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Interfacial neutral- and charged-dangling-bond densities between hydrogenated amorphous silicon and hydrogenated amorphous silicon nitride in top nitride and bottom nitride structures

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The bilayer structures composed of hydrogenated amorphous silicon ($a\text{-Si:H}$) and hydrogenated amorphous silicon nitride ($a\text{-Si}_3\text{N}_4\text{:H}$) are prepared on fused-quartz substrates and their interfacial Si dangling bonds (DBs) are evaluated by electron spin resonance (ESR). The ESR study reveals that the bottom nitride (BN) structure ($a\text{-Si:H/a-Si}_3\text{N}_4\text{:H/fused quartz}$) has a smaller amount of neutral DBs in the interface than the top nitride (TN) structure ($a\text{-Si}_3\text{N}_4\text{:H/a-Si:H/fused quartz}$). The photoconductivity measurements also support this finding. A larger amount of charged DBs in the interface, however, exist in the BN structure than in the TN structure. The larger amount of interfacial neutral DBs in the TN structure is likely to be caused by the UV irradiation from the plasma during the deposition of $a\text{-Si}_3\text{N}_4\text{:H}$ layer. © 1995 American Institute of Physics.

Hydrogenated amorphous silicon nitride ($a\text{-Si}_3\text{N}_4\text{:H}$) is one of the promising materials for the insulating, the passivation, and the isolation layer in Si devices. For example, $a\text{-Si}_3\text{N}_4\text{:H}$ is often used as the insulating layer in the metal-insulator-semiconductor (MIS) structure for hydrogenated amorphous silicon ($a\text{-Si:H}$) thin-film transistors (TFTs). The interfacial defects, however, are a drawback to the electrical properties in TFTs. It has been reported that in the bilayer structures composed of $a\text{-Si}_3\text{N}_4\text{:H}$ and $a\text{-Si:H}$, the electrical properties depend on the order of the deposition.^{1,2} Namely, the bottom nitride (BN) structure, in which $a\text{-Si:H}$ layer is deposited on $a\text{-Si}_3\text{N}_4\text{:H}$ layer, shows better electrical properties than the top nitride (TN) structure, in which $a\text{-Si}_3\text{N}_4\text{:H}$ layer is deposited on $a\text{-Si:H}$. Accordingly, the inverse-staggered-type $a\text{-Si:H}$ TFTs employing the BN structure occupy the mainstream. Such differences in the electrical properties are supposed to originate from the differences in interface characteristics of these bilayer structures. On the other hand, the results reported by Parsons suggest the possibility that the deposition order does not necessarily affect the interfacial quality.³ Tsai *et al.* investigated in detail the interfacial properties of $a\text{-Si:H/a-Si}_3\text{N}_4\text{:H}$ multilayer using electron spin resonance (ESR), light-induced ESR (LESER), and transmission electron microscopy (TEM).⁴ They reported the larger charged dangling bond (DB) density than neutral one in the interface of the multilayer. Their experiments, however, cannot distinguish the interfacial property between the TN and the BN structures because of the use of the multilayer sample. This letter reports the interfacial-DB densities estimated utilizing ESR in the TN and the BN structures. The relationship between the interfacial-DB density and the electrical properties reported up to now is also clarified. The photoconductivity measurements with changing the wavelength of the probing light also give a result supporting that obtained using ESR.

Both $a\text{-Si:H}$ and $a\text{-Si}_3\text{N}_4\text{:H}$ layers were prepared by rf plasma-enhanced chemical vapor deposition (PECVD) with power density of 0.3 W/cm^2 using SiH_4 without dilution and a gaseous mixture of SiH_4 and NH_3 , respectively. Fused-quartz substrates were employed and the nominal substrate temperature was $350\text{ }^\circ\text{C}$ for the deposition of both layers. The TN and the BN structures for samples used in the photoconductivity measurements are illustrated in Fig. 1. The samples for ESR measurements are the same structure as that shown in Fig. 1 without electrodes. The waiting time between the deposition of both layers is 5 min with evacuating the chamber. In the sample for ESR measurements, the thickness of the $a\text{-Si}_3\text{N}_4\text{:H}$ layer was fixed to 60 \AA , and that of the $a\text{-Si:H}$ layer was varied over the range from 50 to 2800 \AA . The samples for photoconductivity measurements have the thickness of 60 \AA for the $a\text{-Si}_3\text{N}_4\text{:H}$ layer and that of $12\text{ }000\text{ \AA}$ for the $a\text{-Si:H}$ layer. These thicknesses were well-controlled and confirmed using a stylus profilometry by measuring the step prepared with the mask during the deposition.

ESR measurements were carried out at room temperature in the dark, and LESER measurements were done at 77 K

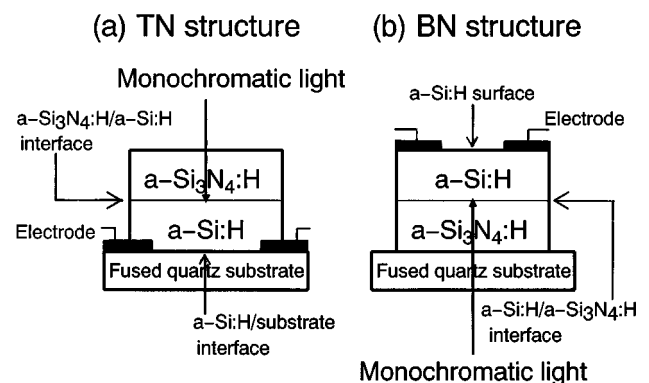


FIG. 1. Schematic diagrams of (a) TN and (b) BN structures for samples used in photoconductivity measurements. Arrows show the irradiation direction of the probing light.

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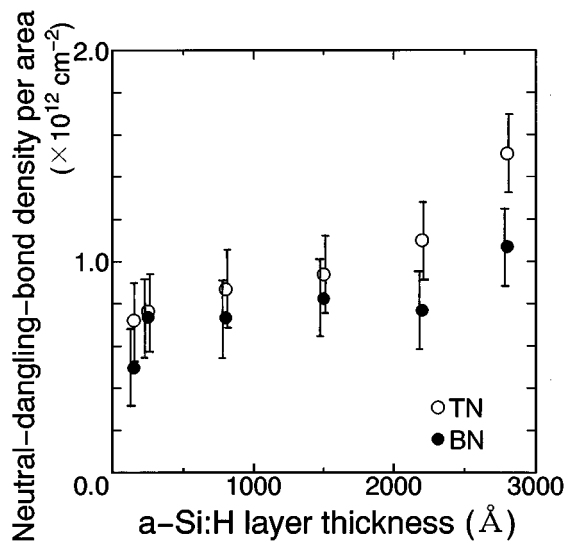


FIG. 2. *a*-Si:H-layer thickness dependence of the neutral-DB density per area for both TN and BN structures. Length of the bar shows the degree of experimental errors.

under illumination using a Xe lamp through an IR-cut filter with the power density of 200 mW/cm².

ESR spectra obtained for both the TN and the BN structures had *g*-values of about 2.0055, showing that both of their origins are Si DBs in the *a*-Si:H layer. The ESR signal due to Si DBs in the *a*-Si₃N₄:H layer, so-called *K*-center with *g*-value of about 2.003, was not observed. Figure 2 shows the *a*-Si:H layer thickness dependence of the neutral-DB density per area for both the TN and the BN structures. The interfacial-neutral-DB density in the TN and the BN structures will be compared. The sum of the neutral-Si-DB densities per area in the *a*-Si:H surface and heterointerface for the TN structure appears to be somewhat larger than that for the BN structure. For example, those for the TN and the BN structures both with *a*-Si:H layer of 2800 Å are 1.5 × 10¹² cm⁻² and 1.1 × 10¹² cm⁻², respectively. The neutral Si DBs in the *a*-Si:H layer for the TN structure originate both from those in *a*-Si₃N₄:H/*a*-Si:H interface and from those in *a*-Si:H/substrate interface. On the other hand, those for the BN structure originate both from those in *a*-Si:H/*a*-Si₃N₄:H interface and from those in *a*-Si:H surface. The sum of the neutral-DB density in *a*-Si:H surface without the native oxide and that in *a*-Si:H/substrate interface for *a*-Si:H films directly deposited on the fused-quartz substrate was estimated by our group to be about 7.0 × 10¹¹ cm⁻².⁵ Our group also reported that the neutral-DB density in *a*-Si:H surface is larger than that in *a*-Si:H/substrate interface.^{5,6} These facts lead to the conclusion that the interfacial-neutral-DB density in the TN and the BN structures can be obtained by subtracting 0.0–3.5 × 10¹¹ cm⁻² and 3.5–7.0 × 10¹¹ cm⁻², respectively, from the sum of the neutral-Si-DB densities per area in *a*-Si:H surface and heterointerface. Therefore, we can conclude that the interfacial-neutral-DB density estimated using ESR in the TN structure is larger than that in the BN structure.

The interfacial-charged-DB density estimated using LESR will be shown. Both of the LESR spectra observed in

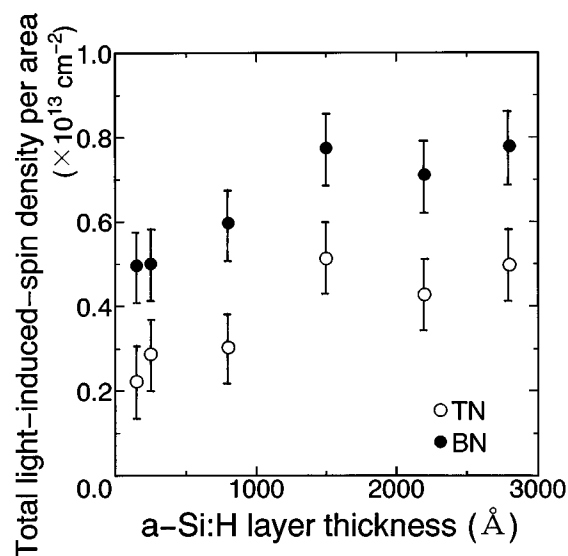


FIG. 3. *a*-Si:H-layer thickness dependence of the total light-induced-spin density per area for both TN and BN structures. Length of the bar shows the degree of experimental errors.

the TN and the BN structures resemble the typical LESR spectrum for *a*-Si:H, which is the superposition of three signals, that is, the signal due to Si DBs in *a*-Si:H and the two signals from other origins. Therefore, the signal due to Si DBs in the *a*-Si:H layer should be separated by the fitting procedure.⁷ It is assumed in the present study that Si DBs observed in LESR measurements consist of the light-induced DBs, namely the charged DBs, and the neutral DBs observed in ESR measurements in the dark. This assumption can be roughly valid, although our recent work set up a question on the precise propriety.⁸ It was also confirmed in the present study that the ESR spectrum before the LESR measurement is recovered with the same intensity after the LESR measurement. The charged-DB density can be obtained by subtracting the neutral-Si-DB density from the Si-DB density estimated following the above-mentioned method. Since the LESR signals observed in this study were too weak to carry out the aforementioned fitting with high reliability, especially for samples with *a*-Si:H layer thinner than 1000 Å, the total light-induced-spin density for the TN and the BN structures are shown in Fig. 3. Total light-induced-spin density was estimated by subtracting the neutral-Si-DB density evaluated by ESR measurements in the dark from the total spin density observed in the LESR measurements. It was also confirmed that the *a*-Si:H-layer-thickness dependence of the charged-Si-DB density deduced from the fitting described above exhibits the larger charged-DB density in the BN structure than that in the TN structure in the same manner as the total light-induced-spin density although there is some ambiguity. Therefore, it can be concluded that the interfacial-charged-DB density in the BN structure is larger than that in the TN structure contrary to the interfacial-neutral-DB density because the charged-DB density both in *a*-Si:H surface and in *a*-Si:H/substrate interface can be negligible.⁷ The larger neutral and charged DB densities in our experiments than those in the multilayer sample reported by Tsai *et al.*⁴

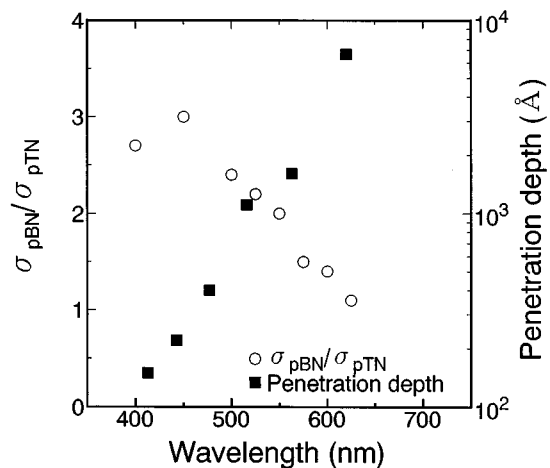


FIG. 4. Ratio of the photoconductivity in the BN structure to that in the TN structure, $\sigma_{pBN}/\sigma_{pTN}$, as a function of the wavelength of the probing light. Wavelength dependence of the penetration depth into *a*-Si:H layer is also shown.

are possibly caused by our sample preparation without optimization. However, it should be noted that our multilayer sample also exhibits smaller neutral DB densities although at present the reason is not clear.

The photoconductivity in *a*-Si:H/*a*-Si₃N₄:H interface for the TN and the BN structures is compared using the following method. The photoconductivity measurements were carried out at room temperature employing the probing light with the power density of 2 mW/cm². The wavelength of the probing light was varied over the range between 400 and 625 nm. As shown in Fig. 1 the monochromatic probing light was irradiated from the *a*-Si₃N₄:H side for the TN structure and from *a*-Si₃N₄:H side via the fused-quartz substrate for the BN structure, respectively. Therefore, the result using the probing light with the shorter wavelength gives the photoconductivity which is more sensitive to the interface because of the shorter penetration depth into *a*-Si:H layer on the assumption that the photoconductivity in the *a*-Si:H bulk layer is larger than that in the *a*-Si:H heterointerface. Figure 4 shows the ratio of the photoconductivity in the BN structure to that in the TN structure, $\sigma_{pBN}/\sigma_{pTN}$, as a function of the wavelength of the probing light. The wavelength dependence of the penetration depth into the *a*-Si:H layer is also shown in Fig. 4.⁹ It is confirmed that the ratio is about 1 for the probing light with longer wavelength and the ratio becomes larger for the probing light with shorter wavelength. This fact suggests that the BN structure shows larger photoconductivity in the interface than the TN structure although the photoconductivity in the *a*-Si:H bulk layer is almost equal. On the other hand, the dark conductivity in the TN structure is almost equal to that in the BN, both of which have the *a*-Si:H layer thickness of 250 Å.

The reason why the interfacial-neutral-DB density in the TN structure is larger than that in the BN structure will be discussed. It is possible that this finding is caused by the UV-light irradiation or the ion bombardment during the deposition of *a*-Si₃N₄:H layer. The following experiments were carried out for clarifying these possibilities. First,

a-Si:H films were deposited on the fused-quartz substrates in the same manner as the samples hitherto shown. Next, *a*-Si₃N₄:H films were deposited under the same condition as described above on two sets of *a*-Si:H films: one is covered with fused-quartz plates and the other is covered with aluminum plates. UV light generated from the plasma is shut off from *a*-Si:H by the aluminum plate, while it penetrates into *a*-Si:H layer through the quartz plate. The ion bombardment to *a*-Si:H layer is, on the other hand, avoided by both of the plates. The plasma-irradiation time was 30 s, equal to the deposition time for *a*-Si₃N₄:H layer. It is found that *a*-Si:H films covered with fused-quartz plates have a larger neutral-DB density by about 40% than those covered with aluminum plates. This fact suggests that the reason why the TN structure has larger interfacial-neutral-DB density than the BN structure is the UV-light irradiation during the deposition of *a*-Si₃N₄:H layer.

On the other hand, the reason why the interfacial-charged-DB density in the BN structure is larger than that in the TN structure is still not so clear. However, *in situ* spectroscopic-ellipsometry study has revealed that the interface in the TN structure is atomically abrupt, while that in the BN structure has the graded transition layer with a width of ~15 Å.¹⁰ The result suggests the possibility that such graded transition layer, namely N-doped *a*-Si:H layer, is responsible for the larger charged-DB density in the BN structure because it is known that a large number of charged DBs exist in N-doped *a*-Si:H films.⁷ It is possible that the above-mentioned larger photoconductivity in the BN interface originates not only from the smaller neutral-DB density but also from the doping of N.

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¹M. J. Thompson, *J. Vac. Sci. Technol. B* **2**, 827 (1984).

²C. Godet, J. Kanicki, and A. V. Gelatos, *J. Appl. Phys.* **71**, 5022 (1992).

³G. N. Parsons, *IEEE Electron Device Lett.* **13**, 80 (1992).

⁴C. C. Tsai, R. A. Street, F. A. Ponce, and G. B. Anderson, *Mater. Res. Soc. Symp. Proc.* **70**, 351 (1986).

⁵H. Yan, A. Morimoto, M. Kumeda, T. Shimizu, and Y. Yonezawa, *Mater. Res. Soc. Symp. Proc.* **258**, 247 (1992).

⁶T. Shimizu, X. Xu, H. Kidoh, A. Morimoto, and M. Kumeda, *J. Appl. Phys.* **64**, 5045 (1988).

⁷T. Shimizu, H. Kidoh, A. Morimoto, and M. Kumeda, *Jpn. J. Appl. Phys.* **28**, 586 (1989).

⁸J.-H. Zhou, T. Okagawa, M. Kumeda, and T. Shimizu, *Jpn. J. Appl. Phys.* **33**, L1135 (1994).

⁹H. Firtzsche, *Sol. Energy Mater.* **3**, 447 (1980).

¹⁰M. Stchakovsky, B. Drevillon, and P. Roca i Cabarrocas, *J. Appl. Phys.* **70**, 2132 (1991).