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p-$Hg_{0.7}Cd_{0.3}Te$에 낮은 저항의 접촉을 얻는 방법에 대한 연구

(Low-Resistance Ohmic Contacts to p-$Hg_{0.7}Cd_{0.3}Te$)

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要約

p-type $Hg_{0.7}Cd_{0.3}Te$에 Au(gold)을 이용하여 낮은 저항을 가진 ohmic 접촉을 얻는 방법이 연구되었다. 그 방법은 먼저, 접촉 영역에 Au을 코팅(coating)하기 전에 HgCdTe를 순간 가열한다(전처리, pre-heating). 가열 온도는 5초 동안 최대 200℃ 이다. Au박막은 $AuCl_3$ 용액에 HgCdTe 웨이퍼를 담가 놓음으로써 형성하였다. 접촉 금속 위에는 Pb과 In을 차례대로 증착해서 pad motal 층을 형성하였으며, 그 후에 다시 전처리와 같은 조건으로 순간 열처리를 한다(후처리, post-annealing). 이렇게 만들어진 접촉의 특성은 열처리 없는 경우에 비하여 크게 향상되었으며, 측정된 접촉저항을 (specific contact resistance)은 5×10^{-3} Ωcm^2 이었다. RBS와 Hall 측정을 통해, 위에서 얻은 낮은 저항의 접촉 특성이 표면 trap center의 증가와 Ai의 확산증가에 인한 것이라고 설명할 수 있었다.

Abstract

Ohmic contacts between Au and p-type $Hg_{0.7}Cd_{0.3}Te$ with low specific contact resistance have been obtained. The contact region of the wafer is first pre-heated for 5 seconds in a rapid thermal processing equipment. The temperature reaches a maximum value of about 200 ℃ at the end of the 5 seconds. Next, a thin Au film is formed on the contact region by immersing the sample in $AuCl_3$ solution. The sample is then post-annealed in the same condition as the pre-heating after Pb/In pad metals are deposited on the electroless Au contacts. The specific contact resistance measured by transmission line model is 5×10^{-3} Ω cm^2 at 80K. RBS and differential Hall measurement data suggest that the above low resistance ohmic contact is ascribed to surface traps and increased gold diffusion rate.

I. Introduction

The fabrication of low resistance ohmic contacts to $Hg_{1-x}Cd_xTe$ is one of considerable importance for device technology, especially for photovoltaic(PV) detectors. While ohmic contacts to n-$Hg_{1-x}Cd_xTe$ can be formed

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readily, ohmic contacts to p-$Hg_{1-x}Cd_xTe$ is very difficult.[1] This difficulty arises from the fact that $Hg_{1-x}Cd_xTe$ has a large work function but there are few metals available with a large enough work function to form an intrinsic ohmic contact to p-$Hg_{1-x}Cd_xTe$. Au is widely used to form the extrinsic ohmic contact to p-$Hg_{1-x}Cd_xTe$, because it has a large work function and long-term stability[2] and is known to be a p-dopant in $Hg_{1-x}Cd_xTe$.[3] By diffusion of Au into $Hg_{1-x}Cd_xTe$, ohmic contacts can be obtained but this diffusion requires relatively high-temperature and long-time annealing[2,4], which must be avoided because of $Hg_{1-x}Cd_xTe$'s thermal unstability. In this paper, therefore, we investigated rapid thermal process to reduce thermal damage to $Hg_{1-x}Cd_xTe$ wafers in forming extrinsic ohmic contacts. We found that both the local pre-heating of the contact region of $Hg_{1-x}Cd_xTe$ and the post-annealing of the Au/p-$Hg_{1-x}Cd_xTe$ contact are important in improving the contact characteristics.

Ⅱ. Experimental Procedure

The wafers used in our experiments are p-type $Hg_{1-x}Cd_xTe$ grown by LPE on (111) oriented CdTe substrates. The composition (x) is 0.3 and the hole concentration is 1~$2x10^{16}cm^{-3}$ at 77K.

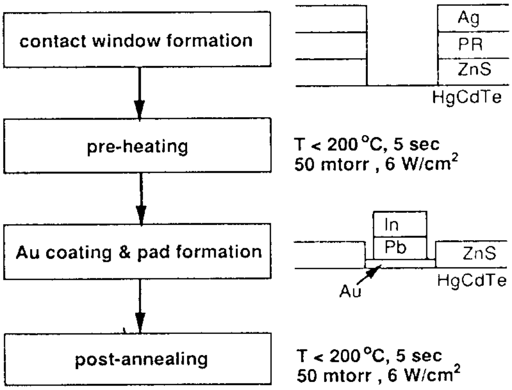


그림 1. 실험 공정

Fig. 1. Process sequence used in this experiment.

The wafers are initially cleaned in boiling TCE, acetone and methanol and then slightly etched to a depth of 1㎛, in 0.5% Br in methanol solution. The fabrication procedure of the ohmic contact is as follows. (See Fig. 1).

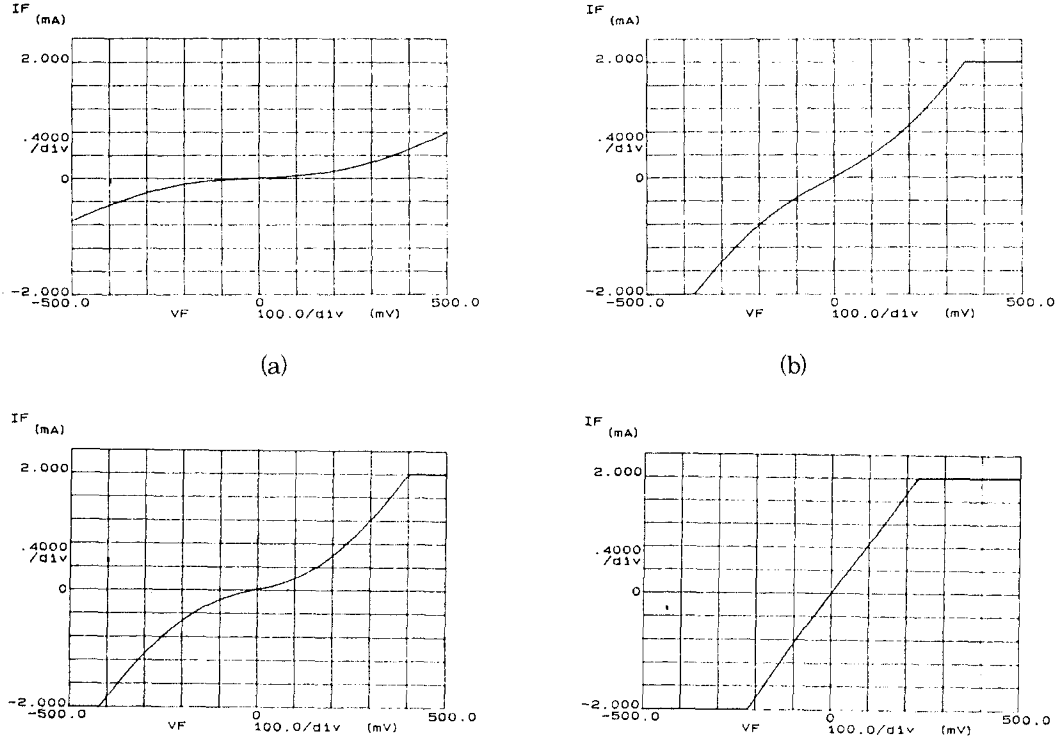
First, a 4000Å-thick ZnS layer is thermally evaporated for the passivation. Instead of patterning the ZnS film directly, a positive photoresist(PR) film is spin-coated and baked, and then Ag is thermally evaporated over the PR layer to a thickness of about 3000Å. Afterwards, Ag is removed from the p-contact region by conventional photolithog-raphy. The etching solution of Ag is $1NH_4OH$: $1H_2O_2$: $5H_2O$. Ag is used as a reflective material in a rapid thermal process employing tungsten halogen lamps because it has a high reflectivity over the visible and infrared region. Thus, the direct thermal damage of the wafer can be reduced by coating Ag film over the non-contact surface of the wafer, providing local heating only to the contact region. To remove the PR on Ag and from the contact region, the wafer is dummy-exposed to UV light and dipped in the PR developer solution. The revealed ZnS on the contact regions is etched in 5HCl: $3H_2O$ solution. The wafer is now ready for the local pre-heating of the contact region of $Hg_{1-x}Cd_xTe$ and is loaded into a vacuum chamber of a rapid thermal equipment. The heating source of the rapid thermal equipment is composed of tungsten halogen lamps and the radiation intensity of the tungsten halogen lamps arriving at the wafer surface is estimated to be about 6 W/cm^2. The temperature of the $Hg_{1-x}Cd_xTe$ wafer is estimated by the thermocouple on silicon wafer which is placed at the vicinity of the $Hg_{1-x}Cd_xTe$ wafer. The chamber is evacuated to 50 mTorr. The sample is pre-heated under this condition for 5 seconds. The temperature of the silicon wafer is raised up to about 200°C at the end of the 5 second period. Next, the remaining Ag is stripped and Au film is formed by immersing the $Hg_{1-x}Cd_xTe$ in $AuCl_3$ solution. After the PR strip, Pb/In pad metals are piled up by the lift-off process. The wafer is then post-annealed in the rapid thermal equipment again using the same temperature cycle as the pre-heating process.

To measure the specific contact resistance and to compare I-V characteristics of Au/p-$Hg_{1-x}Cd_xTe$ contacts, transmission line model (TLM) [5] patterns are fabricated. Ruther-ford back scattering spectroscopy(RBS) and differential Hall measurement are utilized to examine the mechanism.

Ⅲ. Results and Discussion

TLM patterns in this experiment consist of 5 metal contacts with separations of 40, 50, 60 and 70㎛. Each contact pad is 400㎛ in width and 200㎛ in length. Typical I-V characteristics between two Au contacts are shown in Fig. 2.

These I-V curves are measured at 80K from the two points of the TLM pattern separated by 40㎛. Figure 2(a) is the I-V characteristics of the pattern which is fabricated without any thermal treatment. The curve shows non-linear and highly resistive characteristics indicating non-ohmic behavior. Figure 2(b) is obtained from the sample which received the local pre-heating described above and Fig. 2(c) is obtained from the sample the contact of which was post-annealed without the pre-



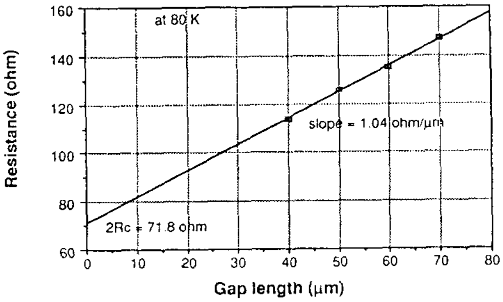
(a) (b)

(c) (d)

그림 2. 열처리에 따른 Au/ p-$Hg_{0.7}Cd_{0.3}Te$ 접촉의 특성 (a) 아무 열처리도 가하지 않은 경우 (b) 접촉전 열처리를 가한 경우 (c) 접촉후 열처리만 가한 경우 (d) 접촉 전후에 모두 열처리를 가한 경우

Fig. 2. Typical I-V characteristics of Au/ p-$Hg_{0.7}Cd_{0.3}Te$ contacts measured at 80K. (a) with no thermal process (b) after metallization over the pre-heated surface (c) after post-annealing the sample of Fig. 2(a) (d) after post-annealing the sample of Fig. 2(b)

heating process. The gradients of the curve (b) and the curve (c) at 0 V are far steeper than that of curve (a) indicating reduced contact resistance but still show non-ohmic characteristics. However, when both the local pre-heating and the post-annealing processes are used, a good ohmic contact is obtained as shown in Fig. 2(d). Good ohmic contact characteristics have been obtained uniformly and reproducibly in several $Hg_{0.7}Cd_{0.3}Te$ wafers. Figure 3 is the plot of resistance versus gap length between the contacts of TLM patterns in the sample of Fig. 2(d) in which the values of the resistance are measured at 80K. From Fig. 3, the specific contact resistance is estimated to be as small as $5\times\ 0^{-3}$ $\Omega\mathrm{m}^2$, which is the lowest value reported to the authors′ knowledge.



a. Contact Resistance R_c = 71.8/2 = 35.9 ohm
b. Transfer Length l_t = R_c/slope = 34.5 μm
c. Specific Contact Resistance

$$\rho_c = R_c\, l_t\, W = 35.9 \times 34.5 \times 400 \times 10^{-8} = 5.0\times10^{-3}\ \text{ohm cm}^2$$

그림 3. TLM 패턴의 측정으로부터 접촉저항율을 추출하는 방법

Fig. 3. Method to extract specific contact resistance from TLM pattern.

Figure 4 shows RBS random and aligned spectra of two $Hg_{1-x}Cd_xTe$ samples which were observed before and after 200℃ 30 sec annealing. The samples were uncapped during the annealing process. The difference between the two random spectra corresponds to the absence of Hg atoms in the near surface region. Then, the RBS spectra were simulated by convolving a Gaussian for the system resolution with a complementary error function for the diffusion profile. This was done for various surface concentrations of Hg and various values of diffusion constants to fit the measured spectra. The best-fitting simulated spectra gives us the Hg loss profile near the surface as shown in Fig. 5. The loss

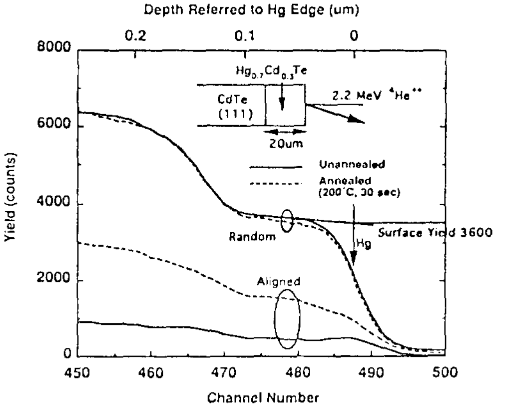


그림 4. 200℃ 30초의 열처리를 받은 $Hg_{0.7}Cd_{0.3}Te$ 표면층의 RBS 스펙트럼

Fig. 4. RBS random and aligned spectra which were observed before and after 200℃ 30sec annealing.

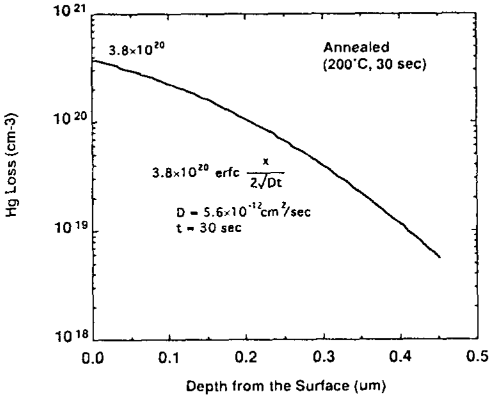


그림 5. 그림 4의 RBS 스펙트럼으로부터 가상할 수 있는 Hg 유실 프로파일

Fig. 5. Hg loss profile simulated from the measured RBS spectra.

is distributed with an error function which has the uppermost layer value of about 4×10^{20} cm^{-3}. This tremendous Hg loss explains clearly the deterioration of the crystallinity near the surface of the annealed sample which can be deduced from the aligned spectra of Fig. 4.

During the pre-heating process where the bare HgCdTe surface is heated, the Hg out-diffusion may take place to create mercury-vacancy acceptor sites which form a shallow p^+-doped layer on the surface[3]. The reason for using the Ag window in our process is to heat the surface locally so that the p^+-doped layers are formed only on the contact regions. The fact, that this local pre-heating process does not damage the epitaxial layer can be inferred from the sheet resistance of $Hg_{1-x}Cd_xTe$ epitaxial layer determined from Fig. 3. This value of about 400 Ω/square is not far from the value obtained from Hall measurement of this wafer which was performed before the fabrication of the TLM patterns.

However, differential Hall measurements indicate that the carrier concentration is not increased as much as expected with the large Hg loss near the surface even when the sample was annealed at 200℃ for 30sec. Therefore, we may conclude that the large Hg loss in the surface does not make many acceptor sites. Thus, the low ohmic contact resistance by the rapid thermal process can be attributted to the following two mechanisms; one is generation of numerous surface traps which reduces the life time at the metal-semiconductor contact, and the other is the increase of the gold diffusion rate during the post-annealing process promoted by the Hg loss which makes a fast path for the gold diffusion.

Ⅳ. Conclusion

We have successfully produced an extremely low-resistance extrinsic ohmic contact to $p\text{-}Hg_{1-x}Cd_xTe$ adopting the rapid thermal processes for local pre-heating and post-annealing, before and after forming electroless Au contacts. Since the proposed method is a rapid process lasting only 5 seconds, it is expected to be nearly harmless to the device performance due to the reduced thermal energy to the $Hg_{1-x}Cd_xTe$ device which is sensitive to high temperature processes.

Acknowledgements

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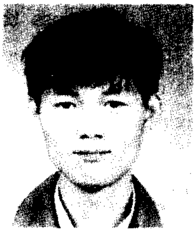

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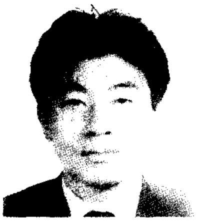

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