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Structural properties of Pt/*p*-InP heterostructures

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Ion-beam-assisted deposition of Pt on *p*-InP at room temperature was performed in order to produce Pt epitaxial films with high quality and Pt/*p*-InP (100) heterostructures with sharp interfaces. From the x-ray diffraction analysis, the grown film was found to be a Pt heteroepitaxial film. Auger electron spectroscopy measurements showed that the composition of the as-grown film was Pt and that the interface quality between the Pt and the InP was relatively good. Transmission electron microscopy showed that the grown Pt was an epitaxial film. These results indicate that the Pt epitaxial films grown on *p*-InP (100) can be used for both stable contacts in optoelectronic devices and Pt/InP metal-semiconductor-field-effect transistors and that the Pt/InP heterostructures can give good motivation for the fabrication of Pt/InP superlattices. © *1996 American Institute of Physics.* [S0003-6951(96)02333-9]

Recently, InP compound semiconductors have been of particular interest due to their applications in optoelectronic and high-speed electronic devices.[1–5] Stable contacts with low contact resistances are very essential for fabrication of these devices.[6] In addition the structural properties and the interfacial stages in the metal/InP heterostructures are very important for the contacts, the thermal and electrical stability of the contacts, and interface problems.[7] Among many metals for Ohmic contacts to InP, Pt is a very attractive metal because of its low resistivity, high thermal stability, and high catalytic activity.[8,9] Even though some work has been performed on the reaction problem between Pt and InP interfaces,[10] to the best of our knowledge, the growth of Pt epitaxial films on InP (100) substrates has not yet been demonstrated due to interfacial problems and the lattice mismatch between the Pt and the InP. For these reasons, we choose to investigate room-temperature deposition of Pt on InP substrates as a means of looking for physical evidence for a Pt/InP heterostructure with a high-quality interface.

This letter reports the structural properties of Pt epitaxial films deposited on *p*-InP (100) substrates by ion-beam deposition (IBD) at room temperature. X-ray diffraction (XRD) measurements were carried out to demonstrate clearly the achievement of heteroepitaxy in the Pt film. Scanning electron microscopy (SEM) measurements were performed to investigate the Pt surface morphology, and Auger electron microscopy (AES) was carried out in order to characterize the stoichiometry of the grown films. Transmission electron microscopy (TEM) was performed to investigate the atomic structure of the Pt/*p*-InP.

The carrier concentration of the Zn-doped *p*-InP substrates with a (100) orientation used in this experiment was 1×10^{16} cm^{-3}. The InP substrates obtained from Sumitomo were alternately degreased in warm acetone and trichloro--ethylene (TCE) three times, etched in Br-methanol solution mechanochemically, rinsed in deionized water thoroughly, etched in a mixture of H_2SO_4, H_2O_2, and H_2O (4:1:1) at 40 °C for 10 min, and rinsed in TCE again. After the wafers were cleaned chemically, they were mounted onto a susceptor in a deposition chamber. After the IBD chamber was evacuated to 1×10^{-6} Torr, the deposition was done at a substrate temperature of 300 K (room temperature). In this case, a focused Ar^+ beam was used to sputter a Pt-metal target. The deposition was done at a system pressure of 2×10^{-4} Torr, and the typical deposition rate was ~1.5 Å/s. The bombarding ion energy and the ion beam current were 1500 eV and 60 mA, respectively. The XRD measurements were performed using a Riguku D/Max-B diffractometer with Cu Kα radiation. The AES measurements were performed on as-grown films using a Perkin-Elmer phi 400 scanning Auger microprobe. The TEM observations were performed in a JEOL 200CX transmission electron microscope operating at 400 kV. The samples for the TEM measurements were prepared by cutting and polishing to an ~30 μm thickness using diamond paper, and then argon-ion milling at liquid-nitrogen temperature to electron transparency.

The as-grown Pt films prepared by IBD had mirrorlike

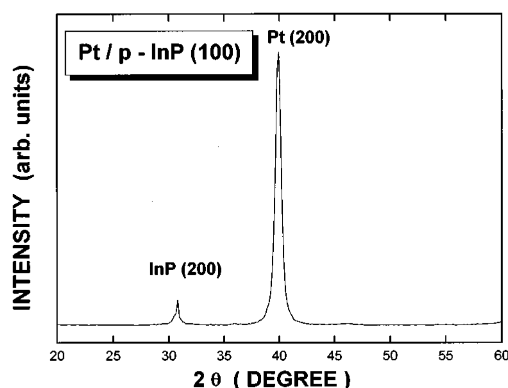

FIG. 1. An x-ray diffraction pattern for the Pt/InP heterostructure.

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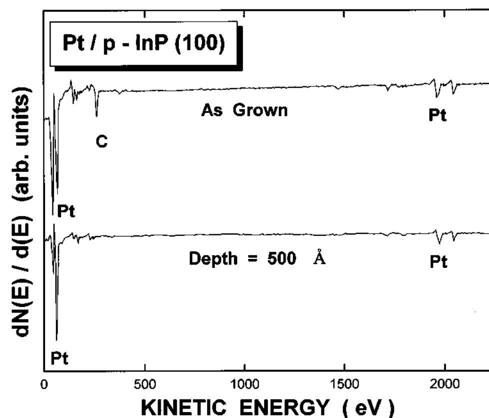

FIG. 2. Auger electron spectroscopy results obtained from the Pt/InP heterostructure. The upper curve was obtained at the Pt surface, and lower curve was obtained at a depth of 500 Å.

surfaces without any indication of pinholes and microcracks, which was confirmed using Normarski optical microscopy. SEM also indicated a mirrorlike surface morphology without any indication of grain boundaries. Figure 1 shows the results of the XRD patterns for a Pt/InP heterostructure. The (200) $K_{\alpha 1}$ diffraction peak of Pt (100) together with those of InP (100) are clearly observed. In particular, the (200) $K_{\alpha 1}$ diffraction peak of the Pt is consistent with the powder diffraction pattern of a Pt film grown on Si (100) by organometallic chemical-vapor deposition[8] and with the diffraction pattern of a polycrystalline Pt metal.[11] Since the values of the full width at half-maximum for the Pt layer are a little smaller than that for the InP substrate, those values show that the quality of the Pt layer is very good. These results indicate that a Pt epitaxial film can be grown on an InP (100) substrate using the IBD technique.

The composition of the Pt thin layer was investigated by AES. The results showed that the as-grown film consisted of Pt and carbon at the surface of the Pt and of only Pt at a 500-Å depth as shown in Fig. 2. The existence of the carbon impurities could be due to contamination from source materials or from the growth chamber during the final growth stage. Figure 3 shows that the interfaces between the Pt and the InP were relatively sharp and that a little Pt, In, and P interdiffused into each layer. The little In and P atoms penetrated in the Pt layer due to the partial dissolution in spite of

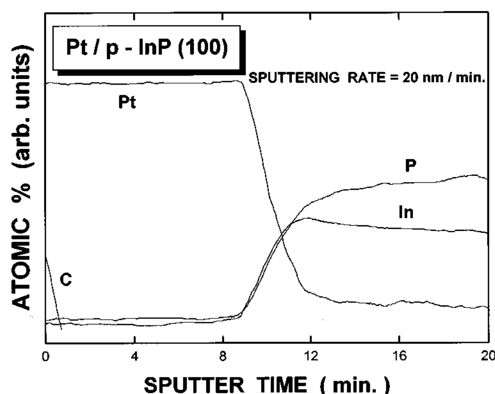

FIG. 3. Auger depth profile of the Pt/InP heterostructure.

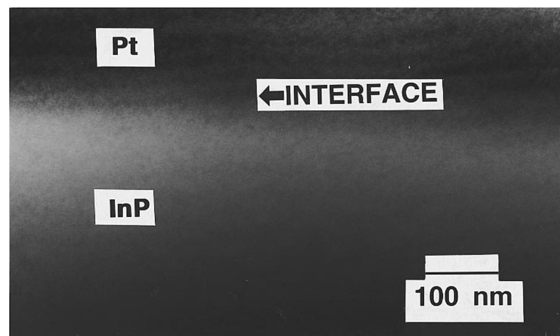

FIG. 4. A bright-field transmission electron microscopy image of the Pt/InP heterostructure.

presenting a relatively flatlike heterojunction.[12] Even though the interfacial problem at the Pt/*p*-InP heterostructure cannot be totally removed, because the deposition of the Pt was performed at room temperature, the interfacial reaction between the Pt and the InP due to thermal effects was probably not present.[7]

In addition to x-ray diffraction and AES measurements, a bright-field TEM image was measured, and it shows the top Pt layer and the bottom GaAs substrate, as shown in Fig. 4. The Pt thin layer has a very smooth surface without any stacking faults and dislocation. Selected-area electron-diffraction patterns from TEM of the Pt/InP heterostructures are shown in Fig. 5. The strong spots are from the InP substrate, and the other spots correspond to the Pt epitaxial film and the interfacial layer. Even though there are some interdiffusion problems, the electron-diffraction pattern shows that the grown Pt thin film has an epitaxial phase.

In summary, the results of XRD, AES, and TEM measurements showed that the Pt layers grown by IBD were heteroepitaxial films. AES measurements showed that the interfacial problem between the Pt and the InP was not significant. Although some details of the electrical properties, such as current–voltage measurements, remain to be clarified, these results indicate that Pt epitaxial films can be grown on InP (100) substrates by IBD. With careful growth of Pt epi-

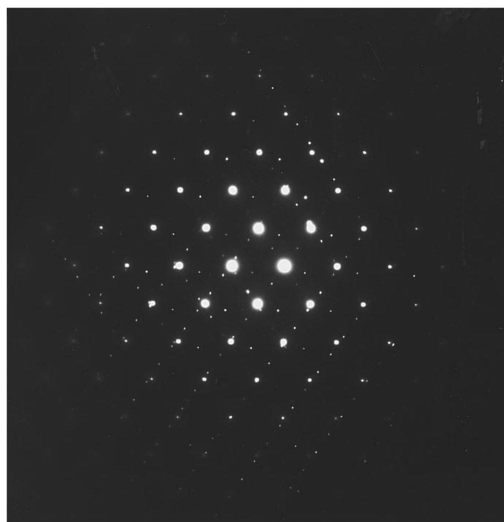

FIG. 5. An electron diffraction pattern from transmission electron microscopy of the Pt/InP heterostructure.

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taxial layers on p-InP substrates, it should be possible to produce high-quality Pt epitaxial films both as very stable contacts in optoelectronic devices and as metal-semiconductor field-effect transistors. Furthermore, the Pt/p-InP heterostructures can give good motivation for the fabrication of Pt/InP superlattices.

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