



Characterization of aluminum deposition on a germanium (100) substrate
by Alan Carl Pfersch

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in
Physics

Montana State University

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Abstract:

The advent of transistors and micro-electronics has generated a great interest in thin films and the study of interfaces between different compounds. For this reason, it is necessary to develop techniques that will allow for controlled deposition of elements on substrate surfaces. The method studied within this thesis concerns a device which evaporates aluminum and directs it towards, in this case, a germanium (100) surface. The purpose of using germanium as a substrate was to study the interface between germanium and aluminum for a separate project testing bacterial corrosion of aluminum. Potential alloying at the interface could cause corrosion rates to deviate from that of pure aluminum. First, an aluminum evaporator was built with small modifications from an existing design. After construction, characteristics about the rates of deposition as a function of current, the uniformity of coverage, and the constancy of deposition needed to be determined. Finally, a study of the aluminum-germanium interface as a function of temperature was conducted using Rutherford Backscattering Spectrometry. It was found that the deposition rate of the evaporator increased with current and then reached a plateau of approximately 10 monolayers per minute. Deposition over time was found to be constant within experimental error while the distribution across the surface was non-uniform and gaussian in nature. The growth of the aluminum on the germanium surface exhibited either mixing with the germanium or island growth before layer by layer growth dominated. The interface between the germanium and aluminum showed no signs of intermixing beyond 40 Angstroms until the sample was heated at which point the germanium began to distribute uniformly throughout the aluminum film. From this information one can conclude that the only real problem in deposition from this evaporator is the thickness distribution across the sample. This can be adjusted for by placing the sample further away from the evaporator. As to the interface between the germanium and aluminum, mixing is not a severe problem unless the sample is subjected to temperatures above 300°C.

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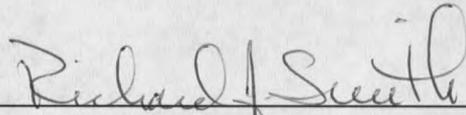
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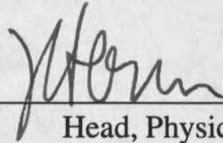


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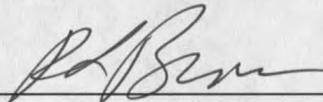


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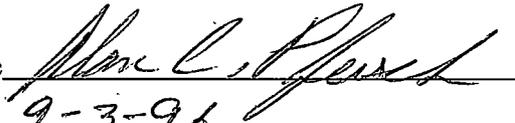
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ABSTRACT

The advent of transistors and micro-electronics has generated a great interest in thin films and the study of interfaces between different compounds. For this reason, it is necessary to develop techniques that will allow for controlled deposition of elements on substrate surfaces. The method studied within this thesis concerns a device which evaporates aluminum and directs it towards, in this case, a germanium (100) surface. The purpose of using germanium as a substrate was to study the interface between germanium and aluminum for a separate project testing bacterial corrosion of aluminum. Potential alloying at the interface could cause corrosion rates to deviate from that of pure aluminum. First, an aluminum evaporator was built with small modifications from an existing design. After construction, characteristics about the rates of deposition as a function of current, the uniformity of coverage, and the constancy of deposition needed to be determined. Finally, a study of the aluminum-germanium interface as a function of temperature was conducted using Rutherford Backscattering Spectrometry. It was found that the deposition rate of the evaporator increased with current and then reached a plateau of approximately 10 monolayers per minute. Deposition over time was found to be constant within experimental error while the distribution across the surface was non-uniform and gaussian in nature. The growth of the aluminum on the germanium surface exhibited either mixing with the germanium or island growth before layer by layer growth dominated. The interface between the germanium and aluminum showed no signs of intermixing beyond 40 Angstroms until the sample was heated at which point the germanium began to distribute uniformly throughout the aluminum film. From this information one can conclude that the only real problem in deposition from this evaporator is the thickness distribution across the sample. This can be adjusted for by placing the sample further away from the evaporator. As to the interface between the germanium and aluminum, mixing is not a severe problem unless the sample is subjected to temperatures above 300°C.

CHAPTER 1

INTRODUCTION

Perhaps the greatest achievement of mankind has been the creation of the transistor and other associated micro-electronics. Our lives have become intermingled with these devices, allowing the invention of machines that would otherwise exist only in the minds of science fiction writers. For this reason, the study of thin films and the interaction of these films with the material they are deposited onto has become important. Thin films of aluminum have become extremely important since it is one of the main components used in the production of micro-electronics. Aluminum is used along with a semiconductor material, such as germanium, to form an alloy that produces what is referred to as a p-n junction. This p-n junction allows current to flow with negligible resistance in one direction and with a large resistance in the other. From this property transistors and electrically controlled micro switches can be constructed. Thin layers of aluminum also act as wires within these electrical devices. This is performed by depositing a thin film of aluminum on the surface and etching it away in a pattern that will produce the desired circuit. From the above discussion one can readily see the advantages of having a device that will deposit a controlled thickness thin film without impurities.

A particular interest in this paper is to study the interface of the aluminum thin film and germanium surface. Experiments are underway to study the bacterial corrosion of aluminum. One means of doing this uses Fourier Transform Infrared Spectroscopy

(FTIR); an internal reflection element can be coated with aluminum and exposed to bacteria. Since the intensity of infrared light transmitted depends on film thickness, the amplitude of the water absorption peak near 1640 cm^{-1} will increase as bacteria corrode through the aluminum. There was a question, however, about potentially changing the rate of bacteria corrosion due to intermixing or alloying at the interface. Another consideration would involve deviations from calculated laser intensity loss for an assumed thickness of aluminum. The use of surface sensitive analytical techniques and the ability to create controlled thickness films of aluminum allow questions of this nature to be answered.

The experiments discussed within this thesis focused on the characterization of an evaporator that was specifically constructed to produce clean ultrathin films of aluminum. Of particular interest will be the rate of deposition, the variance of deposition rates over long term evaporation, and uniformity of thickness on the germanium sample. The determination of deposition rates will also involve a study on how the aluminum grows on the surface of the germanium. Finally, Rutherford Backscattering Spectroscopy will be employed to find out if mixing is occurring at the aluminum-germanium interface.

CHAPTER 2

EXPERIMENTAL TECHNIQUES

Auger Electron Spectroscopy

Auger electron spectroscopy or AES was the main technique used in this experiment. Many other techniques can yield information about the internal structure and composition of a sample but AES has the ability to study very thin films and surfaces. One of the more subtle abilities of AES is to determine the deposition rate of a particular element on the surface of a sample. This also leads to a determination of the manner in which the growth occurs.

The technique of AES involves ionizing atoms within the sample and then measuring the energy of electrons emitted during the relaxation of the ion. In this experiment the spectrometer utilized an electron gun to ionize the atoms in the sample. This gun can supply electron energies from 100eV to 10keV and produce a beam spot size that is less than 5 microns in diameter¹. These electrons then enter the sample and remove an inner shell electron from the atom thus creating an ion. An electron from an outer shell then fills the 'hole' in the inner shell. One of two things can then happen, the atom radiates a photon or energy is transferred to another electron that carries away the excess energy in the form of kinetic energy. The amount of kinetic energy, E_{kin} , that is transferred to the electron is defined by;

$$E_{kin} = E_S - E_X - E'_Y \quad (2.1)$$

where E_S and E_X are the energies of the inner and outer shell respectively. E'_Y is the ionization potential of the electron in shell Y that is being ejected taking into consideration the state of the excited ion. Figure 2.1 gives a schematic outline for a KL_1L_2 Auger process. Depending upon the atomic number of the atoms, the emitted 'Auger' electron can have an energy that ranges from 10 to 2000 eV. Some of these electrons will then leave the sample and can be measured².

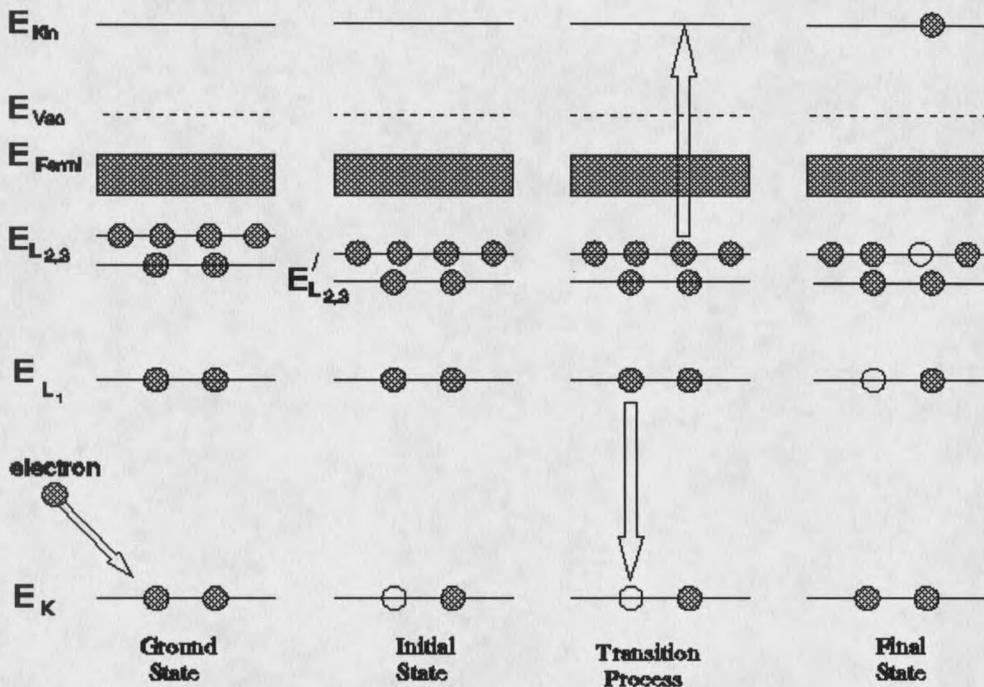


Figure 2.1 : Auger transition process.

Since the Auger electrons are ejected from atoms within a solid as well as on the surface, the energy of electrons leaving the sample will vary. The energy loss of an electron as it travels through a solid is characterized by the mean free path. This distance is defined as the amount of material through which an electron can move before the probability of an inelastic collision becomes $1/e$. The greatest energy loss of an electron in a solid is attributed to plasmons. Plasmons are oscillations of the valence electrons with respect to the positively charged nuclei. The frequency of the oscillation, ω_p , leads to a plasma energy as defined by $E_p = \hbar\omega_p$. Energy losses for the electrons leaving the sample occur in discrete jumps of $\hbar\omega_p$ with values on the order of 10 eV. The value of the mean free path is dependent upon the electron's initial energy, E_0 , and the plasma energy, E_p , of the material. The equation to determine the mean free path, λ , is³;

$$\lambda^{-1} = \frac{m_e e^2 E_p}{8\pi\epsilon_0 \hbar^2 E_0} \ln\left(\frac{4E_0}{E_p}\right) \quad (2.2a)$$

This equation stems from theory and is a close match to experimental data but is not entirely accurate. An empirical equation has been formed which fits experimental results more closely⁴;

$$\lambda(\text{\AA}) = 1430E^{-2} + 0.54E^{1/2} \quad (2.2b)$$

where values for E are in eV. The mean free path of an electron in a solid is generally less than 20 Angstroms. This means that the most energetic of Auger electrons are not likely to be detected if they originated below 50 Angstroms from the surface of the material. This is what makes AES such a surface sensitive technique³.

The device used to detect the kinetic energy of the ejected electrons is called the cylindrical mirror analyzer or CMA for short. A diagram of the CMA is shown in Figure 2. The CMA is made up of two concentric cylindrical electrodes, an electron multiplier, and a magnetic shield¹. The Auger electrons enter through apertures near the front of the inner cylinder and head for the outer cylinder. A negative bias on the outer cylinder, sometimes referred to as the mirror, causes the electrons to arc back towards the apertures at the back end of the cylinder. The electrons then enter a small aperture and are guided to an electron multiplier that will amplify the electron current to produce a signal that is detectable. By adjusting the bias on the outer cylinder the entire energy range of the Auger electrons can be sampled and a spectrum obtained.

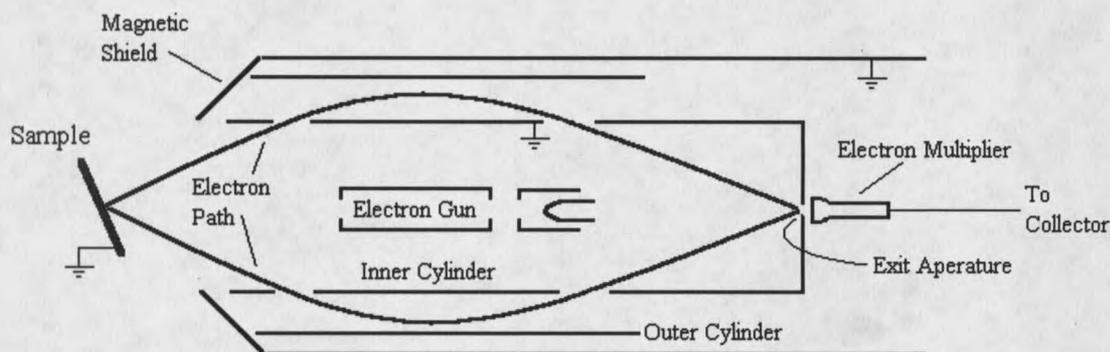


Figure 2.2 : Schematic of CMA

After data from AES has been collected and plotted, the data must be manipulated into a form that can be used to determine relative concentrations of elements and thickness of films. Figure 2.3 shows a sample plot of an AES spectrum along with a plot that has been differentiated with respect to energy. Differentiation of the AES data was initially adopted because the noise in the raw data made interpretation difficult but it is now a

standard in AES evaluation. The first step in evaluating the spectrum involves determining the energy at which the peak occurs and then matching this with known standards. In this way the element or compound associated with that energy can be found. The peak-to-peak amplitudes are then measured and the relative ratios of elements on the sample can be determined. Since the peaks occur at the energy of the Auger electron, this is extremely surface sensitive. Electrons that travel through the sample have their energy attenuated and are lost from the main peak. The cross section of each particular element is different and for this reason the peak-to-peak amplitudes have to be normalized before they can be compared. One method of performing this normalization

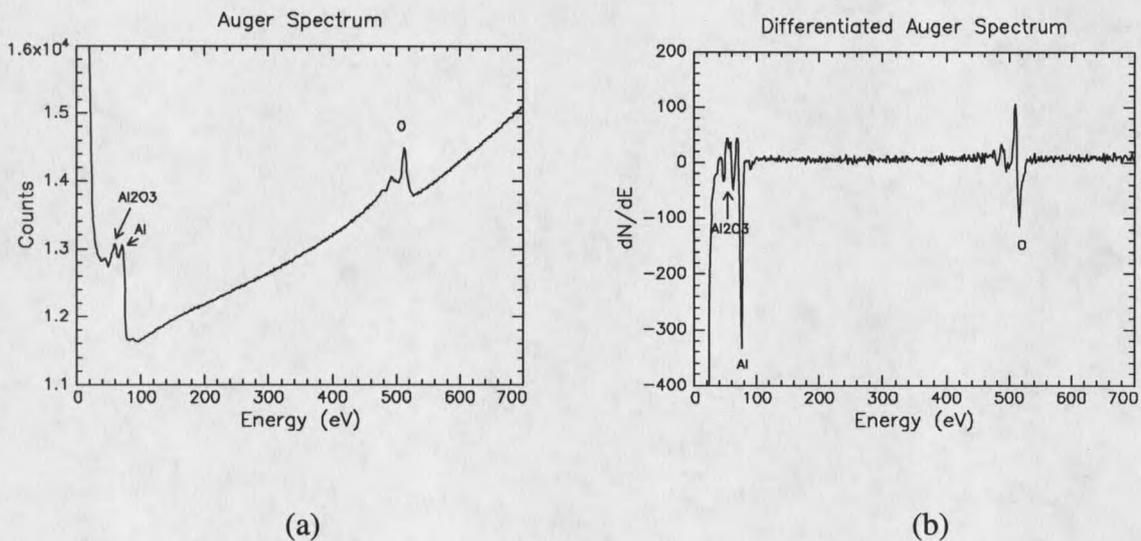


Figure 2.3 : Sample Auger Spectra; (a) shows a plot of the raw data and (b) shows a plot of the data after it has been differentiated. In both plots the oxygen, aluminum, and aluminum oxide peaks have been labeled.

