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Low-pressure metalorganic chemical vapor deposition (LPMOCVD) has been used to grow GaAs epitaxially on GaAs substrates by reacting triethylgallium and arsine. Various deposition parameters such as substrate temperature, total pressure, and V/III ratio were varied systematically. Optical and scanning electron microscopy revealed the presence of oval defects. Photoluminescence shows bandgap luminescence at 1.5 eV. Hall effect data indicate that the deposited GaAs is p-type with a carrier concentration of 10^{17}cm^{-3} and a mobility of 275 cm^2/V.s at room temperature. Secondary ion mass spectrometry analysis shows a high concentration of carbon that acts as a shallow acceptor. Raman spectroscopy shows that the ratio of the intensity of the LO to the TO mode is much larger for the deposited GaAs epilayer than for the bare substrate using the same scattering geometry.

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Growth of Structures for Integrated Optoelectronic Devices

Final Report

Contract #: N00014-91-J-1749

1. Introduction

The proposed objective of this project was to fabricate by a novel low temperature deposition technique optical switches and other optoelectronic devices. These structures are pnpn photothyristors made of III-V semiconductors capable of emitting light and lasing, thus providing high optical gain. Such devices can be used as amplifying repeaters for optical communication and can be interconnected electrically and optically to form optoelectronic neural nets. They can be used in address-decoding circuits that select the destination of the optical message.

Since our deposition system can be operated in several different modes such as low-pressure MOCVD, microwave plasma-assisted MOCVD, and electron cyclotron resonance (ECR) plasma-assisted MOCVD, our technical approach is to compare the growth of GaAs and AlGaAs by several different methods. However, the proposed final goal of this project is to fabricate structures of pnpn photothyristors made of GaAs/AlGaAs using electron-cyclotron resonance (ECR) plasma-assisted MOCVD from arsine and triethylgallium at low temperatures and pressures. GaAs and AlGaAs epitaxial layers were to be deposited, and the layer quality characterized using scanning electron microscopy (SEM), x-ray diffractometry, secondary ion mass spectrometry, Hall effect, and photoluminescence measurements. Doping of GaAs and AlGaAs layers was to be studied and followed by the fabrication of pnpn structures. Finally, electrical and optical characterization of the resulting pnpn photothyristors was to be performed.

2. Growth and Characterization

Our ECR plasma-assisted MOCVD system is shown schematically in Figure 1. It is equipped with a load-lock and a residual gas analyzer which allows us to monitor the background contaminants before each deposition. A turbomolecular pump backed by a forepump is used to evacuate the reaction chamber. The base pressure prior to deposition is usually in the low of 10^{-8} Torr. An activated charcoal filter is installed in

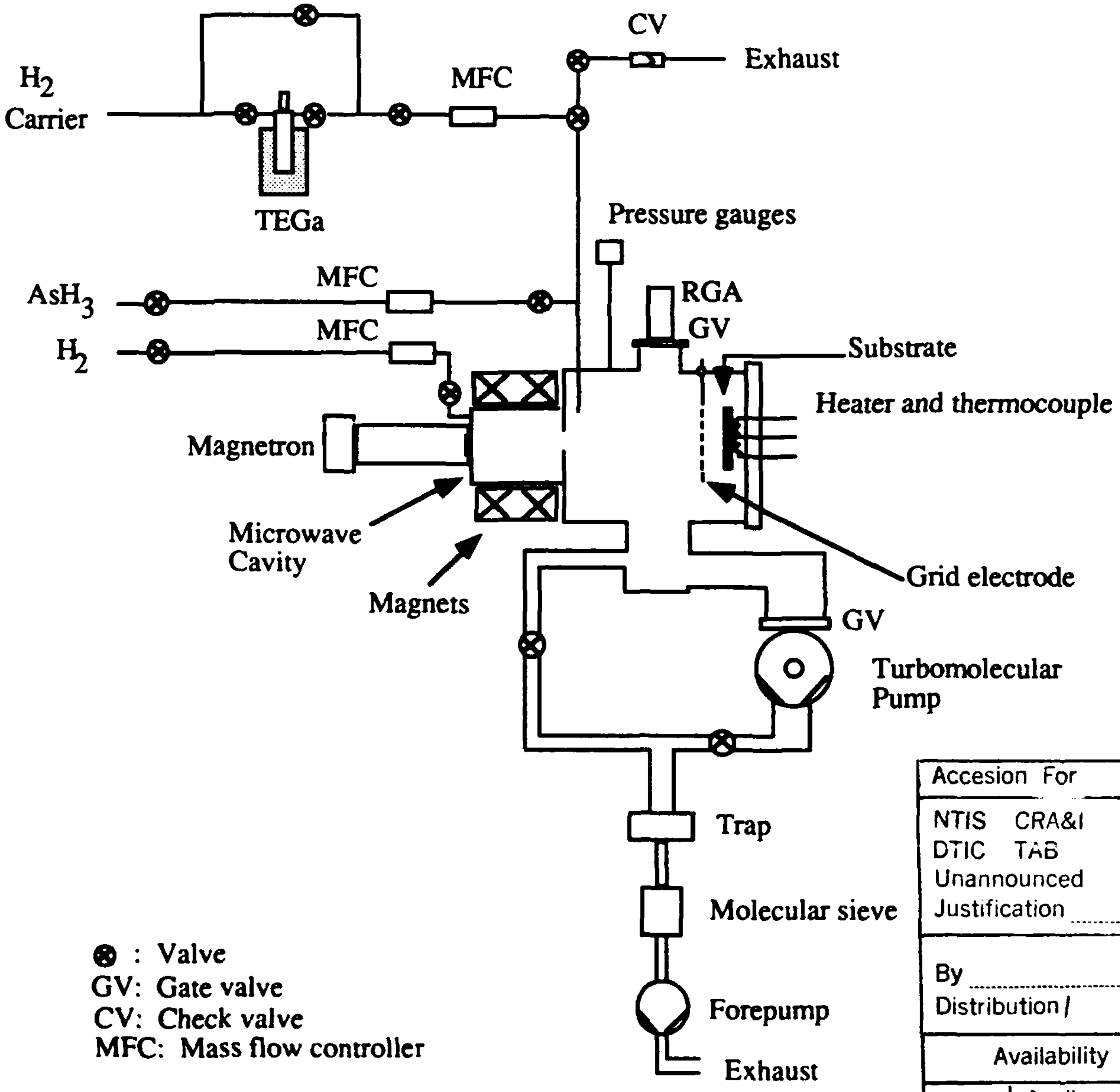

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Figure 1. Schematic diagram of ECR-PA-MOCVD system. A residual gas (RGA) analyzer allows insitu diagnostic. The microwave cavity and the deposition chamber are water cooled.

the system to trap unpyrolized arsine. The substrate is placed on a molybdenum (Mo) holder that rests vertically on a BN-coated graphite heater. The growth temperature and the deposition pressure are monitored by a type K thermocouple and an MKS baratron, respectively. For the precursors, Megabit arsine (AsH_3) from Solkatronics, Inc. and electronic grade triethylgallium (TEG) from Morton International are used for the group V and III source, respectively. TEG is used instead of trimethylgallium (TMG) because TMG has been well-known to produce high carbon contamination[1], while TEG has been reported to give less carbon contamination.[2,3]

The GaAs epilayers were grown on semiinsulating and Zn-doped GaAs substrates with (100) orientation tilted 2^o off towards (110) direction. The substrate pretreatment procedures are as follows: First, the substrates were degreased in trichlorethylene (TCE), acetone, methanol, and rinsed in deionized water. The substrates were then etched in 3% NH_4OH solution for 2 minutes, rinsed in deionized water, blown dry in pure N_2, and loaded immediately into the load-lock. The substrates were transferred into the reaction chamber when the load-lock pressure reached 5×10^{-6} Torr or lower. In order to remove any residual surface oxides, the substrates were initially heated to 650 ^oC under a flowing AsH_3 ambient for 10 minutes. Samples were deposited at growth temperatures of 525 ^oC to 750 ^oC, pressures of 100 mTorr to 300 mTorr, and V/III ratio of 10 to 100.

Optical and scanning electron microscopy were used to analyze the surface morphology of the GaAs epilayers, while a stylus profilometer was used to measure the thickness of the films. Photoluminescence spectra measurements were recorded at liquid nitrogen temperature (77 ^oK) using the 488 nm line of an argon laser as excitation source and were analayzed with a monochromator coupled to a photomultiplier tube (RCA #: 7102). Room temperature Hall measurements were performed using the conventional van der Pauw technique. Raman spectroscopy has also been carried out to analyze several GaAs epilayers.

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[1] G. B. Stringfellow, *Organometallic Vapor Phase Epitaxy: Theory and Practice* (Academic Press, Boston, 1989).

[2] C. Y. Chang et al., *J Cryst Growth* **55**, 24 (1981).

[3] T. F. Kuech and R. Potemski, *Appl Phys Lett* **47**, 821 (1985).

3. Results

Optical and scanning electron microscopy have been performed extensively to analyze the surface morphology of GaAs epilayers. Although smooth, mirror-like films have been grown, in most cases the surface shows the presence of oval defects whose density varies with the deposition parameters. Figure 2 shows the specular surface of a 3 μm thick GaAs epilayer grown at 675 ^{o}C, pressure of 300 mTorr, and V/III ratio of 100. The typical oval defects that appears in most GaAs films are illustrated in Figure 3. The origin of the oval defects is not clear in our system. In the literature, oval defects are very common for GaAs epilayers grown by molecular beam epitaxy (MBE). There are several possible causes for the oval defects. For example: (i) improper substrate pretreatment such as overetched substrate which leaves Ga droplets on the surface or the presence of dust particles on the surface, (ii) Ga spitting in MBE systems because the Ga cell is not fully charged, and (iii) excess of Ga on the substrate surface during growth. To reduce and/or eliminate the oval defects, we have tried several different methods such as varying the etching time during substrate pretreatment, varying V/III ratio, the deposition pressure, and substrate temperature. Furthermore, we have also modified our deposition system to bring the reactant gases closer to the substrate and to modify the gas flow pattern at the substrate. However, we were not able to completely eliminate the oval defects. We observed that at low substrate temperatures the films appear hazy or milky due to high density of oval defects, while high substrate temperatures produce smooth GaAs epilayers. The number of oval defects also decreases with increasing V/III ratio.

Photoluminescence measurements at 77 ^{o}K shows bandgap luminescence at 1.50 eV (Figure 4). Hall effect data obtained at room temperature indicate that the GaAs epilayers are p-type with a resistivity of 0.03 ohm-cm, a carrier concentration of 10^{17} cm^{-3}, and a mobility of 275 cm^{2}/V.s. This value of mobility corresponds to the best room temperature value reported for carbon-doped GaAs with 10^{17} acceptors/cm^{3}.[4] SIMS analysis shows a high concentration of carbon that acts as a shallow acceptor.

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[4] M. Weyers et al., *J Electron Mat* **15**, 57 (1986).

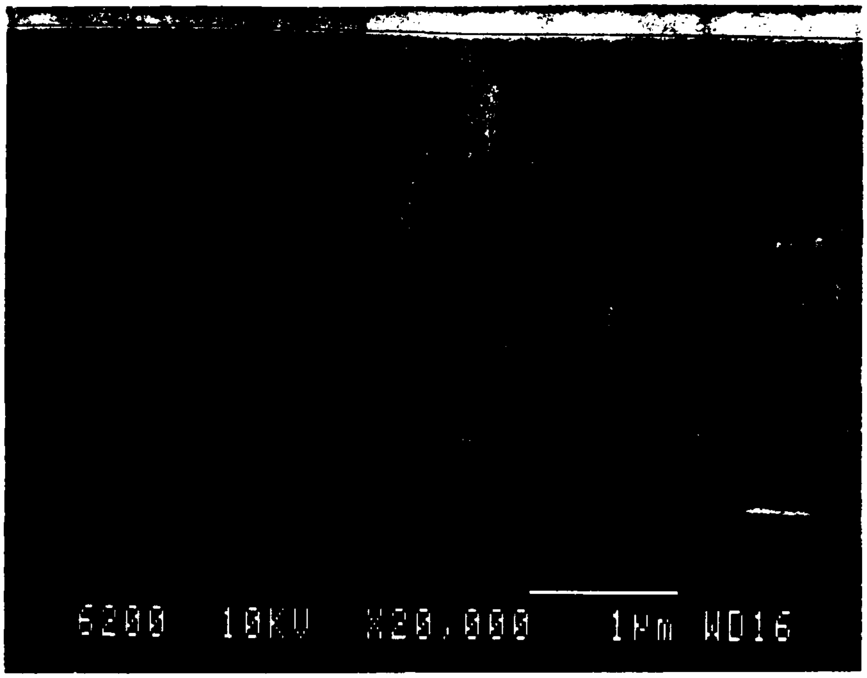

Figure 2. Scanning electron micrograph of a GaAs epilayer grown at substrate temperature of 675 ^{o}C, pressure of 300 mTorr, and V/III of 100.

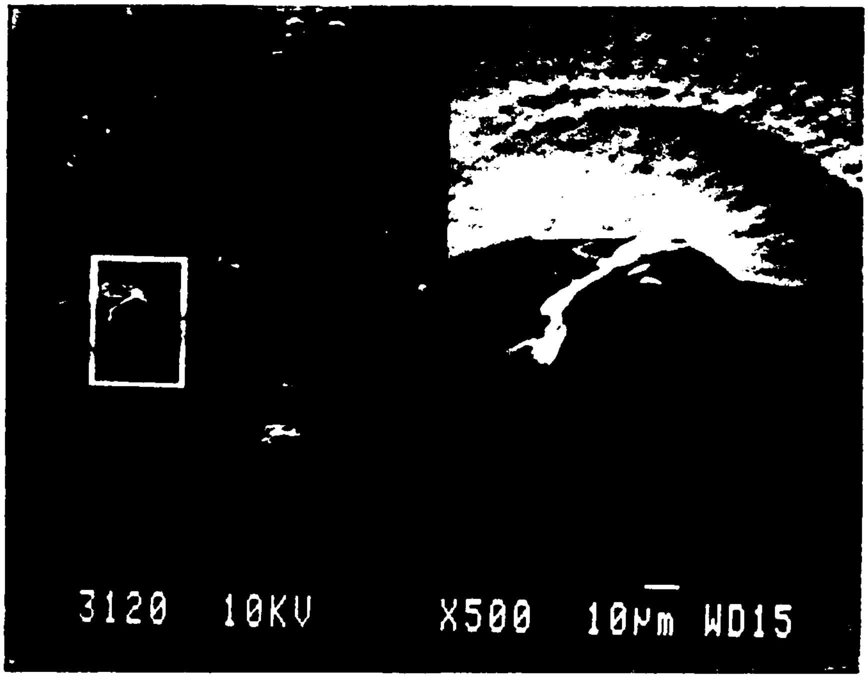

Figure 3. Scanning electron micrograph of typical oval defects on GaAs film.

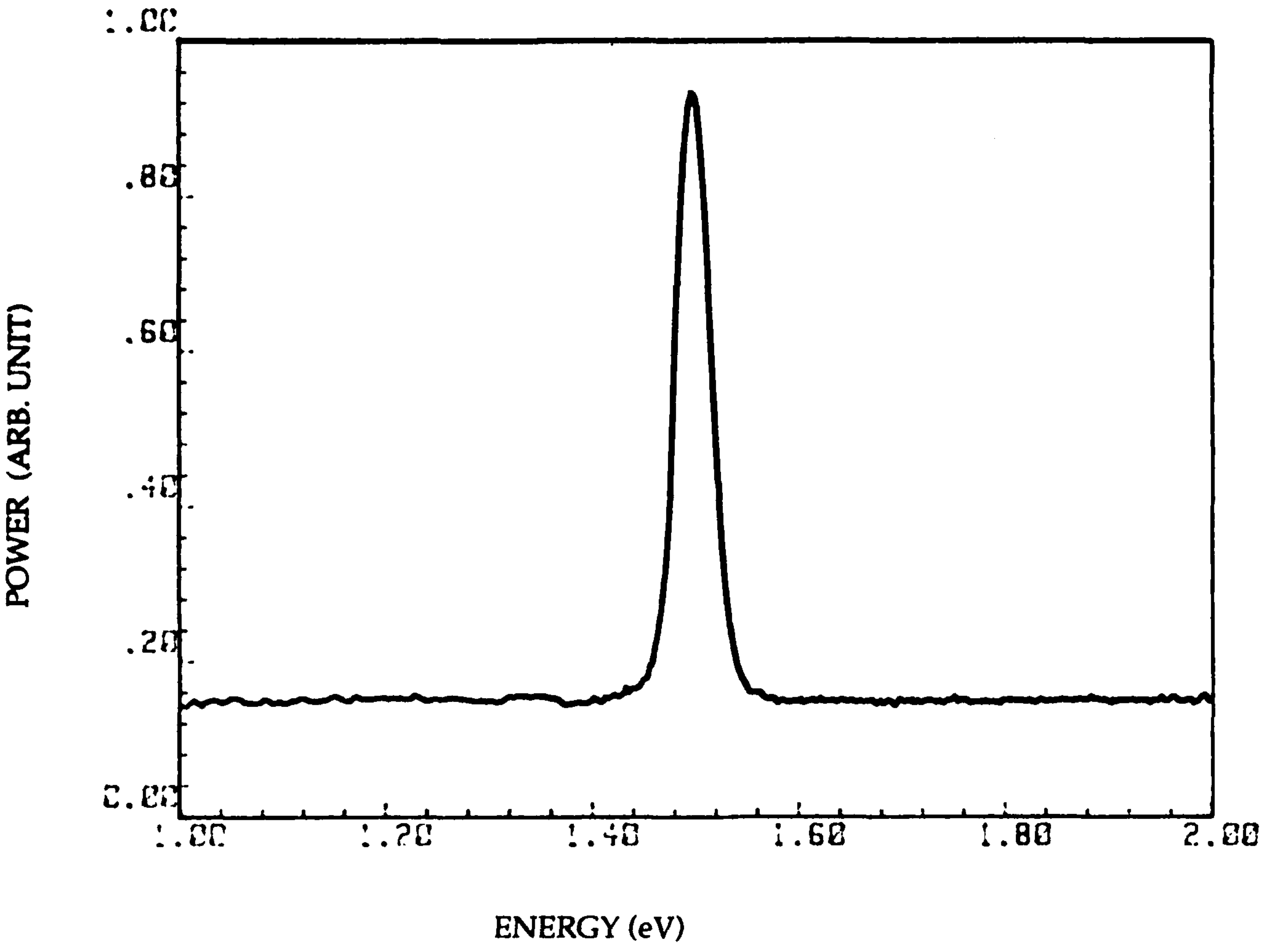

Figure 4. Photoluminescence spectrum of GaAs epilayer measured at 77 ºK.

The Raman spectrum of a GaAs epilayer is shown in Figure 5. The peaks at 268 cm^{-1} and 292 cm^{-1} correspond to TO and LO phonon mode, respectively, which are the same as GaAs crystal.[5] However, as far as we know, this is the first observation that the ratio of the intensity of the LO mode to the TO mode is much larger for the deposited GaAs epilayer than for the bare substrate using the same scattering geometry. Our Raman spectra of the GaAs substrates are similar to Raman spectra reported by others. This inverted ratio of LO to TO intensities may be due to LO phonon-plasmon coupling, internal defects, or phonon confinement as reported for SiC.[6]

4. Conclusions

GaAs epilayers have been grown using low pressure metalorganic chemical vapor deposition and characterized by optical and scanning electron microscopy, photoluminescence, Hall effect measurements, and secondary ion mass spectrometry. SEM results indicate that smooth, mirror-like surfaces have been achieved. However, in most cases the films show the presence of oval defects. Photoluminescence measurements at 77 ^{o}K shows bandgap luminescence at 1.50 eV. Hall effect data indicate that the deposited GaAs is p-type with a carrier concentration of 10^{17} cm^{-3} and Hall mobility of 275 $cm^2/V.s$ at room temperature. SIMS analysis shows a high concentration of carbon that acts as a shallow acceptor, and Raman spectroscopy measurements show that the ratio of the intensity of the LO mode to the TO mode is much larger for the deposited GaAs epilayer than for the bare substrate using the same scattering geometry.

5. Acknowledgments

We thank Dr. Rick Matson of the National Renewable Energy Laboratory for the SEM pictures.

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[5] W. Hayes and R. Condon, *Scattering of Light by Crystals* (John Wiley & Sons, New York, 1978), p. 164.

[6] Y. Sasaki, Y, Nishina, M. Sato, and K. Okamura, *Phys Rev* **B40**, 1762 (1989).

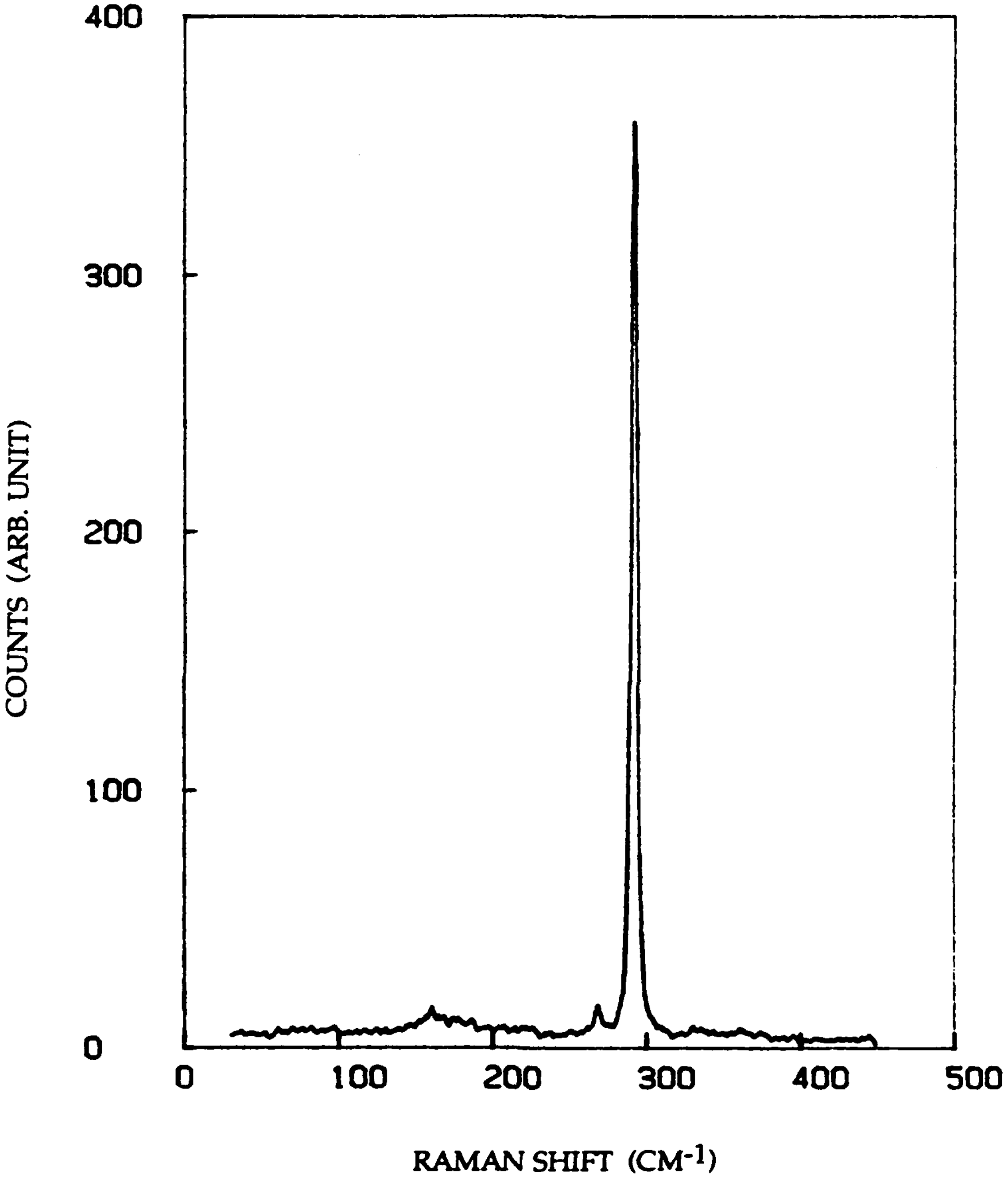

Figure 5. Typical Raman Spectrum of GaAs epilayer.