Development of an Internet Course on Electrically Conductive Adhesives with Experiments

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Abstract

The authors are developing a course on Electrically Conductive Adhesives for Internet delivery from multiple sites. The paper lays out detailed lecture by lecture content, and details of the experimental sequences, which include both high end analytical techniques and experiments which would be adaptable to any basic undergraduate laboratory environment.

1. Introduction

The development of the worldwide web has provided unprecedented opportunity and challenge to the educational community for the delivery of immediate distance instruction, (real-time if desired,) and the range of Internet courses continues to expand exponentially.

The State University of New York system, for example, offers hundreds of courses on the Internet to remote students every semester via the SUNY Learning Network (SLN), and Binghamton University has committed itself to the delivery of graduate materials science and engineering courses. The Watson School, furthermore, has extended the SLN technology to include lecture audio in the package [1]. The first of these courses was a graduate level introduction to electronics packaging, presented in Fall 1998 [2].

While the development of Internet-based courses is clearly intended to reach off-campus students, one of the advantages is the opportunity for collaboration and cooperation with other campuses and universities, which can benefit regular full-time students too [3,4].

In addition to course delivery, the Internet offers new opportunities for faculty and institutional cooperation at both the national and international levels. In this model, material is made available on a cooperative basis amongst faculty on different campuses. Such material may be selected as modules from a complete course, or may exist as independent modules available for adoption into others' courses. This is the model which most directly addresses the need identified by university faculty in forum discussion at the *1st International Academic Packaging Conference* at Georgia Institute of Technology, Atlanta, March 18-20, 1998, for multi-disciplinary assistance in developing packaging course materials outside their own academic disciplines.

There is a structured effort under way to provide such modules (funded jointly by IEEE/CPMT and NSF,) and a real likelihood of them becoming available on a broad basis. The material currently available includes modules or self-contained courses on electronics manufacturing [5], thermal design [6, 7], and signal integrity [8, 9].2. ECA for Electronics Packaging

There are two primary categories of ECA:

- Isotropically Conductive Adhesive (ICA)
- Anisotropically Conductive Adhesive (ACA).
  ACAs are available as paste or film (ACF).

Both types conduct through metal filler particles in an adhesive polymer matrix.

ECAs have been used for electronics packaging applications for decades in hybrid, die-attach and display assembly. There has been growing interest from the electronics industry over the past decade in other kinds of electronics packaging applications. While toxicity issues and environmental incompatibility of the lead in tin-lead solders triggered that greater interest at the outset, it has been the other evident advantages continue to drive further research. ECAs can offer the following additional potential advantages:

- Fine-pitch capability, especially when using ACAs for flip-chip
- Elimination of underfilling with ACA bonding; Low temperature processing capability;
- Flexible, simple processing and hence low cost

Current ECA research activities look forward to both flip-chip and surface mount technology (SMT) applications.

2.1 Isotropic Conductive Adhesives (ICAs)

Ag is usually used as the filler material due to its high conductivity and simple processing for ICA applications. Polymer based metal plated spheres or nickel fillers are mainly used for ACA applications. Figure 1 shows the microstructure of an ICA joint for a flip chip component on an FR-4 substrate. The metallic filler content is high enough (between 25-30 volume percent) to cause direct metallic contact.

2.2 Anisotropic Conductive Adhesives (ACAs)

In an ACA joint, the filler particle is normally between 5-10 volume percent, and does not cause any direct metallic contact. It is only after pressurization during curing that the electrical conduction becomes possible in the pressurization direction as is illustrated in Figure 2. As there is no direct contact between the particles, ACA technology is very suitable for small pitch assembly, and has found applications in flip-chip technology.

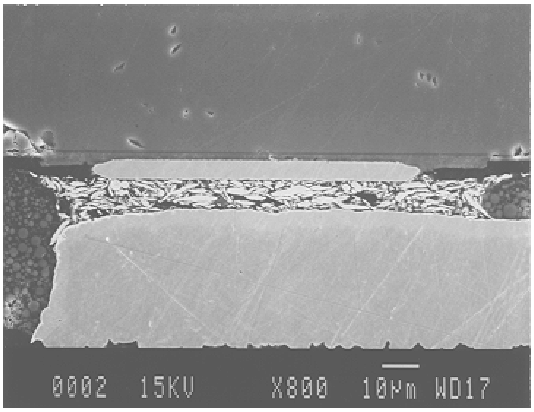


Figure 1. ICA flip- chip joint on an FR-4 substrate.

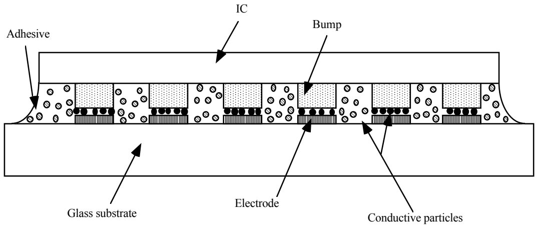


Figure 2. ACA flip-chip joint on a glass substrate.

3. Implementation of the Internet course

The Internet course is based on the existing short course taught jointly by the authors and the Chalmers University course for Ph.D. students, which deal with the fundamentals and applications of conductive adhesives in electronics packaging applications. The outline and introduction of these courses can be found in [9].

The homepage of the Internet course was written in hypertext makeup language (HTML). Some web building software (FrontPage, Dreamweaver) was used. The whole course is separated as several interdependent modules of information. These modules are joined together through hyperlinks embedded into the HTML frame.

Figure 3 illustrates the main structure of the Internet course. The welcome page (Figure 4) is the entrance of the web course. After that, the start page (Figure 5), includes the preface, objectives, guidance to the course, and the site-map of the whole web-site. In the guidance section, we provide instructions on how to use these web course materials. The 3rd stage is the index page. (Figure 6) There are 3 links in this page, directed to the three parts of the course: Introduction to ECAs, Isotropically Conductive Adhesives (ICA), and Anisotropically Conductive Adhesives (ACA). The virtual classroom comes next, with multimedia online lectures, lecture notes, lab tours, etc. The web pages are constructed and maintained by Chalmers University of Technology and State University of New York at Binghamton together. The general introduction to ECAs is handled jointly. Chalmers and Binghamton Universities are individually responsible for the other two parts, ACA and ICA, respectively.

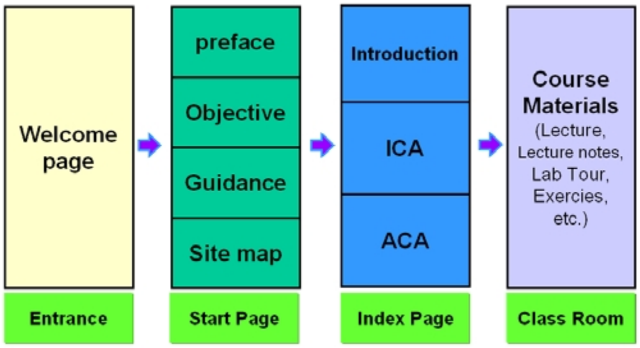
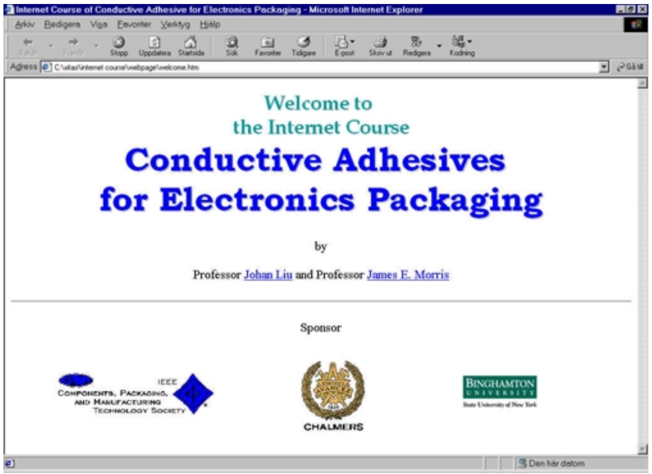


Figure 3. Main structure of the course



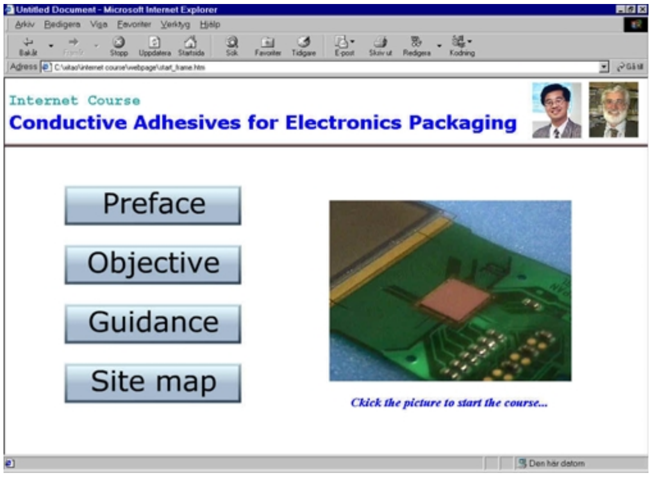
Welcome to
the Internet Course
Conductive Adhesives
for Electronics Packaging

by

Professor Johan Liu and Professor James E. Morris

Sponsor

Figure 4. The welcome page of the course



Internet Course
Conductive Adhesives for Electronics Packaging

Click the picture to start the course...

Figure 5. The start page

The Contents listings are the same for each section. Figure 7 shows the ten sections for the ACA part:

- Content
- Multimedia lecture
- Lecture notes
- Text books
- Exercises
- Lab tour

Table 1. Lectures on "Introduction to Electrically Conductive Adhesives (ECA) for Electronics Packaging."

1.	ICA/ACA/ACF/NCA Technologies
2.	Technology Drivers: Environment & Economics
3.	Applications Survey: ICA/ACA/ACF/NCA

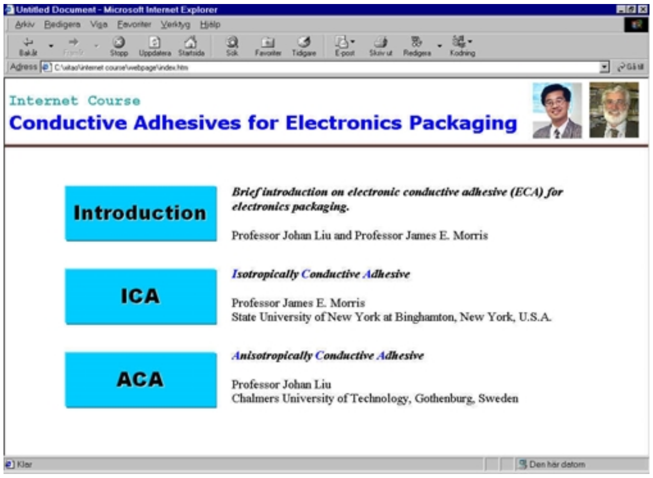
Table 2. Lectures on "Isotropically Conductive Adhesives (ICA) for Electronics Packaging."

1.	ICA Introduction
1.1	Structure and Percolation
1.2	ICA Technologies
2.	Materials
2.1	Metals (& more percolation)
2.2	Polymers
2.3	Cure: Modeling
2.4	Cure: Experimental
3.	Electrical Conduction
3.1	Percolation Theory and Size Effects
3.2	Inter-Particle Contact
4.	Electrical Measurements
4.1	Electrical Reliability
4.2	Measurement Techniques
4.3	Structural Effects
5.	Electrical Modeling
6.	Mechanical
6.1	Adhesion
6.2	Drop Test
6.3	Mechanical Cycling
7.	Thermal
7.1	Thermal Conductivity
7.2	High Current Effects and Power Applications
8.	Reliability
8.1	Electromigration
8.2	Environmental Testing (Electrical & Mechanical)
8.3	Thermomechanical Cycling
9.	Miscellaneous
9.1	Manufacturing Enhancements
9.2	Other ICA Concepts
9.3	Related Technologies
10.	Future Research & Summary

Table 3. Lectures on "Anisotropically Conductive Adhesives (ACA) for Electronics Packaging."

1.	ACA Introduction
1.1	Polymer system
1.2	Filler system
1.3	Driving forces and potential advantages for ACA
1.4	ACA technologies
2	Conduction mechanism
2.1	Electrical conduction
2.2	Thermal conduction
3	Characterization techniques
3.1	Polymer characterization
3.2	Mechanical properties characterization
4	Processing & quality control
4.1	Dispensing
4.2	Stencil printing
4.3	Film attach
4.4	Open and bridging results and modelling
4.5	Flow modelling
4.6	Conduction formation during bonding
4.7	Curing degree
5	Joint quality judgement and repair
6	Failure mechanism
6.1	Oxidation
6.2	Hydrolysis
6.3	Fall off
7	Joint quality and process control
7.1	ACA quality general consideration
7.2	Effect of particle hardness
7.3	Effect of adhesive layer thickness
7.4	Effect of bonding pressure
7.5	Effect of substrate material and stiffness
7.6	Effect of pad size
7.7	Effect of particle size
7.8	Effect of temperature ramp rate
8	Reliability
8.0	General consideration on reliability testing standard
8.1	Reliability testing methods
8.2	Failure criteria
8.3	ACA on glass
8.4	ACA in Flip-Chip on Flex
8.5	ACA in Flip-Chip on Rigid substrate
8.6	BGA Reliability
9	Modeling & simulation
9.1	Electrical modeling at DC
9.2	Electrical modeling at high frequency
9.3	Materials data
9.4	MicroDAC and Laser-Morei measurement
9.5	FEM simulation
9.6	Life prediction
10	Environmental aspects & Life Cycle Analysis
11	Application examples
11.1	CoG
11.2	Surface mount
11.3	Flip-chip on rigid board
11.4	Chip on flex
11.5	Smart-card
11.6	Flex to rigid board interconnect
12	Conclusions

- Experiments
- Glossary
- FAQ
- Links.



Internet Course

Conductive Adhesives for Electronics Packaging

Introduction

Brief introduction on electronic conductive adhesive (ECA) for electronics packaging.

Professor Johan Liu and Professor James E. Morris

ICA

Isotropically Conductive Adhesive

Professor James E. Morris
State University of New York at Binghamton, New York, U.S.A.

ACA

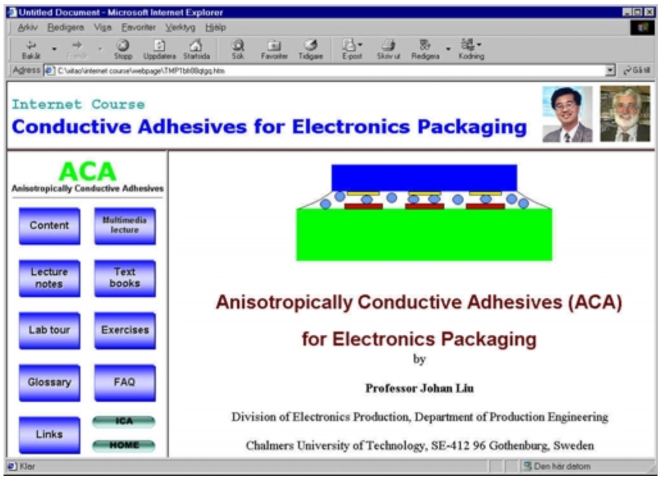
Anisotropically Conductive Adhesive

Professor Johan Liu
Chalmers University of Technology, Gothenburg, Sweden

Figure 6. The index page

The content of the ACA part is selected from the Chalmers Ph.D. student course mentioned before [9]. Each chapter and section in the content page is a hyperlink directed to the corresponding lecture. Sections 2 to 5 provide the core of this part, and are described in detail below. In order to help the user to understand the materials well, a glossary, FAQ (frequently asked questions), and some useful electronics packaging links are included.

The Introductory, ICA, and ACA lecture topics are listed in Tables 1, 2, and 3, respectively.



Internet Course

Conductive Adhesives for Electronics Packaging

ACA

Anisotropically Conductive Adhesives

Anisotropically Conductive Adhesives (ACA)

for Electronics Packaging

by

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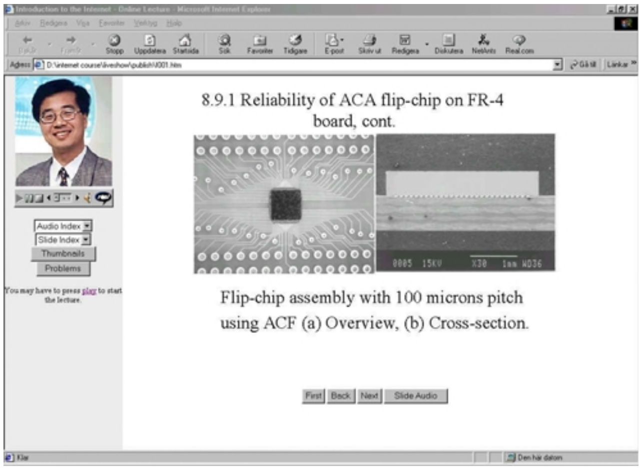
Figure 7. Interface of ACA part

3.1 Multimedia Lecture

The multimedia lecture modules are created by using the Sync-O-Matic 2000 developed by Dr. Charles Severance at Michigan State University [10]. Sync-O-Matic was developed for education purposes. It is currently in use in hundreds of locations around the world to produce web-based lectures. It combines audio, video, PowerPoint slides and the slide timing to provide high quality web lectures. The multimedia lectures are based the PowerPoint slides prepared for this course. As a first step, we include only the audio commentary for these slides. The slideshow will play automatically with the voice from the instructor. The students can play the whole chapter, or a part starting from any slides. Students can select the slide from slides index or thumbnails. Figure 8 shows the interface of the multimedia lecture.



You may have to press play to start the lecture.

8.9.1 Reliability of ACA flip-chip on FR-4 board, cont.

Flip-chip assembly with 100 microns pitch using ACF (a) Overview, (b) Cross-section.

Figure 8. The multimedia lecture interface

3.2 Lecture Notes

Compared with the conventional campus lecture, the obvious advantage of the web course is that it can be played as many times as needed. Although the web course can be played unlimited times, it is better to give the students the printable lecture notes. All the slides used in the multimedia lecture can be found in this section in Acrobat format. The lecture notes are separated as chapters in order to be downloaded. Other related materials, like discussion topics, comments from the teacher will be also included in the future.

3.3 Text books

The book "*Conductive Adhesives for Electronics Packaging*" edited by Johan Liu [11] is selected as the principal text for this course. The Contents and Introductions of this book are also on this page. A hyperlink to the publisher is available. Some selected chapter or sections might be scanned and added to this section with the permission of the author and publisher, for convenience as supplementary reference materials. Other reference books will be introduced by hyperlinks, where possible.

3.4 Lab tour

The lab tour is another important part of the course. It helps the students comprehend the knowledge they learned in the lecture, and helps them relate the theoretical lecture material to experimental laboratory processes, just as the real laboratory component of a conventional course would. In order to let the students be familiar with the lab, the instruments in the lab are introduced first. Therefore, two distinct parts of the lab tour are provided here: the equipment, and the process. In the instrumentation part, we put up the picture, capability, specification, and the operational instructions of the instrument. The web-site of the "*Electronics Packaging Virtual Laboratory*" at Budapest University of Technology and Economics [12] provides a good example. The instruments introduced include:

- Plasma etching and cleaning equipment
- ACF Flip-Chip bonder
- Screenprinter
- Acoustic Microscopy
- Dispenser
- Automatic pick and place machine
- Manual Pick & Place equipment
- Ultrasonic cleaner
- Pressure cooker
- Shear tester
- Thermal bonder
- Ageing furnace
- Laser-interferometer for high resolution strain analysis in electronics packaging
- Multi-functional Mechanical Tester in humidity and elevated temperature environment
- Differential Scanning Calorimeter (DSC)
- Thermogravimetric Analyzer (TGA)
- Dynamic Mechanical Analyzer (DMA)
- Thermal Mechanical Analyzer (TMA)

In the process part, the demonstration of the application of each instrument will illustrate:

- Designing a conductive adhesive test vehicle
- Assembly of the conductive adhesive test vehicle
- Reliability test set up
- Data collection from the test vehicle
- Analytical instruments for inspecting the test vehicle
- Data analysis and conclusion of test

The process will be explained in detailed text with pictures as first stage. The web pages of the "The Virtual Packaging Laboratory" at Georgia Institute of Technology are nice example for this purpose [13]. In order to make the process more comprehensible, videos and/or animations to show the real lab operation should be added on the web in the future.

Some industry tour is also planned in this section.

3.5 Interactive Exercises

In order for the existing book to function effectively as a classroom text, it must be supplemented by a comprehensive set of quantitative problems and worked examples, with design integrated wherever possible. These materials will be placed on the web-site, along with a continuously updated listing of the literature readings mentioned above.

Some existed calculation programs can be revised and grafted on the web as interactive exercises. One candidate is the simulation program developed by L. Li and J. Morris at SUNY at Binghamton, [14,15]. This program calculates the probability of an ACA contact failure for random particle distributions and input parameters: particle size and density, pad size and pitch, and minimum pad capture criteria. Alternatively, it will calculate ACA particle specifications for given pad size and failure probability. We will investigate the possibility of developing further interactive exercises in the future.

3.6. Laboratory experiments

The web-site will contain a sequence of experiments for the student, or for an instructor to adapt. Because the specific apparatus available to a given student (or instructor) is not known, the experimental instructions can only be given in general terms. However, some will have access to state of the art microelectronics fabrication and test equipment, while others will need to utilize basic laboratory equipment found in any lower division engineering sciences lab and materials found at home. Two distinct sets of instructions will be provided to accommodate these two extremes. The "high-tech" versions will be developed at Chalmers, while the "kitchen-sink" versions (which will not always be feasible,) will be developed at Binghamton.. Sample data sets will be provided for both. Most experiments will be adaptable to either ICA or ACA interests, but any special instructions or comments necessary for either will be included. The experiments are listed below.

1. Test sample preparation and cure: Basic familiarization; cure to manufacturer's specs; may require multiple attempts to establish a satisfactory product.
2. Adhesion: Pull and shear tests; may vary surface cleaning procedures as control parameter.
3. Drop test: Vary mass with fixed adhesive bond area.
4. Electrical test I: Establish test structures; (a) cross and (b) longitudinal print for 4-terminal measurements; (c) daisy chains if available.
5. Electrical test II: Temperature coefficient of resistance.
6. Electrical test III: High frequency effects.
7. Electrical test IV: Size effects.
8. Variation of resistance with pressure during cure.
9. Reliability I: Environmental test I: Temperature and humidity; use 3- and 4-terminal measurements to separate bulk and interface resistances.
10. Reliability II: Cure effects; variation of electrical properties, adhesion, drop test, humidity test reliability with degree of cure from under-cure to over-cure.
11. Reliability III: Thermomechanical load cycling.
12. Reliability IV: Electromigration.
13. High current effects: Steady state and pulsed current effects for power applications.
14. Structural analysis: SEM studies (high tech only).
15. Cure studies: DSC and TGA (high tech only).

4. Future plan

The design and construction of the interactive web site is an ongoing process. To make the Internet ECA course successful, there is still a lot of work to be done.

4.1 Video

Due to limitations in data transfer speeds available to many users, we will avoid using video on the web pages in the first stage. With the prevalence of the broadband Internet, it will be possible to play the online video with assured quality. In the two most important sections of the course, the multimedia lectures and lab tour, we expect that video can be added in the next development stage. Sync-O-Matic can support video as well, there is no software problem. However, studio and related equipment requirements to record the lectures and experiments fully, and the huge storage space necessary, will constrain our video use to dynamic demonstrations which require the medium in short clips..

4.2 Keep the course fresh

The web pages should be updated continually. The project will also include the development of supplementary notes to continuously update the textbook material with the latest research data. Eventually this material will become incorporated into subsequent editions, but in the meantime, the web-site/text combination will become a "living document" reference resource in the field.

5. Conclusion

The development of the Internet course on Conductive Adhesive for Electronics Packaging has stepped out, with the cooperation of Chalmers University of Technology in Sweden and the State University of New York at Binghamton in the USA. The course will be accessible soon through the Internet. It provides the fundamentals and applications of conductive adhesives in electronics packaging applications. Students and engineers can improve their knowledge of ECAs for electronics packaging by the multimedia lecture and lecture notes. It also provides a possibility for students to be familiar with the lab instruments and experiments.

The next step is to consummate the web-site. Video and interactive exercises will be added.

Acknowledgements

This work is partially sponsored by the National Science Foundation, USA, through the Packaging Research Center of Georgia Instiute of Technology, and by the IEEE CPMT Society. The project began January 2001.

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