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Curing Process of Electrically Conductive Adhesives and Formation of Resistant Coatings using Atmospheric Pressure Plasma

Toru Sasaki[1,2], Kodai Igarashi[2], Motoki Maegawa[2], Van-Phuoc Thai[3], Kazumasa Takahashi[2], Takashi Kikuchi[2,4]

[1] Department of Science of Technology Innovation, Nagaoka University of Technology,
[2] Department of Electrical, Electronics, and Information Engineering, Nagaoka University of Technology,
[3] Department of Mechanical Engineering, Ho Chi Minh City University of Technology and Education,
[4] Department of Nuclear Technology, Nagaoka University of Technology,

sasakit@vos.nagaokaut.ac.jp

In surface-mount technology for electronic components, conductive adhesives are used to bond components to substrates as an alternative to solder. While these adhesives enable bonding at lower temperatures than solder, thermal curing is typically required to achieve sufficient electrical conductivity and mechanical strength. However, conventional thermal processes pose significant challenges, including thermal damage to heat-sensitive materials and long processing durations.

To overcome these limitations, this study investigates the use of atmospheric pressure plasma (APP) generated by dielectric barrier discharge, which offers high chemical reactivity at low temperatures, as a novel curing method for conductive adhesives. The objective is to demonstrate that APP can effectively cure conductive adhesives at lower temperatures than conventional thermal processes, and to elucidate the underlying curing mechanisms.

Temperature measurements during APP exposure revealed that processing can be conducted at temperatures below 100°C for irradiation times of less than 20 minutes. Both silicone-based and epoxy-based conductive adhesives exhibited improved electrical conductivity after plasma treatment, with a significant decrease in volume resistivity. Cross-sectional imaging using field-emission scanning electron microscopy (FE-SEM) revealed a reduction in adhesive layer thickness, indicating that curing was effectively promoted [1]. These findings confirm that APP enables curing at significantly lower temperatures than thermal curing. Furthermore, a comparison of energy consumption during the effective curing time (within 5 minutes) revealed that APP required substantially less energy−approximately one-eighth for silicone-based and one-third for epoxy-based adhesives—compared to thermal treatment.

Elemental analysis via energy-dispersive X-ray spectroscopy (EDX) revealed notable differences in surface composition between plasma-cured and thermally cured samples. In plasma-treated specimens, the surface carbon concentration increased with longer irradiation durations. Additionally, selective radical irradiation experiments using vacuum ultraviolet (VUV) light demonstrated that exposure to O and OH radicals resulted in similar surface modifications to those observed under APP treatment. These results suggest that reactive species, particularly radicals, are the primary contributors to the curing of adhesives during plasma exposure. This was further supported by Fourier-transform infrared (FT-IR) spectroscopy, which revealed that plasma irradiation promotes polymerization reactions, resulting in the solidification of the adhesive. These findings are consistent with those reported for an atmospheric pressure plasma-assisted curing method [2].

In this method, a simple plasma-assisted process was developed to coat SiO_xC_y thin films onto conductive silicone adhesives, significantly improving their oxidation resistance. The coating process requires neither precursor materials nor post-treatment, and it preserves the original electrical conductivity of the adhesive. The resulting thin film exhibits strong hydrophobicity, effectively protecting the adhesive from degradation by acid and ozone exposure. The film's structure consists mainly of Si_3^+:[–[Si(R)(-O-)-O–] and Si_4^+: [Si(-O-)2–O–].

In conclusion, this study demonstrates that atmospheric pressure plasma enables the low-temperature and energy-efficient curing of both silicone-based and epoxy-based conductive adhesives. The curing mechanism is primarily governed by radical-induced polymerization reactions, presenting a promising alternative to conventional thermal processes.

References

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