Temperature annealing effect on ITO film

To cite this article: K P Kotlyar et al 2018 J. Phys.: Conf. Ser. 1124 041035

View the article online for updates and enhancements.

You may also like

- Pulsed laser deposited indium tin oxides as alternatives to noble metals in the near-infrared region
  Xu Fang, C L Mak, Shiyu Zhang et al.

- Development of EGFET-based ITO pH sensors using epoxy free membrane
  Naser M Ahmed, Fayroz A Sabah, Nal H Al-Hardan et al.

- Wet etching mechanism and crystallization of indium–tin oxide layer for application in light-emitting diodes
  Shui-Hsiang Su, Hsieng-Jen Kong, Chun-Lung Tseng et al.
Temperature annealing effect on ITO film

K P Kotlyar¹, D A Kudryashov¹, I P Soshnikov¹,²,³, A V Uvarov¹, R R Reznik⁴
¹St. Petersburg Academic University of the RAS, Khlopin 8/3, St. Petersburg 194021, Russia
²Ioffe Physical-Technical Institute of the RAS, Politekhnicheskaya 26, St. Petersburg 194021, Russia
³Institute for Analytical Instrumentation of the RAS, Rizhsky 26, St. Petersburg 198095, Russia
⁴ITMO University, Kronverkskiy pr. 49, St. Petersburg 197101, Russia

Abstract. In the work we investigate processing and optoelectronic properties of ITO films coated on glass and Si substrates using RF magnetron deposition. Temperature annealing modifies the properties of the ITO film that affects the final characteristics of devices where they are used. It was discovered that a great change of characteristics is observed by annealing under the temperature of 200°C: the increase of the transmission up to 90% and decrease of film resistance from 160 to 40 Ω·□⁻¹. The ρc is 4·10⁻³Ω·cm² for Au and 2·10⁻³Ω·cm² for Ag contacts.

1. Introduction
Thin films of indium tin oxide (ITO) are a unique material that combines good electrical conductivity and optical transparency [1-7]. ITO is used as a transparent ohmic contact and current spreading layer in different types of solar cells, LEDs, to make transparent conductive coatings for displays, etc. The ITO also has good chemical stability [5]. In development of devices with using ITO films it is critical to consider the initial properties of the films and their compatibility with the device, as well as the method and conditions of their depositing [1, 2]. All these parameters influence the final characteristics of the device; it is especially important for devices with increased temperature sensitivity (organic LEDs, solar cells based on nanowires, etc.). One of the ways of processing devices is deposition of conducting ITO film without the heating of the sample and modification of the properties of films received by low-temperature heating. This work is dedicated to the research of optoelectronic properties of ITO films under thermal annealing.

2. Experiment
ITO thin films were deposited on glass (2x2 cm²) and Si(111) substrates by RF magnetron sputtering (BOC Edwards Auto 500 RF) at a power of 50 W and argon pressure of 1.3 mTorr [1]. 3 inch target with a composition of 90% In₂O₃-10%SnO₂ was used. It is deposited without heating the samples. Distance between target and substrate was 100 mm. The sputtering chamber was evacuated to less than 5·10⁻⁶ mbar prior to deposition. All the ITO samples were with film thickness about 100 nm. Film thickness was measured with a profiler AMBiOS XP-1. The surface morphology is studied using scanning electron microscopy (SEM). Same glasses were heated on the hot plate at 100 and 200°C for 1 hour under atmospheric pressure. The resistivity of ITO films was measured with a TLM probe method. Au and Ag contacts were formed by photolithography methods. The optical transmittance of
the films was measured using spectrophotometer based on Solar Laser Systems M266 monochromator. Then, the ITO contact was formed and investigated for semiconductor devices: InGaN/GaN LEDs and piezonanogenerators.

3. Results and discussion

3.1. Electrical properties

At an annealing temperature below 200°C, the resistance of ITO layer did not change. As a result of annealing at 200°C, the resistance decreased from 160 to 38 Ohm·□⁻¹. This result correlates with the data for the annealing of films obtained by other deposition methods [5]. We formed two types of contacts: samples with Ag or Au contact for ITO. Resistance of Ag/ITO turned out to be less than Au/ITO (4·10⁻³ vs. 2·10⁻³ Ohm·cm²) and slightly depended on the annealing temperature of the ITO film. This may be due to the higher relative affinity of work function from silver and ITO than to gold (4.62 eV for ITO [3], 4.7 eV for Ag and 4.8 eV for Au). Also note that the measured film resistance for samples with Ag contacts was lower and equalized for both types of metallization after annealing. The increase in annealing temperature may have led to oxygen-deficient films and changing crystalline structure of films [2, 5].

3.2. Optical properties

As can be seen from figure 1 for samples that are not subjected to heat treatment and annealed at 100°C, the optoelectronic properties remained practically unchanged. As a result of annealing at 200°C, the transmission coefficient of the film increases, especially in the short-wave region (350-480 nm) important for blue LEDs. A study of the morphology of the ITO film deposited on Si before and after annealing by the SEM method did not reveal any differences. The film has a weakly expressed texture and microcrystalline structure. In [5-7], a similar change in the optoelectronic properties is explained by a change in the structure of the films. Firstly, the number of oxygen vacancies is changed and consequently changed light absorption and free-electrons. Secondly, the film crystalline structure changes (from amorphous to crystalline). Thus, in order to improve the conductivity and the transmission of the ITO film, it must be annealed at higher than 200°C. Also, based on the results presented in the paper, one can choose the preferred type of metallization.

![Figure 1](image.png)

**Figure 1.** Dependence of the transmission coefficient of the ITO film on the annealing temperature.

3.3. Formation of ITO contact for semiconductor devices

Figure 2 shows the LED design (a) based on planar technology and the transition to three-dimensional nanostructures - nanorods or nanowires (NWs) [8]. When investigating the optoelectronic properties...
of such structures, it is necessary to form contacts. One of the ways - the formation of the top contact - coating ITO. The space between NWs is filled with a polymer. Note that such a design is suitable not only for the formation of vertically radiating structures but also for photovoltaic and vertical integrated nanogenerators. The presence of a complex structure implies the setting annealing modes. Therefore, annealing at 200°C is suitable for us. Figure 3 shows SEM images in the cross-section geometry of 100 nm ITO on Si and an example of the top contact of the ITO for the array of GaAs NWs. In the image, you can see the tops of the NWs covered by the ITO sticking out of the ITO layer. This technology is tested and works well for creating test prototypes of various devices.

Figure 2. Designs of LED.

Figure 3(a, b). The cross section (a) view of the ITO film; The isometric view (b) of the top ITO contact for GaAs nanowire array.

4. Conclusion
The change of characteristics is observed by annealing under the temperature of 200°C: the increase of the transmission up to 90% and decrease of film resistance from 160 to 40 Ohm·□⁻¹. The $\rho_c$ is $4 \cdot 10^5 \Omega\cdot\text{cm}^2$ for Au and $2 \cdot 10^3 \Omega\cdot\text{cm}^2$ for Ag contacts. This result can be used for create nanostructure devices with increased temperature sensitivity

Acknowledgments
The study of ITO properties were financially supported by the Russian Foundation for Basic Research (project 18-07-01364 A) and FASIE. The nanowire samples were grown under the support of the Ministry of education and science of Russian Federation (state task, project No. 16.9791.2017/8.9).
References
[1] Kudryashov D, Gudovskikh A, Zelentsov K 2013 Solid State Phenomena 200 10
[2] Yakovlev S P, Soshnikov I P, Korabiev V V, Poloskin D S, Yagovkina M A 2004 J. Surf. Invest.: X-Ray, Synchrotron Neutron Tech. 4 57
[3] Sihm K H, Paek M C, Lee B T, Kim C, Kang J Y, 2001 Appl. Phys. A 72 471
[4] Lin Y C, Chang S J, Su Y K, Tsai T Y, Chang C S, Shei S C, Kuo C W, Chen S C 2003 Solid-State Electron. 47 849
[5] Reza Fallah H, Ghasemi M, Hassanzadeh A, Steki H 2007 Mater. Res. Bull. 42 487
[6] Koseoglu H, Turkoglu F, Kurt M, Yaman M D, Akca G K, Gulnur A, Ozyuzer L 2015 Vacuum
[7] Reza Fallah H, Ghasemi M, Javad Vahid M 2010 Renewable Energy 35 1527
[8] Tsai Y.-L., Lai K.-Y., Lee M.-J., Liao Y.-K., Ooi B. S., Kuo H.-C., He J.-H. 2016 Prog Quantum Electron. 49 1