A New Approach to Chemical Analysis of Packaging/Assembly Materials: SARIS^{TM} Laser Ablation ICP Mass Spectrometry

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Abstract

Our recent studies with laser ablation ICP mass spectrometry (LA ICP-MS) have been focused specifically on the development of this technique for practical analysis of packaging/assembly materials involved in back-end manufacturing processes where elemental composition, element ratios, and trace metallic contamination are of critical importance. In this paper we will describe the advantages of the LA ICP-MS technique, and applications where LA ICP-MS has been applied to packaging manufacturing for defect reduction in materials and overall yield enhancement. Because LA ICP-MS can be used to analyze conductive, semi conductive and insulating materials without any sample pretreatment, applications have included bonding wires, solder bumps, lead frames, polymer materials, adhesives, and final packages. Environmentally sensitive contaminants such as cadmium, chromium, lead, mercury, and tin are shown to be easily analyzed from any solid materials. Finally, the complementary aspects of LA ICP-MS versus alternative techniques such as SEM-EDX and X-ray fluorescence (XRF) for back-end manufacturing processing are also discussed.

Laser Ablation ICP Mass Spectrometry

Coupling a high power pulsed laser with inductively coupled plasma mass spectrometry (LA ICP-MS) has been extensively studied in academia in an effort to understand the fundamentals of laser-matter interactions [1].

LA ICP-MS involves the conversion of solid materials into a plume of atomic vapor and micro particles by focusing a high-power and pulsed laser beam onto a sample surface. The plume of atomic vapor and micro particles is transported in an argon carrier gas to the high-temperature RF plasma (ICP) for efficient vaporization, atomization and ionization. The ions produced by the ICP (plasma temperature can be as high as 10,000K) are then counted by a quadrupole, time of flight (TOF), ion trap, or a magnetic sector based high-resolution mass spectrometer.

A major advantage of LA ICP-MS is its ability to analyze, without a sample pretreatment, a wide range of diverse solids including conductive and non-conductive, homogeneous and heterogeneous, inorganic and organic, transparent and non-transparent, as well as refractory materials. This ability is mainly attributed to the high power density and efficient energy coupling to solids of the focused short-pulse UV laser beam and the efficient ionization provided by the steady-state ICP plasma.

LA ICP-MS has been studied in our laboratory [2] and the analytical methodology we have developed for solving semiconductor-manufacturing problems is known as SARIS™. One of the areas we have been working on is to apply this technique to characterize a variety of packaging materials. In addition to analyzing uniform materials, the SARIS version of LA ICP-MS also permits spatial characterization of heterogeneity in solids.

Verification of Metals in Epoxy Die-Attach Adhesives

One application of SARIS™ LA ICP-MS is for qualitatively determination of certain metals such as copper, gold, and silver in epoxy adhesives for die–attach paste. This application can be used to either verify the presence of metals for conducting adhesive or the absence of metals in those adhesives used as insulating barriers. Figure 1 shows a representative mass spectrum obtained using SARIS™ with a conducting epoxy adhesive.

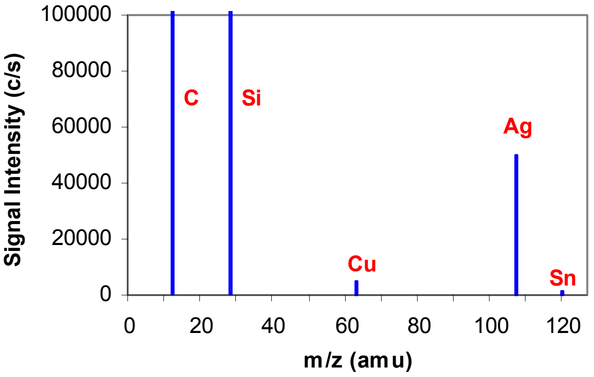

Figure 1. Spectrum obtained with a metal filled adhesive.

Compositional Analysis of Solder Bumps

Microscopic analysis of solder bumps less than 200 µm in size have been performed via SARIS™ LA ICP-MS. Table 1 shows the elemental compositions obtained with the same tin-lead solder bumps using SARIS™, wet method, and XRF.

Table 1. Quantitative analysis results obtained with Tin-Lead solder bumps by SARIS™, wet chemistry, and XRF

Methodology	Tin (Sn)	Lead (Pb)
SARIS™ LA ICP-MS	7.6%	92.4%
S.D (n=10)	0.3%	0.3%
Wet Method*	7.4%	92.6%
X Ray Fluorescence	5.1%	94.9%

* Acid digestion followed by ICP-OES analysis

Wet method was used here to evaluate the accuracy of SARIS™ LA ICP-MS. The analysis was done by chemically

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dissolving a portion of the solder layer on the wafer with the same composition as the solder bumps and then analyzing the resultant solution for lead and tin using ICP optical emission spectroscopy (ICP-OES). The data in Table 1 shows that SARIS™ is in good agreement with the wet method. The data obtained by XRF, however, are off by more then 2%.

Another elemental composition example where SARIS™ is being investigated is the analysis of Lead-free solders such as NiPdAu and SnAgCu. These types of solders are in response to the industrial transition to 100% Lead-free packages.

Evaluation of Bonding Wires

Gold wire bonding has been analyzed by SARIS™ LA ICP-MS for minor or trace impurities. Presence of some undesirable impurities in gold wire bonding or formation of gold alloys with some other metals, in some cases, can severely deteriorate the bond and reduce its conductivity. Compared to popular SEM-EDX, SARIS™ was not only much more sensitive but also capable of analyzing some elements that SEM-EDX is unable to detect due to overwhelming spectral overlaps caused by gold matrix. Examples of these elements are phosphorus, sulfur, molybdenum, lead, and zirconium.

In the same principle, SARIS™ has be utilized to analyze unwanted impurities in aluminum bonding wire materials. Final package interconnect test hardware including testing probes and contactors that are made of gold or nickel can be evaluated and minor metal additive in the thin film coatings on the probes can be verified or quantified.

Analysis of Environment Sensitive Substances

SARIS™ LA ICP-MS methods are being developed in our laboratory in an effort to analyze packaging materials for some substances that have impacts on the environment and are regulated by industry or local government. These environment-related substances are either natural impurities, which cannot be totally removed in a refining process, or the impurities that are introduced during a synthesis or a manufacturing process, the total removal of which is technically impractical. The materials we have investigated include plastic encapsulations, substrates, lead frames, PCB board, bonding wires, epoxy adhesives and chips. Table 2 lists initial reporting limits obtained using SARIS™ for cadmium, total elemental chromium, lead, and mercury.

Table 2. Representative reporting limits determined by SARIS™ LA ICP-MS in bulk silicon

Element	Reporting Limits ppmw (µg/g)
Cadmium (Cd)	5
Total Chromium (Cr)	5
Lead (Pb)	5
Mercury (Hg)	10

In addition to quantitative analysis, SARIS™ LA ICP-MS has been used to quickly screen packaging materials for those environment-related substances as well. For example, printed circuit boards, rerouting and coating resins have be evaluated for hazardous halogens and antimony. Figure 2 shows the ICP-MS spectra obtained with epoxy resin with and without the presence of bromine and antimony based flame-retardants.

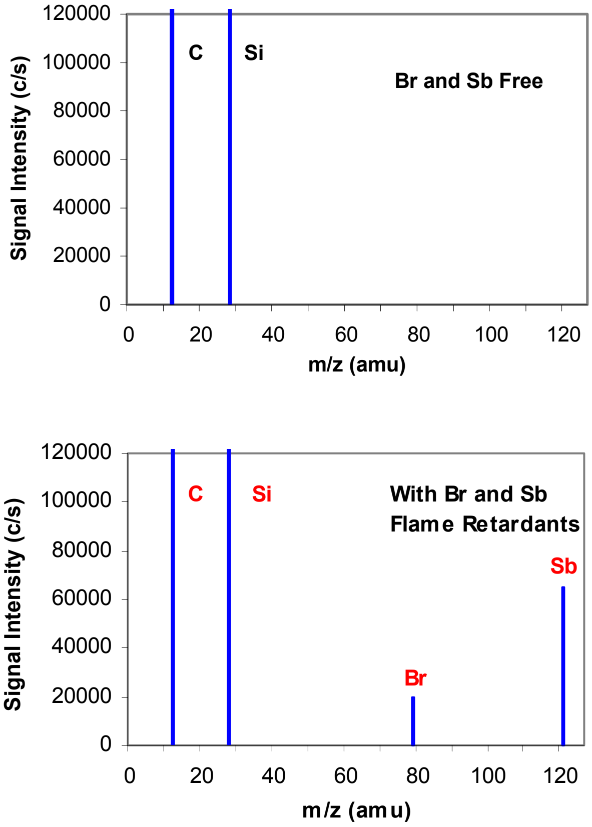

Figure 2. Spectra obtained for epoxy resin with and without bromine and antimony flame-retardants.

Conclusions

SARIS™ LA ICP-MS has been studied and used in our laboratory to analyze packaging/assembly materials in the electronics industry. The initial data and some applications presented here show that SARIS™ allows both qualitative screening and quantification, thus providing an alternative approach to material compositional verification and cleanliness control for packaging operation. This technique can be comparable to, or better than, SEM-EDX and XRF and can be used with vary fast turnaround time to determine major, minor, trace elements in various packaging materials.

References

1. Russo, R.E. et al, The Physics of Laser Ablation in Microchemical Analysis, *Analytical Chemistry*, Vol. 74, No. 3 (2002), pp. 70A-77A.
2. Li, F.H. and Anderson, S., Using Direct Solid Sampling ICP Mass Spectrometry to Complement SEM-EDX and SIMS in Characterizing Semiconductor Materials, in Characterization and Metrology for ULSI Technology, Seiler D.G. et al. (Ed.), American Institute of Physics (New York, 2003), pp 715-719.