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THIN FILM REACTIONS ON ALLOY SEMICONDUCTOR SUBSTRATES

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ABSTRACT

The interactions between Pt thin films and $In_{.53}Ga_{.47}As$ have been studied. An important result is that the reaction kinetics deviate from those of other metal/compound semiconductor reactions. The kinetics can be divided into two stages, where the reaction slows by a factor of 5 after ~60 minutes of annealing at 400 °C. In addition, Auger depth-profiling indicates that an In-rich layer develops at the reacted layer/substrate interface.

INTRODUCTION

The electrical characteristics of metal contacts to semiconductors are critical for proper device operation. These characteristics and their stability are generally dependent on the phases and the morphology of the interface [1-6]. If the metal reacts with the substrate, the electrical characteristics of the device may be affected. Reaction with the metal layer can lead to formation of defects in the substrate, or the formation of new phases with undesirable electrical properties [1-3].

The reaction may continue during operation of a device until either the metal or active parts of the semiconductor are completely consumed. However, a controlled reaction may actually improve the stability or electrical properties of the system. Growth of an intermediate product layer which inhibits diffusion between the metal contact and the semiconductor substrate would increase the lifetime of a device.

The reactions between thin films of Pt on $In_xGa_{1-x}As$ have been the focus of this study. In this system, many product phases are possible which may be useful in inhibiting subsequent reactions. In Pt/GaAs reactions, a layered structure develops, with a heavily textured $PtAs_2$ product phase growing at the substrate/reaction product interface. $PtAs_2$ is cubic, with a lattice parameter slightly larger than that of GaAs. The lattice parameter of $In_{.53}Ga_{.47}As$ is within 2% of that of $PtAs_2$, so it may be possible to induce the formation of a high-quality $PtAs_2$ layer which inhibits further reactions.

EXPERIMENT

(100) $In_{.53}Ga_{.47}As$ (grown on InP by MBE) and GaAs substrates were degreased, etched in H_2SO_4:H_2O_2:H_2O (5:1:1), rinsed in deionized H_2O, and blown dry in N_2. 70nm of Pt were deposited on the substrates by plasma-enhanced sputtering, using a Perkin-Elmer Model 2400 radio-frequency plasma generator. The samples were encapsulated with SiO_2 prior to annealing to inhibit decomposition of the substrate. The specimens were heat treated in an Ar:H_2 (95:5) atmosphere using various annealing schedules.

ranging from 350 ° C to 600 ° C, and from 10 to 180 minutes.

The specimens were examined by a combination of X-Ray Diffraction (XRD) using a Siemens Kristalloflex Diffractometer (Cu Kα), Rutherford Backscattering Spectrometry (RBS) using a 1.95MeV $^4He^+$ beam, and Auger depth profiling, using a Perkin-Elmer Phi 660 Scanning Auger Microprobe.

RESULTS

Rutherford Backscattering spectra were taken of samples annealed for various times, t, at 400 ° C. Using these spectra, the thickness, x, of the substrate that reacted during each anneal was measured. Diffusion limited reactions have been observed for the Pt/GaAs case, where $x^2 \sim t$. A plot of x^2 vs. t for the Pt/$In_{.53}Ga_{.47}As$ reactions at 400 ° C is shown in Figure 1, overlayed with results for Pt/GaAs reactions at 400 ° C also obtained in this study.

Auger depth profiles were taken of these samples to determine the distribution of elements in the reacted microstructure. In Figure 2.1 and 2, the profiles for as-deposited and fully reacted specimens are shown. The protrusion of the Pt signal into the substrate in Figure 2.1 is probably a sputtering artifact, as it was not observed in this specimen by RBS. The Auger spectrum in Figure 2.2 is consistent with some vertical separation of the product phases. Of special note is the significant increase of the In signal immediately above the substrate.

In Figure 3, the x-ray diffraction spectrum for a fully-reacted specimen, annealed at 500 ° C for 120 minutes is shown, with the peaks correlated with their phases. The anneals for all the anneals between 350 ° C and 600 ° C show the same phases present. The only significant variation between the spectra at different temperatures is in the small shift of some of the peaks, such as those near 2Θ of 28 ° , 40 ° , and 58 ° .

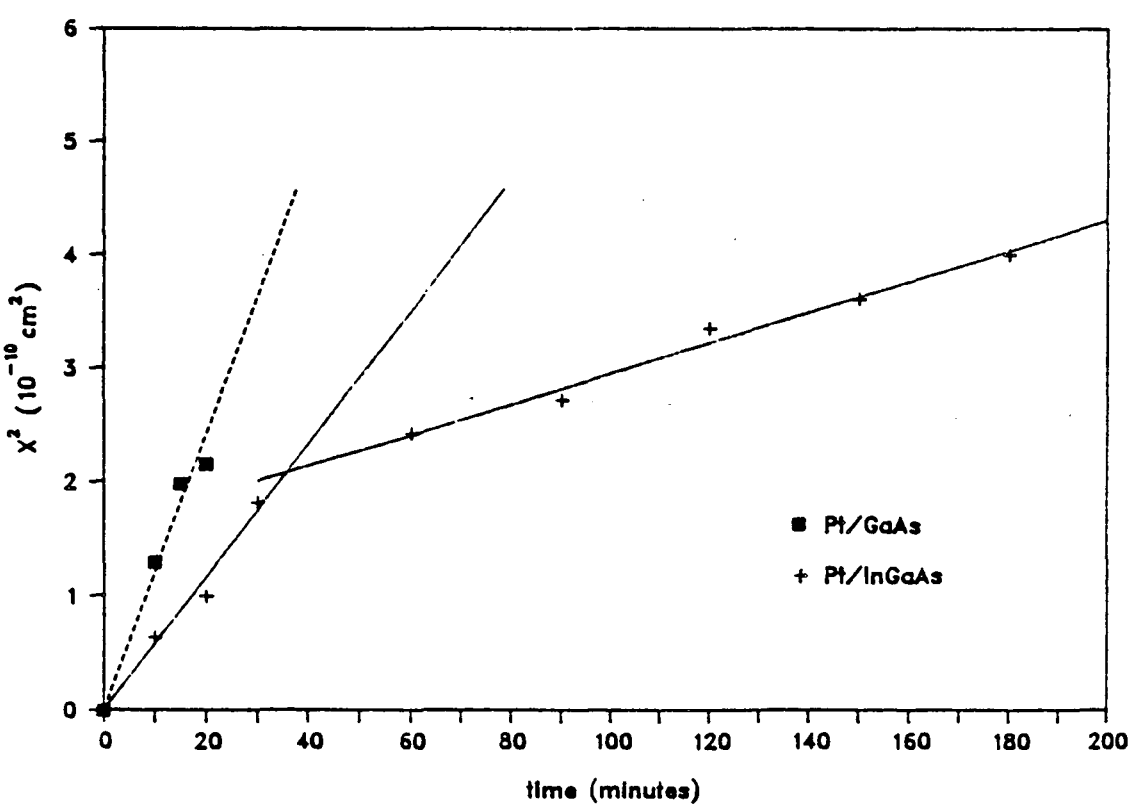

Figure 1: Plot of x^2 vs. annealing time, where x is the amount of substrate reacted.

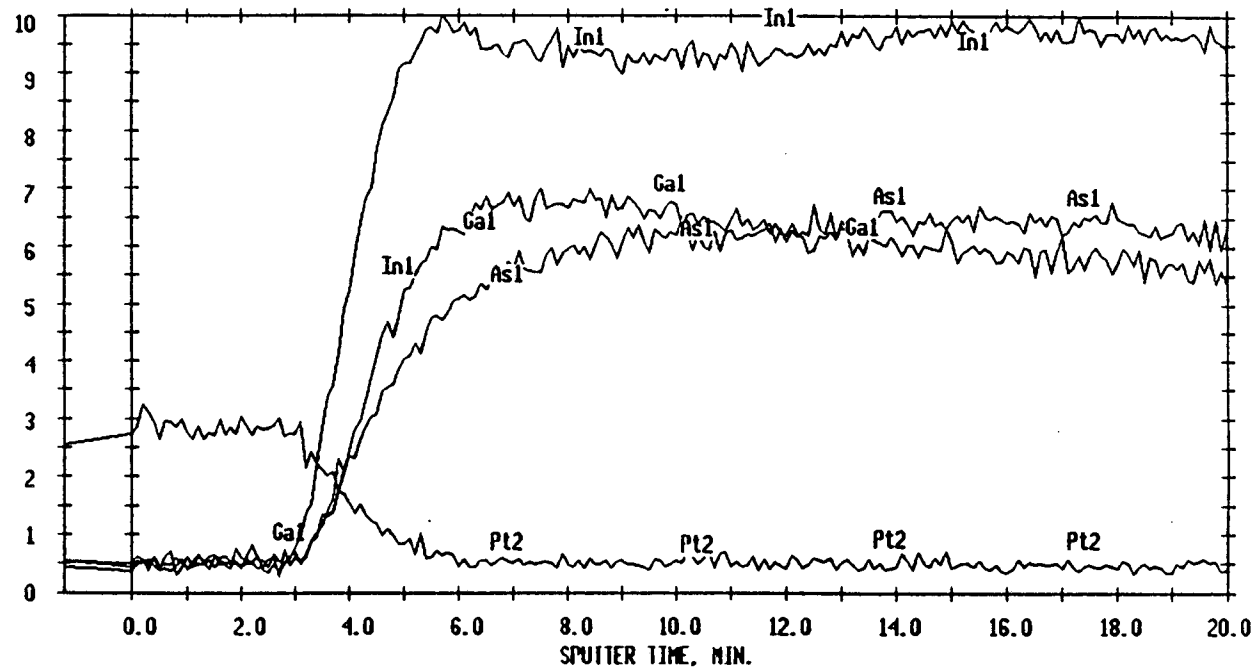

Figure 2.1: Depth profile of Auger energies for a $Pt/In_{.53}Ga_{.47}As$ specimen, as-deposited. Vertical scale arbitrary units.

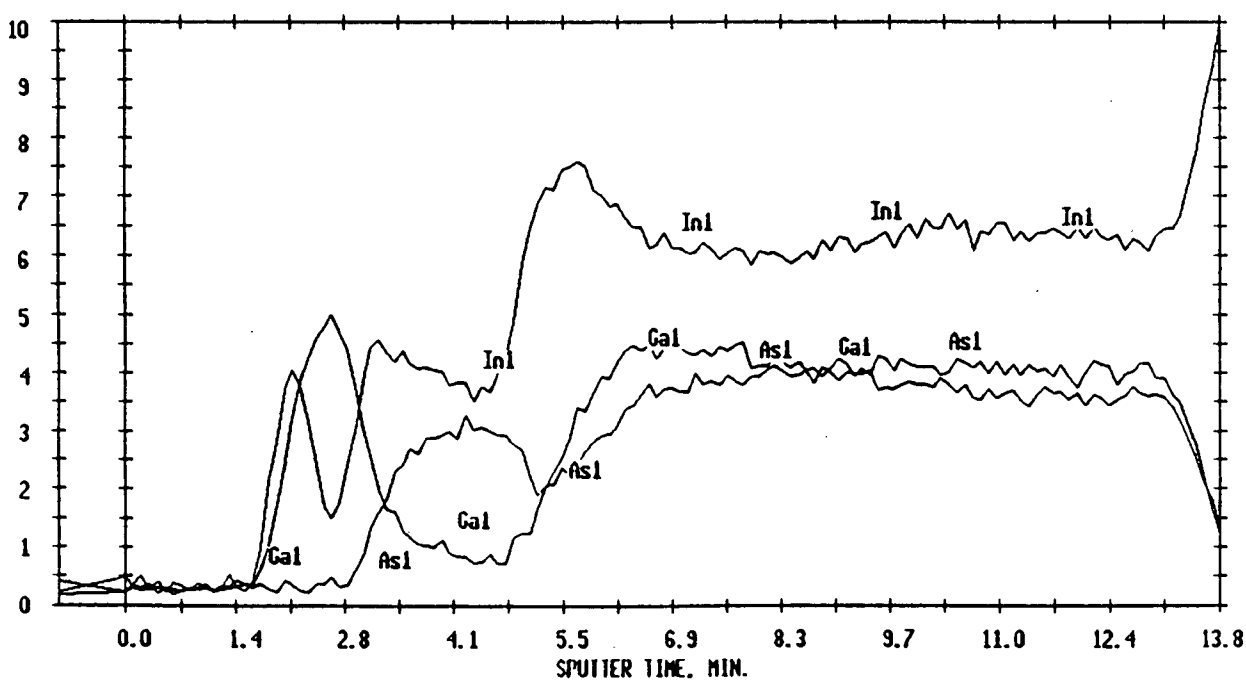

Figure 2.2: Depth profile of Auger energies for a $Pt/In_{.53}Ga_{.47}As$ specimen annealed at 500 ° C for 30 minutes. Vertical scale arbitrary units.

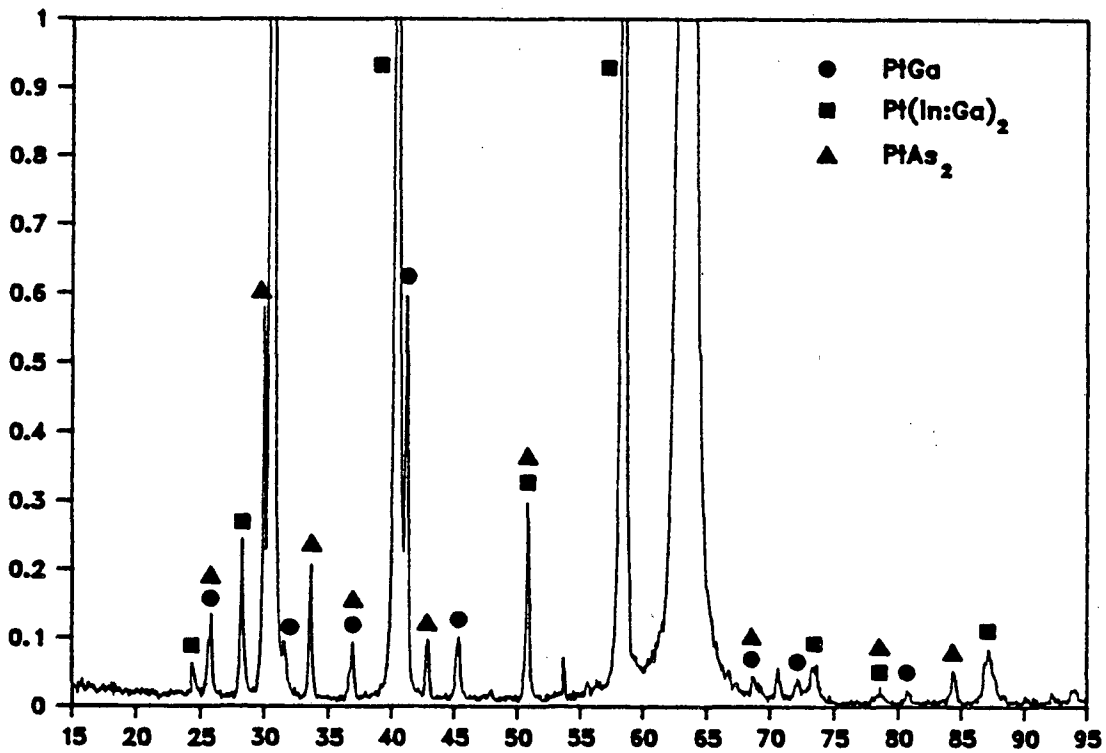

Figure 3: Indexed XRD spectrum for a fully reacted $Pt/In_{.53}Ga_{.47}As$ specimen, 500 ° C:30 minute anneal.

DISCUSSION

Kinetics

For many metal/compound semiconductor interactions, the reaction rate is diffusion limited, i.e. exhibits a parabolic dependence on time. This study shows that the early stages of the $Pt/In_{.53}Ga_{.47}As$ reaction progress at a rate similar to that of Pt/GaAs. For longer annealing times, the reaction slows dramatically, to a rate ~one order of magnitude slower than for Pt/GaAs. This reduction in reaction rate should prove useful in developing more stable contacts to compound semiconductors in this system by inhibiting contact/substrate reactions.

Substrate Composition

An additional result of this study was the development of an In-rich layer beneath the reacted layer. The Auger depth profile showed a substantial increase of the In signal in the sample at this layer, as compared to the as-deposited case. This increase in the In composition is not unexpected, based on previous studies of Pt/GaAs [7, 8, 9] and Pt/InP [10], which suggest that Ga diffuses more easily than In through the reacted layer. An increase in the In concentration of the substrate below the metallization is a significant result for the production of ohmic contacts, as the Schottky barrier height of $In_xGa_{1-x}As$ decreases for increasing In concentrations [11].

Phase Formation

Results show that $Pt/In_{.53}Ga_{.47}As$ reacts to form the reaction products encountered in the Pt/GaAs reaction: PtGa, Pt_3Ga, and $PtAs_2$. In addition, a ternary phase, $Pt(In{:}Ga)_2$, develops, which is a solid solution between the cubic fluorite phases $PtIn_2$ and $PtGa_2$. The amount of Ga in the ternary phase increases with annealing temperature, which causes a decrease in the lattice parameter of the phase. This change in the lattice parameter of $Pt(In{:}Ga)_2$ causes the shift in the peak positions observed in the x-ray diffraction spectra. The lattice parameter of $Pt(In{:}Ga)_2$ can be determined from the shift, and is plotted in Figure 4 as a function of annealing temperature.

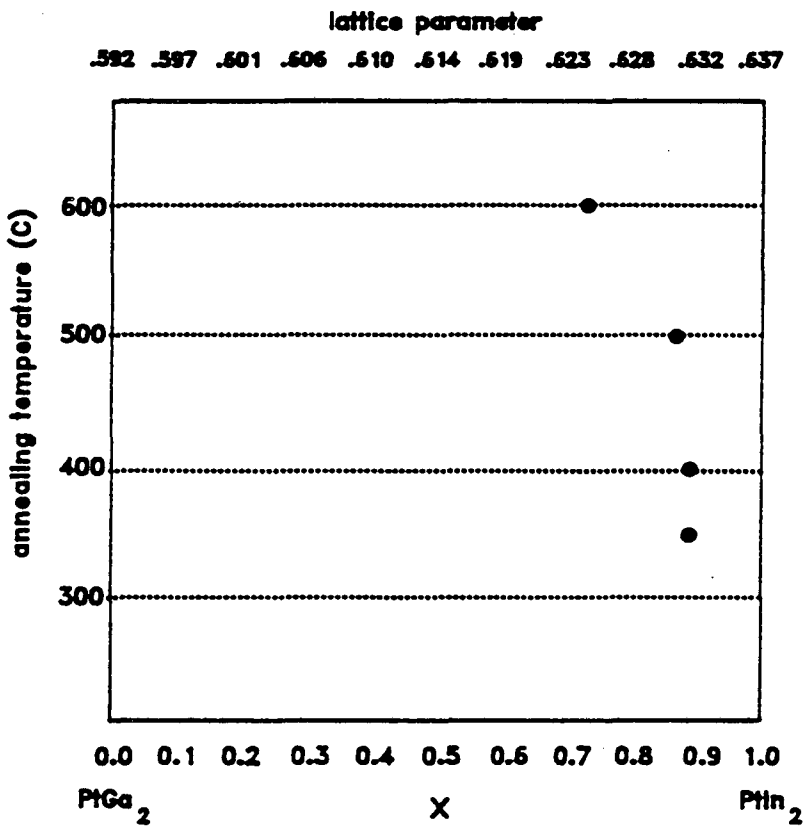

Figure 4: Variation in the lattice parameter and composition of $PtIn_{2x}Ga_{2-2x}$ with annealing temperature.

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