

Characteristics of the metal insulator semiconductor structure:AlN/Si

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fractions of a volt at speeds greater than 40 ps, when used with reasonable bias voltages. To demonstrate this capability, a sample having a damage dose of $3 \times 10^{14} \text{ cm}^{-2}$, mobility of $40 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$, relaxation time of 22 ps, and a single 25- μm gap was mounted in a high-speed low-reflection coaxial mount.⁹ This provided an efficient, linear, easy to use photodetector. In addition, the photodetector is small in size and easy to fabricate. A typical output pulse is shown in Fig. 4, for which the incident dye-laser optical-pulse average power was approximately 40 mW, focused with a 3-cm lens. The electrical pulse has a FWHM of 55 ps and a rise time (10–90%) of 30 ps. This is close to the instrument limit for the sampling oscilloscope. Autocorrelation measurements indicate a FWHM of 28 ps. Reflections are less than 10%. Peak output voltage is 300 mV, which is twenty times larger than the response from CVD amorphous detectors.¹

In summary, we have demonstrated that radiation damage can be used to make high-speed photoconducting materials with short carrier lifetimes suitable for applications in picosecond opto-electronic devices. The mobilities are at least an order of magnitude larger than comparable amorphous materials. Experiments are now in progress to make more detailed evaluations of these materials and their utilization for a variety of picosecond opto-electronic devices. Other materials and damage techniques are also being studied to develop faster and more sensitive photoconduct-

ing films. By using other approaches, such as implanting silicon into silicon, it should be possible to learn more about the nature of the disorder associated with radiation damage and the transition to the amorphous phase.

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Characteristics of the metal insulator semiconductor structure:AlN/Si

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Single-crystal AlN layers have been grown on Si substrates at $\sim 1200^\circ\text{C}$ using metalorganic chemical vapor deposition. The metal/AlN/Si MIS structures have been investigated by the MIS conductance method. It was found that the interface-state density N_{ss} and electron capture cross section σ_n in the depletion region are of the order of $10^{11} \text{ eV}^{-1} \text{ cm}^{-2}$ and 10^{-17} cm , respectively.

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Aluminum nitride (AlN) possesses a wide band gap of $\sim 6.2 \text{ eV}$,¹ and good physical and chemical stability even at high temperature. Thus AlN is a prospective material for electrically insulating and passivation layers for other semiconductors. Furthermore, the metal/AlN/silicon (Si) MIS structure has potential use for surface-acoustic-wave monolithic devices, because AlN is a piezoelectric material.

Recently, the fabrication of the Al/AlN/Si MIS structures has been attempted by chemical and plasmachemical

vapor deposition using aluminum halides.² However, the growth of AlN layers on Si substrates for the fabrication of the MIS structure was carried out only in the temperature range below 1000°C , i. e., below the temperature range of single-crystal growth, because of problems which occur at higher temperature.³ The electrical properties of the MIS structure, Al/AlN/Si, were measured only for flat-band conditions using capacitance-voltage characteristics.

In order to investigate the characteristics of the single-

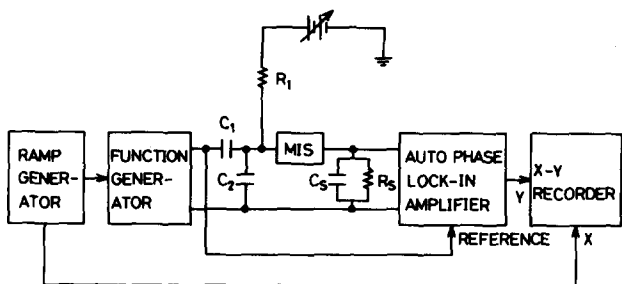


FIG. 1. Block diagram of measuring apparatus.

crystal AlN/Si MIS structure, we have grown epitaxial AlN layers on (111) oriented *n*-type Si substrates ($2.3 \Omega \text{ cm}$) at $\sim 1200^\circ\text{C}$ using the metalorganic chemical vapor deposition (MO-CVD^{4,5}) and fabricated the MIS structure. We have carried out the measurements of the electric behavior as the MIS capacitor and determined the interface state parameters at the epitaxial AlN/Si interface using the MIS conductance method.

The growth technique and apparatus utilized are similar to the growth of AlN films on sapphire substrates.⁶ Before growth, polished Si wafers were chemically cleaned, etched in hydrofluoric acid, and rinsed with deionized water. Si substrates were brought up to growth temperature over a period of 10 min. The epitaxial growth of AlN layers was carried out at $\sim 1200^\circ\text{C}$ at a rate of $\sim 200 \text{ \AA}/\text{min}$, and to a thickness of $\sim 1000 \text{ \AA}$. After growth, the samples were slowly cooled to room temperature over a period of $\sim 2 \text{ h}$. The epitaxial orientation relationship, as determined by reflection electron diffraction, i.e., (0001) AlN on (111) Si, was identical with the results previously reported.^{4,5}

Evaporated films of Al, Au, or Pt of 1 mm in diameter were used as metal electrodes. The capacitance and conductance of MIS capacitors were measured using the phase-sensitive detection with the auto-phase lock-in amplifier in the frequency range from 50 Hz to 50 kHz. A block diagram of the setup is shown in Fig. 1. This measurement apparatus consists of the circuit⁷ which is independent of frequency and the auto-phase lock-in amplifier NF LI-574. This instrument is versatile enough to permit not only the capacitance- and conductance-voltage plots but also the capacitance- and conductance-frequency plots. Therefore in the measurement of the admittance of the MIS capacitor to evaluate the interface state parameters by the MIS conductance method, this

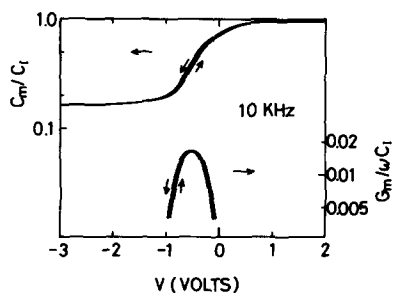


FIG. 2. Capacitance and conductance in units of insulator capacitance vs field-plate bias of the Al/AlN/Si structure. Flatband voltage is -0.1 V .

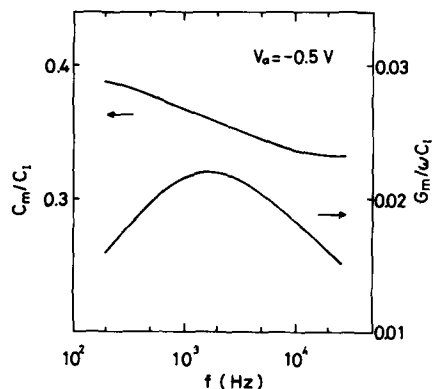


FIG. 3. Capacitance and conductance in units of insulator capacitance vs frequency of the Al/AlN/Si structure.

plotter has the advantages that it does not require long-time measurements and can plot the admittance as a function of frequency keeping the field-plate bias fixed, compared with the plotting using a capacitance bridge.

Typical capacitance- and conductance-voltage curves of the Al/AlN/Si MIS structure are shown in Fig. 2. The flat-band voltage is -0.1 V . In some sample, the flat-band voltage had a positive value, consistent with the results reported previously.² However, the fixed charge density in AlN layer could not be determined from this flat-band voltage, because the energy difference between the metal and the semiconductor work functions of this MIS structure has not been determined. The hysteresis of capacitance- and conductance-voltage curves indicates the type, which is called the ion-drift type or polarization type, in the MOS structure. The width of hysteresis is below 0.05 V , when the bias scanning speed is $1.4 \text{ V}/\text{min}$. The effects of the difference of metal electrodes on the type and width of the hysteresis could not be found in our measurements.

The parameters of the interface states were evaluated using the MIS (MOS) conductance method.⁸ The typical capacitance- and conductance-frequency curves of the Al/AlN/Si MIS structure are shown in Fig. 3. The capacitance increases as the frequency is lowered, while the conductance shows a peak. The characteristics curve of G_{ss}/ω vs $\log f$, where G_{ss} is the conductance of interface states and $\omega (= 2\pi f)$ is the angular frequency, is shown in Fig. 4. The frequency dispersion factor σ_g is about 3.5, when we fit this curve to the statistical model.⁸ The interface-state density N_{ss} and electron capture cross section σ_n obtained are shown in Fig. 5. The interface-state density in the depletion

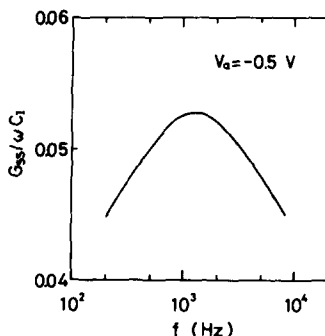


FIG. 4. Conductance of interface states in units of insulator capacitance vs frequency of the Al/AlN/Si structure.

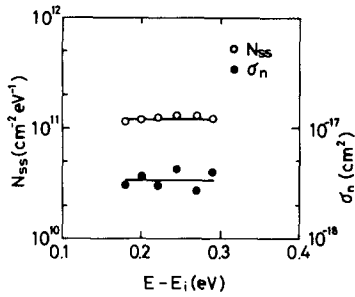


FIG. 5. Interface state density N_{ss} and electron capture cross section σ_n of interface states at the epitaxial AlN/Si as a function of the energy. The energy is measured relative to the mid gap.

region is of the order of $10^{11} \text{ eV}^{-1} \text{ cm}^{-2}$ and the electron capture cross section is of the order of 10^{-17} cm^2 .

In conclusion, we have fabricated the metal/AlN/Si MIS structure by the growth of AlN layer at $\sim 1200^\circ\text{C}$ using MO-CVD, carried out the measurements of the electric behavior as the MIS capacitor, and determined the interface-state parameters at the epitaxial AlN/Si interface using the MIS conductance method. We obtained the following results: (i) flat-band voltages of the MIS capacitors have negative values in some samples and positive values in others; (ii)

the width of hysteresis is below 0.05 V, when the bias scanning speed is 1.4 V/min; (iii) the interface-state density N_{ss} and electron capture cross section σ_n in the depletion region are of the order of $10^{11} \text{ eV}^{-1} \text{ cm}^{-2}$ and 10^{-17} cm^2 , respectively. Further investigation will be necessary in order to establish the relation between the electric behaviors and epitaxial growth conditions.

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