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**Research Paper**

# A study of Physically Implanted Surface Islands by direct Nd:YAG Laser Beam Irradiation

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**Abstract** Physically implanted surface islands of Nano Carbon Tube (NCT) and α-$Fe_2O_3$ particles have been produced on Al-doped ZnO (AZO)/glass surfaces by simple and direct ND:YAG laser beam irradiation. Sheet resistance of the reconstructed surface increased by about 3.6% of over AZO. Minimal surface damage can be repaired by ND:YAG laser beam irradiation in conjunction with proper impurities. Implanted islands of NCT, which are considered to be a good conductive impurity, on AZO increased the sheet resistance by about 1.8%, while implanted islands of α-$Fe_2O_3$, an insulating impurity, on AZO increased sheet resistance by about 129% compared with a laser beam treated AZO. This study provides insight regarding surface implantations of nanowires and micro-circuits, doping effects for semiconductors and optical devices, surface area and impurity effects for catalysis.

**Keywords:** ND:YAG LASER, IMPLANT, AZO, Nano Carbon tube, α-$Fe_2O_3$

## I. Introduction

Surface structures within conducting layers are of great importance in terms of electrical conductivity.[1-3] The current passing through such surfaces is very similar to the movement of waves on the seashore. The flow of seawater is affected by physically embedded rocks and islands on the seashore. Thus, the study of physically embedded surface islands within materials is an important area of surface physics. Creation of the interstitial islands on the thin film surface by laser beam irradiation is useful to produce physical surface islands regardless of ionization of materials, chemical reactions and side effects [4-6]. The electric properties of impurity islands on the thin film surface follow their unique electrical properties as surface point defects [7,8]. For general conductive thin films, the creation of surface islands, which follow their unique physical properties, should be useful for surface implantations of nanowires and micro-circuits, doping effects for semiconductors and optical devices, surface area and impurity effects for catalysis.

The Nd:YAG laser produces useful and powerful beam irradiation to implant particle islands on thin films [9]. Surface islands should be studied regarding the reconstruction of surface point damage, the diffusion of the local poli-crystallizations, and the alteration of surface conductivity by Nd:Yag laser direct beam implantation [10,11]. Among the conductive thin layers that are not metals, Al-doped ZnO (AZO) thin films have been attracted much attention for their special properties such as, good conductivity, high transmittance, easy deposition process, low material cost, high thermal stability, chemical stability and so on [12-14].

In this study, we report the demonstration of physically implanted surface islands of Nano Carbon Tube (NCT) and α-$Fe_2O_3$ particles on AZO/glass substrates by high power Nd:Yag laser beam irradiation and the evolution of the electrical properties are discussed.

## II. Experimental Procedure

Al-doped ZnO films of ~100 nm thickness on glass were prepared as a substrate by R.F. magnetron sputtering.[12] Then, 2 cm × 2 cm AZO/glass substrates were cut into four 1 cm × 1 cm pieces. Nano carbon tube powder was selected for preparing conductive impurity islands, and α-$Fe_2O_3$ powder was used for insulating impurity islands in this work. A small amount of impurities was submerged in distilled water and stirred about 30 minutes. Impurities floated due to the surface tension of water and were put on the AZO/glass. Water was removed by absorptive paper.

Laser implants can be produced by the heat of laser

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irradiation as well as irradiation pressure. To confirm the effect of irradiation pressure, a laser beam progressed along a horizontal line and the sample surface was place perpendicular to the beam. The laser beam (5 mm diameter, 532 nm, 500 mW, and 4 ns.) radiated once, directly to the center of the sample surface. Wet powder particles could be adhered to the AZO surface by this beam, and were then dried for a week at room temperature. Heat treatment was avoided due to the possibility of chemical reactions.

Dried impurity particles on the AZO surface were implanted by direct laser beam. Samples were radiated at 2 mm intervals from the center, five times horizontally and three times perpendicularly to cover the surface. The highest beam power of the laser, 1064 nm, was selected to provide enough power for the implantation of impurity particles. There was no significant difference between the dried and wet states.

## III. Results and Discussion

Figure 1(a) shows a Scanning Electron Microscope (SEM) image at 50,000 × magnification, detailing the surface morphology of the AZO. The AZO grains were spread out uniformly. There were no C grains. Figure 1(b) shows the SEM image of the adhered NCT particles on the AZO/glass shot one time by the laser beam. It clearly shows the tube form of the NCT particles. Figure 1(c) shows the SEM image of the surface morphology of the implanted NCT on the AZO/glass. The tube form of the NCT particles was disrupted to form carbon particles, which were implanted on the AZO surface by 15 cycles of laser beam irradiation. The pressure of the Nd:YAG laser beam was powerful enough to smash and implant the impurity particles. Since the sample stood perpendicularly, a number of impurity particles had been dispersed outward by the laser beam shot. Figure 1(d) shows the Energy Dispersive Spectrometer (EDS) data of the NCT implanted AZO by 15 cycles of laser beam irradiation. There was no carbon detected from the AZO EDS data. Carbon was detected at a level of 3.14 At % in the EDS data from the NCT implanted AZO. Figure 1(e) shows the X-Ray Diffraction (XRD) data of the NCT implanted AZO. The peak of the AZO was enlarged, spread and divided into two peaks after 15 cycles of laser beam irradiation. This is a general behavior of thin films after laser beam irradiation [15]. The XRD data of the NCT implanted AZO showed similar behavior. A carbon peak was not found in the XRD data and it is thought that the amount of implanted carbon was below the level of detection for XRD.

The cross-section SEM image is helpful in clarifying the implantation structure. Figure 2 shows the cross-section SEM images of the NCT implanted AZO/glass after one cycle of laser beam irradiation. Figure 2(a) shows various penetration depths of the NCT particles on the AZO/glass. Each was measured at depths of 49.66 nm, 79.94 nm, and

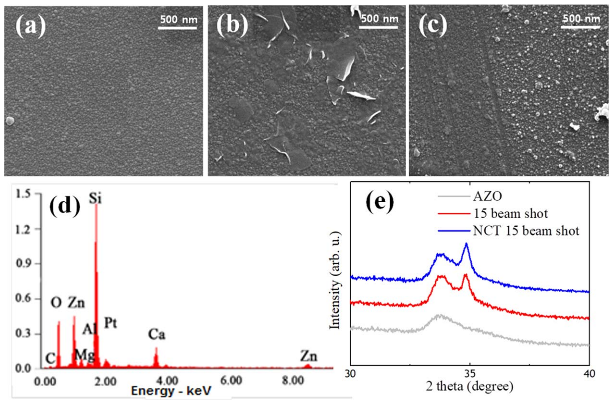


**Figure. 1. SEM images at 50,000 × magnification, EDS, and XRD data of the NCT implantation on AZO/glass. (a) SEM image of AZO. (b) SEM image of adhered NCT particles by 1 laser beam shot. (c) SEM image of implanted NCT by 15 cycles of laser beam irradiation. (d) EDS data and (e) XRD data of the NCT implanted AZO by laser beam irradiation 15 times.**

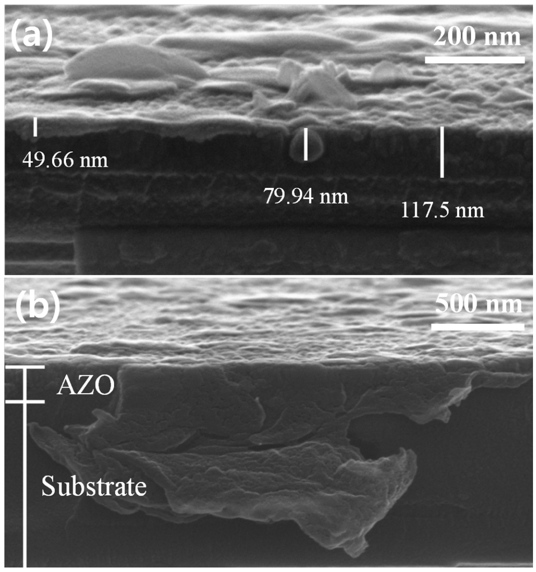


**Figure. 2. Cross-section SEM images of NCT implanted AZO by laser beam irradiation. (a) Implanted NCT particles on the AZO/glass. (b) Penetrated NCT particles into the glass substrate through the AZO layer.**

114.1 nm. Figure 2(b) shows the NCT particles that penetrated into the glass substrate through the AZO layer. One shot of the laser beam is enough to smash and implant the impurity particles.

Figure 3 shows the SEM images and XRD data of α-$Fe_2O_3$ particles implanted into AZO. Figure 3(a) shows a 2,000 × magnification SEM image of implanted α-$Fe_2O_3$ particles with one laser beam irradiation. It clearly shows α-$Fe_2O_3$ particles about 3 μm in size on the AZO surface. Figure 3(b) shows a 50,000 × magnification SEM image of an area free of implantation. This indicated that the surface of the AZO grains was reconstructed by laser beam irradiation. The size of most small grains was about 3 nm. The size of the big grains was about 80 nm. The laser beam shot reconstructed the surface grains to a size below

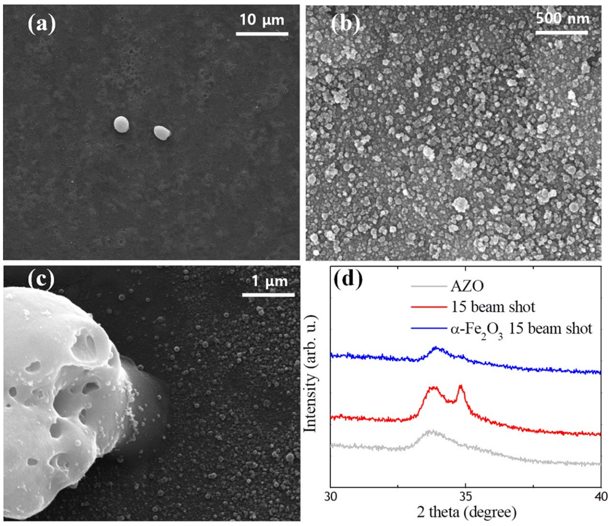


**Figure. 3. SEM images and XRD data of α-$Fe_2O_3$ particles implanted into AZO. (a) 2,000 × magnification SEM image of the implanted α-$Fe_2O_3$ particles after one cycle of laser beam irradiation. (b) 50,000 × magnification SEM image of a non-implanted area. (c) 30,000 × magnification SEM image of (a). (d) XRD data of α-$Fe_2O_3$ implanted AZO by 15 cycles of laser beam irradiation.**

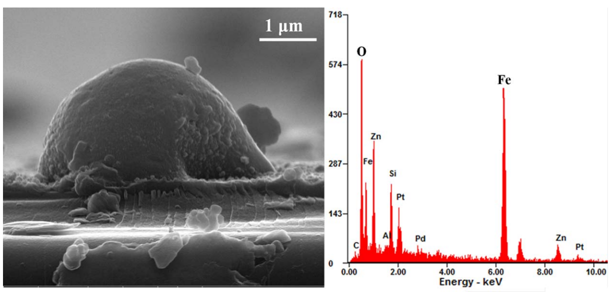


**Figure. 4. Cross-section SEM image and EDS data of α-$Fe_2O_3$ implanted AZO.**

100 nm [16]. This meant that surface point damage below 100 nm sizes can be recovered by laser beam irradiation. Figure 3(c) shows a 30,000 × magnification of the SEM image depicted in Fig. 3(a). It shows a partially melted area of α-$Fe_2O_3$ particles by the instantaneous heat of the laser beam. This partial melting behavior helped the solid implantation of the impurity particles. Both the pressure and the heat of the Nd:YAG laser beam contributed to physical implantation of the impurity particles. Figure 3(d) shows the XRD data of the α-$Fe_2O_3$ particles implanted on the AZO. The XRD data of the α-$Fe_2O_3$ implantation shows a different behavior with NCT implantation. It is similar to the AZO rather than the laser beam treated AZO.

Figure 4 shows the cross-section SEM image and EDS data of the α-$Fe_2O_3$ implanted AZO. Figure 4 shows an implanted α-$Fe_2O_3$ particle about 3 μm size on the AZO/glass. It shows some melting borders of the α-$Fe_2O_3$, several tiny fragments around the particle and permeated AZO. The EDS data around this particle shows a relatively high and increased Fe peak.

A comparison of the sheet resistances is the best way to understand the effects of surface islands on the current passing through thin films [17]. Sheet resistance was measured by a 4 point probe. The average sheet resistance of the AZO reference was 918.59 $\Omega/cm^2$. The average sheet resistance of the AZO radiated for 15 cycles with the laser beam was 952.11 $\Omega/cm^2$, which was about 3.6% of the incremental sheet resistance compared with AZO. The average sheet resistance of NCT implanted AZO is 969.42 $\Omega/cm^2$, which was about 1.8% of the sheet resistance compared with laser beam treated AZO and 5.5% of the incremental sheet resistance compared with AZO. The average sheet resistance of α-$Fe_2O_3$ implanted AZO was 2181.27 $\Omega/cm^2$, which is about 129% of the incremental sheet resistance compared to laser beam treated AZO.

An incremental increase of about 3.6% of the sheet resistance between the AZO and laser beam radiated AZO can be understood to be caused by surface reconstruction of AZO grains from Fig. 3(b). Even NCT is a very good conductor; there is about a 1.8% incremental increase in sheet resistance compared with laser beam treated AZO. It is thought that the implanted NCT islands have lost their characteristic tube form. Another possible consideration is that there might be imperfect contact on the border line of the wrecked and smashed NCT islands by laser beam irradiation. As a simple consideration, it is acceptable that about 129 % of the incremental sheet resistance of α-$Fe_2O_3$ implanted islands to compare with laser beam treated AZO. Implanted insulator islands increase the resistance on the current passing throw surface. However, a resistance of 2181.27 $\Omega/cm^2$ as an insulator is not so high in a series connection, and not so low in a parallel connection. To understand this, more study regarding the tiny surface islands on the current passing throw surface is needed.

## IV. Conclusions

In this study, a smoothly spread AZO surface has been reconstructed by Nd:YAG laser beam irradiation on the entire surface. By reconstructing surface grains, the sheet resistance increased by about 3.6% compared with the AZO. Some minimal surface damage can be repaired by Nd:YAG laser beam irradiation with proper impurities. Physically implanted surface islands of NCT and α-$Fe_2O_3$ particles have been produced on an AZO/glass by simple and direct Nd:YAG laser beam irradiation. Through XRD, SEM, EDS measurements, NCT and α-$Fe_2O_3$ particle islands were identified in successful implantation on the AZO surface. Since there were only very tiny islands, very few in number, on the surface, small differences of sheet resistances were expected due to the characteristics of the parallel connection. Alterations of the sheet resistance by impurity islands are not as small as a simple parallel connection. On the other hand, the electric behaviors of physically implanted islands are acceptable. In simple consideration, they are conductor and insulator impurities.

It looks like physically implanted impurity islands have followed their unique electric properties. More study is necessary to understand the electric behaviors of the implanted surface islands.

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## References

[1] Y. J. Moon, H. Kang, K. Knag, S -J Moon, and J. Y. Hwang, *J. Electron. Mater*. 44, 1192 (2015).
[2] H. Kim, H. -H Park, and J. Kim, Mat. *Sci. Semicon. Proc.* 48, 79 (2016).
[3] Q. Qi, Y. Liu, H. Zhang, J. Zhao, and Z. Huang, *J. Alloy. Compd.* 678, 375 (2016).
[4] D. Murley, N. Young, M. Trainor, and D. McCulloch, *IEEE Trans. Electron. Dev.* 48, 1145 (2001).
[5] I. Ozerov, M. Arab, V. I. Safarov, W. Marine, S. Giorgio, M. Sentis, and L.Nanai, *Appl. Surf. Sci.* 226, 242 (2004).
[6] A. Medvid, P. Onufrijevs, and A. Mychko, *Nano-scale Res. Lett* 6, 582 (2011).
[7] W. Lin, R. Ma, W. Shao, and B. Liu, *Appl. Surf. Sci.* 253, 5179 (2007).
[8] R. Kumaravel, S. Bhuvaneswari, K. Ramamurthi, and V. Krishnakumar, *Appl. Phys. A* 109, 579 (2012).
[9] A. K. Dubey and V. Yadava, *J. Mater. Proc. Tech* 195, 15 (2008).
[10] F. Gonella, *Nucl. Instr. and Meth. in Phys. Res. B* 166, 831 (2000).
[11] Y. Q. Wang, M. Curry, E. Tavenner, N. Dobson, and R. E. Giedd, *Nucl. Instr. and Meth. in Phys. Res. B* 219, 798 (2004).
[12] H. Yu, M. Kim, Y. Kim, J. Lee, K. -K. Kim, S. -J. Choi, and S. Cho, *Electron. Mater. Lett* 10, 2 (2014).
[13] I. Volintiru, M. Creatore, and B. J. Kniknie, *J. Appl, Phys* 102, 043709 (2007).
[14] T. Minami, *Thin Solid Films* 516, 1314 (2008).
[15] G. Barucca, E. Santecchia, G. Majni, E. Girardin, E. Bassoli, L. Denti, A. Gatto, L. Iuliano, T. Moskalewicz, and P. Mengucci, *Mater. Sci. Eng. C* 48, 263 (2015).
[16] H. Sankur and J. T. Cheung, *Appl. Phys. A* 47, 271 (1988).
[17] K. S. Kim, Y. Zhao, H. Jang, S. Y. Lee, J. M. Kim, K. S. Kim, J. -H. Ahn, P. Kim, J. -Y. Choi, and B. H. Hong, *Nature* 357, 706 (2009).