ION INDUCED OPTICAL EMISSION FOR SURFACE AND DEPTH PROFILE ANALYSIS*

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ABSTRACT

Low-energy ion bombardment of solid surfaces results in the emission of infrared, visible, and ultraviolet radiation produced by inelastic ion-solid collision processes. The emitted optical radiation provides important insight into low-energy particle-solid interactions and provides the basis for an analysis technique which can be used for surface and depth profile analysis with high sensitivity. The different kinds of collision induced optical radiation emitted as a result of low-energy particle-solid collisions are reviewed. Line radiation arising from excited states of sputtered atoms or molecules is shown to provide the basis for surface and depth profile analysis. The spectral characteristics of this type of radiation are discussed and applications of the ion induced optical emission technique are presented. These applications include measurements of ion implant profiles, detection sensitivities for submonolayer quantities of impurities on elemental surfaces, and the detection of elemental impurities on complex organic substrates.

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1. INTRODUCTION

Among the many processes that occur when a beam of low energy ions or neutral particles impact on a surface are the backscattering of a fraction of the incident particles, the sputtering of atoms, molecules and ions from the surface, the secondary emission of electrons by potential and kinetic processes, and the production of intense visible, ultraviolet, and infrared optical radiation [1] as a result of collision process. The optical radiation is produced by inelastic processes involving outer shell electrons. In the energy range 30 eV to 100 keV where the beam energy is large compared to both the binding energy of atoms in the solid and to the excitation energy of outer shell electrons, radiation is observed from sputtered particles, reflected particles, and the solid itself. This radiation provides direct information on the identity and quantum state of sputtered and reflected particles (including neutral atoms leaving the surface), the velocity distribution of radiating particles, and the transfer of projectile energy to the electrons in the solid. Measurements of this collision induced optical radiation is, therefore, a powerful tool for studying fundamental processes which result from the interaction of low energy atomic particles with a solid. In addition this radiation provides the basis for a sensitive surface analysis technique for elemental surface analysis. Surface constituents and contaminants can be determined with high sensitivity by identification of optical lines and bands that are produced in the collision process. The purpose of this paper is to review the different types of collision induced optical radiation, to discuss the characteristics of radiation from sputtered atoms, and to present practical examples of surface and depth profile analysis. Finally, we will indicate some of the advantages and limitations of this technique.

II. SOURCES OF ION INDUCED OPTICAL RADIATION

In low energy (30 eV - 100 keV) ion-solid collisions, at least five distinct kinds of collision induced optical radiations have been identified. The first of these is due to sputtering accompanied by simultaneous electronic excitation which gives rise to radiation from excited states of sputtered surface constituents [2,3,4]. The interaction of the impinging beam with the solid results in the sputtering of atoms, molecules, and ions from the surface. A fraction of the particles sputtered from the first few monolayers of the solid escape from the surface in excited states and decay optically well away from the surface where the perturbation of atomic levels by the solid is negligible. This results in the emission of discrete atomic and ionic emission lines as well as molecular emission bands, broadened only by the Doppler effect. An important factor in understanding the intensity of a spectral line arising from an excited state of a sputtered atom is the role played by non-radiative de-excitation processes. These processes are of the Auger and resonance type, and they can significantly alter the fraction of sputtered atoms which give rise to the emission of photons [5,6].

The second type of collision induced optical emission is radiation from backscattered or reflected beam particles [7-11]. Discrete atomic or ionic emission lines arising from backscattered particles are observed particularly in those cases where light projectiles (H, He) impact on heavy targets. The excited particles decay optically in vacuum after having experienced violent, momentum changing collisions on the surface or in the bulk of the solid. Nonradiative de-excitation processes of the Auger and resonance type can materially alter the fraction of backscattered particles which emerge from the solid in an excited state.

Two distinct kinds of broad band continuum radiation are produced by ion-solid collisions. The first of these is intrinsic continuum luminescence from the solid [12-15]. This broad band continuum emission originates in the bulk of the solid and results from the excitation of electrons in the solid or radiative recombination of electron-hole pairs. Electron excitation or electron-hole pair production results from the inelastic loss of projectile energy to the electrons in the solid. The intensities of luminescent continuum from the solid are quite sensitive to the velocity of the impinging projectile. At impact energies where elastic collisions with target nuclei is the dominant energy loss mechanism, the intensities are quite low. Similar broad band emissions are produced by other types of radiation such as electron and x-ray bombardment and comparison of the ion bombardment results to cathode luminescence and x-ray fluorescence results provide insight into the collision mechanisms responsible for producing these emissions.

The second type of broad band emission is the radiative continuum from sputtered molecular species. Certain ion bombarded transition metal targets give rise to a broad band continuum emission which is observed spatially to distances of a few millimeters in front of the target [16-18]. Evidence indicates that this radiation arises from neutral, excited molecular species, probably metal oxide molecules [18], ejected from the surface in the sputtering process. The lack of spectroscopic data from conventional sources has made the identification of the radiating molecular species difficult, but the fact that oxygen on the surface is necessary to excite these broad band emissions strongly suggests that these radiations arise from metal oxide molecules [18]. In addition, recent work shows that in rare gas ion bombardment of a variety of targets, the emission of continuum radiation in the vacuum ultraviolet spectral region arising from excited rare gas dimers is a common occurrence [19].

The fifth type of collision induced optical emission is radiation from excited molecules on the surface. Recent work indicates that radiation is observed from CN [20] and possibly other molecules bound to the surface. The vibrational bands are observed to be broad as compared to the free radical case, and the excitation is believed to be associated with exciton recombination at the surface.

It is the first mechanism, sputtering accompanied by simultaneous electronic excitation, which provides the basis for a simple and sensitive technique for surface and depth profile analysis. Surface constituents including surface contaminants are determined by identification and analysis of optical lines and bands that arise from particles sputtered as a result of the impact of a beam of low energy ions or neutral atoms on the surface. This technique [21-24] (called SCANIR--Surface Composition by Analysis of Neutral and Ion Impact Radiation and IBSCA--Ion Beam Spectrochemical Analyses) is a very sensitive probe of the surface region, since sputtered particles originate from the first few monolayers of the solid. In addition, measurements made as a function of bombardment time can be used to provide depth profile information if the sputtering rate for the solid under investigation is known or can be measured.

III. CHARACTERISTICS OF RADIATION FROM SPUTTERED ATOMS

Figure 1 shows examples of radiative spectra arising from the bombardment of Cu and Ni surfaces by Ar^+ (4 keV). The current density used for these measurements was $\sim 2 \times 10^{-6}$ amps/cm², and single photon counting techniques were used

for sensitive radiation detection. As indicated in Fig. 1, radiation is observed from low-lying excited states of neutral Cu, Ni and various contaminants (Na, CH). In addition, one also observes radiation from neutral H ($H\alpha$, $H\beta$), presumably arising from water vapor or hydrocarbon surface contaminants. Radiation from these excited particles allows identification of atoms and molecules sputtered from the surface and makes this attractive as a tool for surface composition analysis. At these low impact energies, only the low lying excited states of the neutral atoms are efficiently populated. This leads to a relatively simple spectrum uncomplicated by numerous lines from higher excited states or from intense lines arising from atoms in various stages of ionization. The narrow line spectrum illustrated in Fig. 1 arises because the atoms radiate in vacuum at distances from the surface where distortion of the atomic levels is negligible.

There is a marked dependence of the intensity of radiation from sputtered atoms which depends on the sputtered atom and the nature of the bombarded target. In general, it has been found that the intensity of radiation arising from atoms sputtered from metal targets is significantly lower than that observed from insulating targets and oxidized metal targets. In the case of metal targets, emission efficiencies (defined as the number of photons emitted in a single line per incoming ion) for typical prominent lines are measured to be in the range of 10^{-4} - 10^{-6} photons/incident ion. For insulators these same emission efficiencies are measured to be as large as 10^{-2} - 10^{-1} photons emitted/incident ion. In addition there is a large difference in the velocity distribution of radiating atoms as inferred from line profile measurements. Line profile measurements show that only the high velocity components of atoms sputtered from metal or semiconducting targets efficiently emit radiation,

but from insulators and oxidized metal targets the low velocity sputtered atoms also efficiently emit radiation [5,6]. This is illustrated in Fig. 2 which shows emission line profile measurements of the same optical line produced by the bombardment of silicon and SiO_2 . The emission line from SiO_2 is observed to be much narrower as compared to the silicon target. These measurements strongly suggest that in the case of the silicon target, the radiating silicon atoms are moving with significantly higher velocity, which leads to a Doppler broadened emission line. than in the case of the oxidized or insulating SiO_2 target where the radiation is emitted predominantly by low velocity sputtered atoms.

These two striking features, the line intensity and the velocity distribution of radiating atoms have to be discussed in terms of the excitation process and the subsequent interaction of the excited atoms with the surface. There is very little information about the excitation process, since atoms that are excited during a collision of a beam particle with a target atom usually travel some distance through and near the solid before emitting radiation. The electron configuration in the outer shells of these moving atoms undoubtedly are strongly modified during collisions with atoms and electrons in the solid. For the case of sputtered particles, it is not clear whether the primary excitation mechanism occurs due to the interaction of moving particles with target conduction electrons or whether electron excitation results from curve crossings of quasimolecular states formed in the collision complex (either target-projectile or target-target quasimolecules).

In some cases [25], the ion bombardment optical spectra has been found to resemble closely an arc discharge which would imply a plasma in local thermodynamic equilibrium with electron collisions being the dominant excitation mechanism. However in the case of alloys, recent results [26] show that the

emitting source is not in thermodynamic equilibrium because a single temperature is not sufficient to fit line intensities from different constituents. It has also been suggested [27] that, in the case of oxides, a bond breaking or dissociative excitation process involving oxygen containing molecules plays an important role in determining the state of excitation of the sputtered particle. According to this model adsorbed or chemisorbed oxygen is simultaneously ejected from the solid with a target atom in the form of a quasi-molecule. If sufficient energy is available in the collision complex, then curve crossing processes in the receding quasi-molecule can lead to the population of excited molecular states which then dissociate to yield excited or ionized sputtered particles.

Dissociative excitation undoubtedly plays a role in the case of ionic crystals such as the alkali halides. Many of these molecules exhibit continuous absorption in the vapor phase as a result of transitions from the bound ionic ground state to flat or repulsive excited states [28]. In addition, it has been shown for a number of these molecules that adsorption of ultraviolet light can lead to excited atoms by photo dissociation of the repulsive excited molecular state into excited atomic states [28]. For these ionic crystals, if molecules are sputtered from the solid in excited molecular states during the collision, they would dissociate into atomic species in both ground and excited states, and atomic radiation would be observed from the excited atoms. This may account for the fact that radiation from the halogen constituents of alkali-halide crystals is substantially weaker (by about three orders of magnitude) than from the alkali constituents. The excited atomic states of the alkali constituents can be populated through dissociation of low lying excited repulsive

molecular potentials. The radiative excited states of the halogens can only be populated through dissociation of very highly excited repulsive molecular states.

Apart from the excitation process, when sputtered excited particles recede from the surface into vacuum they can interact with the solid via non-radiative electron transfer processes of the Auger and resonance type. From the work of Hagstrum on potential secondary electron emission, it is clear that these electron transitions between slow particles and the surface occur with high probability when the atom-surface separation is a few Angstroms [29]. Figure 3 schematically illustrates these processes as they relate to excited sputtered particles. The transition rate $R(s)$ for these non-radiative processes as a function of atom-surface separation (s) has been approximated by [29]

$$R(s) = A \exp(-as) \quad (1)$$

where A and a are constants characterizing the non-radiative transition rate. From Eq. (1) it can be shown that the probability (P) that an excited sputtered particle can escape the surface without undergoing a non-radiative transition is [5]

$$P = \exp. - \left[\frac{A}{av_{\perp}} \right] \quad (2)$$

where $v_{\perp}$ is the velocity component of the sputtered atom normal to the surface. The quantity $\frac{A}{a}$ is sometimes called the survival parameter and is of the order $10^6 - 10^7$ cm/sec. for sputtered particles [2,5]. With this value for the survival probability Eq. (2) shows that low velocity sputtered particles, which are the great majority of all sputtered particles, will have little chance to escape from the surface and radiate. This then provides a plausible explanation

for the fact that from a metal surface the mean energy of radiating particles is significantly greater than the mean energy of all sputtered particles. This also naturally accounts for the fact that the emission efficiency for atoms sputtered from metal targets is relatively low since most particles are subjected to non-radiative de-excitation.

The same reasoning has been applied to the case of oxidized metal targets and insulators through the band structure model [5,6,35]. In the case of wide band gap insulators, in many cases it is energetically impossible for the non-radiative electron transfer process to occur due to the band gap. Under these conditions, one would also expect radiation from slow excited particles, which would account for enhanced emission intensity, and a narrow emission line width. Although this model successfully accounts for the enhanced emission intensity and reduced emission line width from oxidized metals and insulators, there is at least one experiment [30] which suggests that the enhanced emission intensity is directly related to the formation of substrate atom-oxygen bonds. When these substrate atom-oxygen quasi-molecules are sputtered, the final atomic states would then be populated by dissociative excitation at distances where the non-radiative de-excitation process would not operate [27]. This would also explain why targets such as Au which have a relatively high sputtering yield, have such a relatively low photon yield. These metals do not readily adsorb oxygen to form chemical bonds.

In summary, it is not clear at present whether the intensity changes of lines from sputtered atoms upon oxidation are related to a change in the overall band structure or whether the details of the metal-oxygen bond formation and bond breaking explain the observed enhancement effects. For the clean metal case, the non-radiative de-excitation model describes the velocity distributions (Doppler shapes) of emitting particles. The change in intensity

and velocity distribution when bombarding an oxide is also naturally explained by the reduced probability for the non-radiative de-excitation process, but evidently in the oxide case, details of the chemical bonds play a role. The combination of SIMS and beam induced light emission could be a powerful technique to identify and study the chemical effects.

IV. APPLICATIONS OF ION INDUCED OPTICAL RADIATION TO SURFACE AND DEPTH PROFILE ANALYSIS

Figure 4 shows examples of multielement elemental surface analysis for the case of two mineralogical samples, volcanic glass and a Tektite. These two radiative spectra were produced by N_2^+ (3.5 keV, $\sim 10^{-6}$ amps/cm² equivalent neutral current) bombardment. Prominent lines are identified by element and wavelength. Both samples have common oxide constituents of sodium, aluminum, calcium, and silicon. In addition the Tektite contains substantial quantities of Mg and Fe oxides as indicated by optical lines from these elements, whereas the volcanic glass has little or none. Neutral particle rather than ion bombardment was used on these insulating targets to avoid any problems with charge build-up or impurity migration [31].

Estimates of detection sensitivity and calibration of the ion induced optical emission technique can be accomplished by using samples containing impurities distributed homogeneously at known concentration in the bulk of the sample. For oxide impurities in silicate matrices, these detection limits vary from 1×10^{-5} (weight fraction of the oxide impurity) for Li to 1×10^{-3} for Ti [24]. Substantial improvement in these detection limits can be achieved by improving the photon collection efficiency.

The use of this technique for quantitative analysis of the composition of silicates has been reported by Tsong *et al.* [32]. The quantitative procedure involves comparison of intensities to standards of known composition. This

procedure also requires a measurement of the sputtering rate or the amount of material removed from the solid. A similar procedure has been used to determine the hydrogen concentration in a number of natural and synthetic quartz samples after a working curve was established using standard samples [33]. Unfortunately, this procedure cannot be directly applied to the case of metal targets due to the influence of oxygen and other adsorbed species on the emission intensity. A possible way to reduce these undesirable chemical effects may be to use oxygen as the bombarding projectile. This technique is routinely used in SIMS analysis to avoid similar undesirable effects.

Two other methods that can be used to estimate detection limits and serve to calibrate the ion induced optical emission technique are the use of ion implanted samples and the use of samples with a known concentration of impurity on the surface [34]. Figure 5 shows results obtained from an Al^+ (25 keV, $10^{15}/\text{cm}^2$) implanted SiO_2 film (1500 Å thick) on silicon. This sample was impacted by Ar^+ (8 keV, $\sim 3 \times 10^{-6}$ amps/ cm^2) and the intensity of prominent Al and Si optical lines was measured as a function of bombardment time in order to obtain the depth distribution of the implanted Al. The significant decrease in the intensity of the Si optical line occurs when the sputtering front reaches the SiO_2/Si interface region. The decrease in optical intensity is indicative of the difference in emission efficiency of an oxidized target and an elemental target. The measured time required to reach the SiO_2/Si interface provides an *in situ* method to determine the sputtering rate (~ 22 Å/min) if the film thickness is known. The aluminum depth distribution is determined from the sputtering rate and the measured aluminum optical intensity versus time. The dotted line in Fig. 2b is the Gaussian profile fit to a range of 353 Å and a standard deviation of 164 Å. The fit is

reasonable except in the tail of the distribution where the deviation is probably due to recoil implantation of aluminum by the argon beam. From the peak aluminum concentration (1% atomic) and the measured signal/noise ratio (200 : 1) we estimate a detection limit of $\sim 5 \times 10^{-5}$ (atomic fraction) for aluminum in an SiO_2 matrix, in good agreement with results obtained for aluminum impurities contained in bulk silicate samples [22]. Similar ion implant profiles measured by the optical emission technique have been reported for the case of Al in Ag and Na into Si [36].

Figure 6 shows results obtained using silicon wafers with a known (as measured by backscattering) concentration of Cr on the surface. These samples were prepared by purposely evaporating Cr onto clean silicon wafers. The intensity of the $\text{CrI-4254 } \text{\AA}$ optical line was measured from each sample during bombardment by Ar^+ (8 keV, $\sim 4 \times 10^{-6}$ amps/cm²). The integrated photon signals, which should be proportional to the number of Cr atoms removed from the surface, are in the ratio of 1 : 9.2 : 126. This result is in reasonable agreement with concentration ratios as measured by 2 MeV backscattering 1 : 10.6 : 113, and confirms the linearity of the optical technique at these levels of surface contamination.

The ion induced optical emission technique can also be used to determine elemental impurities on very complex organic substrates. Figure 7 shows results obtained from substrates of interest to printed circuit technology. These results were obtained from epoxy coated printed circuit hardboards being prepared by the additive technology where a Pd-Sn activating bath is used to catalyze electroless copper deposition. The results of Fig. 7 were obtained from the epoxy surface of a hardboard just prior to immersion in the Pd-Sn

activating bath. This board had been swell etched in a chrome-sulphuric acid bath, washed in deionized water and subsequently rinsed in HCl and then deionized water. The epoxy substrate was then impacted by Ar^+ (5 keV, $\sim 10^6$ amps/cm²), and as indicated in Fig. 7, intense lines arising from chromium and calcium are observed in the wavelength range 4200 - 4350 Å, as well as an intense band of radiation which arises from an excited state of the CH molecule. Chromium is present on the surface as an impurity transferred from the chrome-sulphuric acid treatment; the origin of calcium is unknown, and the intense molecular band arises from sputtered hydrocarbon molecular fragments. This band of radiation is the single most intense radiative feature seen from any organic species, and it can be used to demonstrate specifically that one has organic impurities on elemental surfaces. Also shown in Fig. 7 are depth profiles for Cr and Fe from this board. These profiles were determined by measuring the intensity of Cr and Fe optical lines as a function of bombardment time. For this substrate, the sputtering rate has not been measured, but we believe a sputtering rate of $\sim 5 - 10$ Å/min is a reasonable estimate. These profiles show that chromium is confined primarily to the near surface region, and subsequent quantitative measurements showed the Cr concentration to be $\sim 10^{15}$ /cm². In addition, the Fe profile shows a deficiency at the surface. The bulk epoxy contains $\sim 4\%$ (by weight) of FeO, and subsequent measurements showed that Fe was leached from the surface by the HCl treatment to produce the surface deficiency of iron.

One other example of results of interest to printed circuit technology is shown in Fig. 8. These results were obtained from components used in the fabrication of flexible circuits by the subtractive process. These circuits are fabricated from a copper clad, fiber reinforced epoxy substrate,

and circuits fabricated from this laminate had been found to have a very low surface insulation resistance. When the etched epoxy surface of one of these circuits was impacted by Ar^0 (8 keV, 3×10^{-6} amps/cm² equivalent neutral current) intense optical lines arising from sputtered chromium were observed as shown in Fig. 8. The presence of substantial chromium in the surface region of this circuit was totally unexpected because chromium is not a constituent of the epoxy, nor is it a part of the processing chemistry. However, results obtained from the surface of the copper foil used on the laminate showed a chromium rich surface region. The profile of chromium in the surface region of the copper foil is also shown in Fig. 8. Since bombardment time is related to depth (we estimate $\sim 10 \text{ \AA/min}$) these measurements show that chromium is localized to the first few monolayers of the foil. Subsequent quantitative chromium analysis by atomic absorption showed the chromium contamination to be $\sim 2 \times 10^{-7}$ grams Cr/cm². The presence of this chromium rich surface region was traced to a chromate stain proofing treatment applied to the foil by the manufacturer to prevent the oxidation of the copper foil. When the laminate was etched, the chromate stain proofing layer was not removed by the ammonium persulfate etch, and the presence of this chromium rich surface layer on the epoxy surface was shown to degrade the electrical resistance measured between adjacent circuit lines. Removal of this surface layer resulted in two orders of magnitude improvement in the insulation resistance.

The results shown in Figs. 7 and 8 illustrate application of the optical emission technique to practical problems involved with very complex surfaces. These results demonstrate elemental surface and depth profile analysis on surfaces which are difficult to examine by other surface sensitive techniques such as Auger, ESCA, backscattering, and SIMS. Charging of the surface makes

Auger, ESCA and low energy ion scattering difficult. The ejection of sputtered molecular ion fragments from the epoxy substrate complicates SIMS analysis. The presence of elements with nearly equal mass numbers on the surface and in the bulk complicates low and high energy backscattering. The ion or neutral particle induced optical emission technique provides a very simple and sensitive method for qualitative analysis of these very complex surfaces of technological interest.

SUMMARY:

The optical emission produced when low energy particles impact on a solid is a unique method to study fundamental low-energy particle-solid collision processes. Radiation arising from various mechanisms shows that the participants in the collision process including sputtered particles, reflected particles, the solid itself, and species excited on the surface can be left in excited states as a result of the collision. Since a significant portion of these excited states decay by the emission of radiation, much can be learned about the detailed processes of the collision as well as about the interaction of excited particles with the solid and the nature of the coupling between the surface and excited states of nearby particles. Future optical emission experiments can be expected to provide more detailed information on the various excitation mechanisms, the atomic processes which influence the ejection of positive ions, negative ions, and excited neutral species, and about fundamental sputtering mechanisms. These experiments should contribute greatly to our basic understanding of inelastic low-energy ion-solid collision phenomena.

In addition to providing fundamental insight, the radiation from sputtered species provides a sensitive and simple technique for elemental surface composition analysis. Detection sensitivities are a function of the species and the chemical environment, but in favorable cases they can be

as high as one part in 10^5 , and substantial improvement can be obtained by improving the photon collection efficiency. The advantages of this technique include: (1) multielement detection capability, including hydrogen; (2) the possibility for surface analysis and depth profiling; (3) relatively few cases of interference; (4) high sensitivity. The major limitations of this technique include: (1) calibration for depth and concentration is required; (2) the influence of oxygen and other adsorbed species on the emission intensity from metal targets. Further systematic experimentation is necessary in order to provide a more satisfactory understanding of the chemical effects, but the optical emission phenomena should find wide application as a technique to aid in the solution of production, development and research problems involving the elemental composition of surfaces, interfaces, and the bulk of materials.

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FIGURE CAPTIONS

- Fig. 1 Spectra of radiation produced by Ar^+ (4 keV) on Cu and Ni surfaces (from Ref. 12).
- Fig. 2 Emission line profile measurements of $\text{SiI} - 2882 \text{ \AA}$ from SiO_2 and silicon. Line profile measurements were made in second order with an instrumental resolution of $\sim 1 \text{ \AA}$ (from Ref. 6).
- Fig. 3 Schematic representation of the metal-excited atom energy level system. Two possible non-radiative de-excitation processes, Auger de-excitation and resonance ionization are indicated.
- Fig. 4 Spectrum of radiation produced by N_2^+ (3.5 keV) on volcanic glass and tektite (from Ref. 21).
- Fig. 5 Profile results for Al^+ (25 keV, $10^{15}/\text{cm}^2$) implanted SiO_2 (1500 $\text{\AA}$ thick) on silicon.
- Fig. 6 Chromium impurities on silicon. The optical intensity of $\text{CrI} - 4254 \text{ \AA}$ is plotted as a function of bombardment time for three different levels of chromium contamination.
- Fig. 7 Surface impurities and depth profiling of printed circuit boards. The left hand side shows a portion of the spectral distribution of radiation from the epoxy surface. The depth distribution for Cr and Fe in the near surface region is shown on the right hand side.
- Fig. 8 Surface analysis of dielectric surface and copper foil. The left hand side shows a portion of the spectral distribution of radiation from the etched dielectric surface. The depth profile of Cr in the near surface region of the copper foil is shown on the right hand side.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

PROFILE OF Al^+ (25keV, $10^{15}/\text{cm}^2$) IN SiO_2 (1500 Å)

Fig. 5

DETECTION OF CHROMIUM ON SILICON

Fig. 6

FLEXIBLE CIRCUIT

COPPER FOIL

Fig. 8