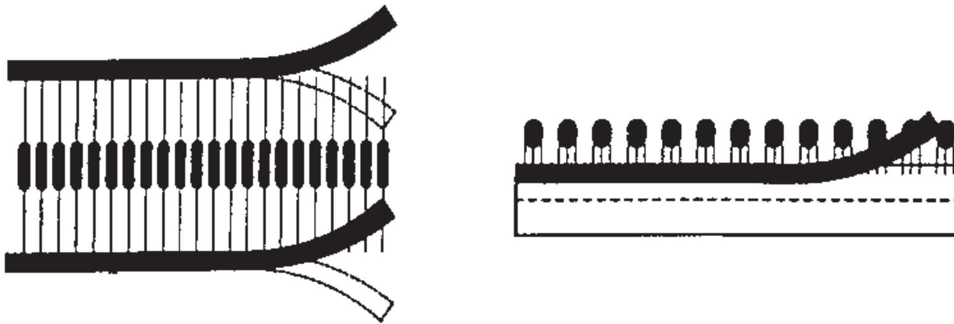

Figure 9 Two examples of adhesive tapes for component supply. (From Ref. 3.)

4. Possible tape lengths up to 5000 m on a spool for effective production
5. Well-defined strength–elongation behavior

It must be noted that the adhesion properties and aging behavior of the supply tapes are determined by the corresponding properties of the adhesives used, whereas the mechanical strength depends primarily on the carrier tape.

A. State of the Art

Tapes for component supply in loading installations usually consist of an acrylate- or rubber-based adhesive (also thermosetting) on a paper or polyester foil carrier (dependent on the mass of the components). Depending on the type of application, different materials are used for the adhesive and the carrier for covering tapes. Most important carrier materials are foils (PVC, polypropylene, cellulose, polyester, polyimide), papers, and woven and nonwoven fabrics (cotton, glass). Adhesives frequently used are based on rubbers, silicones, and acrylates. Carrierless adhesive foils are used, for example, for the bonding of copper foils and polyimide films to get special base materials for circuit boards.

VII. ADHESIVES FOR BASE MATERIALS FOR CIRCUIT BOARDS

The majority of base materials for circuit boards are combinations of a copper foil with a laminate, where the laminate itself consists of a carrier material and a resin. Thus properties of the base material such as mechanical strength, dimensional stability, and processibility are determined primarily by the carrier material. On the other hand, the resin materials are responsible for the thermomechanical and electrical properties as well as for its resistance against chemicals and moisture. Frequently used carrier materials are based on glass and carbon fibers, papers, and polyamide, whereas the majority of the laminating resins are thermosets such as epoxies, phenolics, cyanates, bismaleimide triazine (BT) resins, maleimides, and various combinations of these [13].

Furthermore, the overall properties of the base materials for circuit boards are determined essentially by the joint between the copper foil and the laminate. This joint can be realized by both an added adhesive and by the laminating resin itself, which additionally, acts as adhesive. An additional adhesive is needed in the manufacture of flexible circuit boards (e.g., polyimide/copper) or of paper-based rigid circuit boards. During this process the adhesive is deposited on the bottom side of the copper foil after

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it is joined to the laminate by heating under pressure. The primary requirements for such adhesives are:

1. Adjustable processing behavior
2. Systems without or with low organic solvent contents
3. Sufficient bonding strength at elevated temperatures (250 to 320°C for short times)
4. Dielectrical stability, low dielectric constant
5. Resistance against etching and galvanic processes

For the production of base materials for circuit boards with higher performance (e.g., glass/epoxy or graphite/cyanate ester combinations) and of multilayer boards, the laminating resin acts as adhesive or special bonding prepregs must be used. The requirements for the resins, which act as adhesive, depend on both the processing conditions and the desired properties of the final circuit board and are similar to those described above.

A. State of the Art

Base materials for circuit boards based on phenolic resin/paper laminates are used primarily for low-performance materials, which are needed, for example, in consumer electronics. The actual properties standard of these materials meets the requirements of the market. The laminating adhesives used for the manufacture of base materials are organic solutions or aqueous dispersions of thermosetting resins such as poly(vinyl butyral)–phenolic resin or acrylate–phenolic resin.

Flexible circuit boards consist primarily of polyimide-based carriers. The problem of bonding the copper foil on the polyimide carrier has not yet been solved satisfactorily. Due especially to their low bonding strength at elevated temperatures, the production of such materials is very limited. Nevertheless, adhesives for copper–polyimide systems were developed, where one-component epoxy resins (e.g., epoxy–polyester mixtures) and reactive hot melts (e.g., phenolic resin–nitrile rubbers) reached importance.

A wide range of high-performance materials for circuit boards is available for such systems, where the laminating resin acts simultaneously as adhesive for the copper foil. The majority of the systems consist of resins, which are based on epoxies, bismaleimides, cyanates, BT resins, and carrier materials, made from glass and carbon fibers and polyamides. Since the properties of the resins are adjustable over a wide range using combinations and modifications of the resins, the bonding strengths desired for the resulting circuit board base materials can be achieved for almost all kinds of applications. On the other hand, further developments are needed to get base materials having, for example, high thermal and moisture resistance.

VIII. OUTLOOK

The future development of electronical circuitries will be characterized by miniaturizing of components and circuits as well as a more and more dense packing of components on the printed circuit board. For this reason, the surface-mounting technology of electronical components will become more and more important. Additionally, using SMD techniques, a higher level of production of electronical circuitries can be reached. The preparation of special adhesives in one important precondition for the success of SMD techniques. In this connection it is essential to look for new reaction principles for one-component adhesives

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having higher curing rates at lower temperatures to increase the production rates and reduce the energy consumption and to replace the solder process by electrical- and/or thermal-conducting adhesion bondings.

The next era in loading technology has already begun. This technology is characterized by conducting tracks made in thin-layer technology by metal-sputtering processes and by electronical functions realized in thick-layer technology by structurated deposition of inorganic or organic pastes with well-defined electrical properties. Concerning this matter, the development of organic pastes with well-defined and adjustable electrical properties and rheological behavior is necessary.

In the future, environmental protection will become more and more a matter of concern. Harmless technologies and recycling processes for both the adhesives and the entire circuits will have to be developed. In this connection, the following requirements must be met by the polymeric materials: nontoxicity, low, or no, volatile-product content during use, suited for repairing and disassembling processes of components and recycling.

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