A metamaterial based on titanium nitride nanoantennas for efficient absorption of solar energy in flexible solar cells combined with thermoelectric generator

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The prospects for the use of metamaterial based on TiN and TiON nanoantennas for the most efficient absorption of solar radiation in a wide range of wavelengths in a combined device, including a photovoltaic cell and thermoelectric generator, are analyzed.

INTRODUCTION

Currently, the issue of efficient conversion of solar energy into electrical one is of considerable interest [1, 2]. Photovoltaic converters can convert only a part of the solar spectrum, while at the same time much of the energy is absorbed as heat. In order to avoid energy losses, devices containing both a photovoltaic converter and a power thermoelectric generator can be used. In thermoelectric generators, thermal energy is converted into electrical voltage due to the Seebeck effect, which is caused by the movement of charge carriers under the action of an external heat flux. Thus, part of the solar spectrum (especially in the infrared region) passes through a polymer photocell and can be used as an additional source of energy. The basic idea of a combined solar cell is to make the most complete use of solar radiation, including the part of the spectrum that has passed through the photocell. For a more efficient absorption of transmitted radiation in a wide range of wavelengths, it is effective to use a metamaterial thin film based on a refractory material, such as TiN, TiON [3, 4].

THEORETICAL STUDY

The optical characteristics of the metamaterial light absorbing film were calculated on the basis of the finite difference method (FEM) in the Lumerical FDTD software [5]. The absorption was calculated on the basis of S-parameters as follows: $A = 1 - R - T$, where $R = |S_{11}|^2$ and $T = |S_{12}|^2$ are reflection and transmission coefficients, respectively.

RESULTS AND DISCUSSION

Since the spectral range, in which surface plasmons can be excited, is very limited for sunlight, therefore the best solution is to use the structure shown in Fig. 1a. Part of the energy of sunlight is absorbed by the excitation of plasmon resonance, while the other part is absorbed by a continuous film of metamaterial. The results of numerical simulation of metamaterial absorption are shown in Fig. 1b for gold (Au), titanium nitride (TiN), titanium nitride (TiN) synthesized in Prof. Shalaev group (for comparison), and titanium oxynitride (TiON). Despite the fact that a thin TiN film (obtained in Prof. Shelayev group) exceeds the TiN film in terms of absorption efficiency, the TiON film provides a higher (by 8%) efficiency of integrated absorption in the infrared region (as shown in Fig. 1b). For comparison, this figure shows the spectrum of sunlight. Thus, TiON films can potentially be used to create ideal absorbers as the elemental base of thermal photovoltaics.

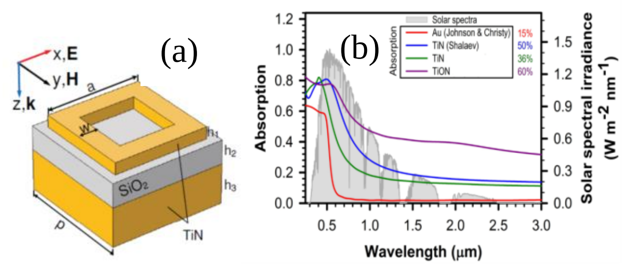

Fig. 1 (a) Schematic picture of the functional element of the meta-surface. (b) Absorption spectra of a thin film of Au, TiN and TiON.

CONCLUSION

It has been shown that titanium nitride (TiN) and titanium oxynitride (TiON) are the most promising metamaterials for efficient absorption of radiation in a wide range of wavelengths. The use of metamaterial in a combined device, including a photocell and a thermoelectric converter, allows achieving an additional increase in the absorption of solar energy due to its conversion into thermal energy, which is subsequently used to generate electrical energy by a thermoelectric generator. This concept may play an important role in the development of a new generation of flexible high-efficiency solar cells.

REFERENCES

1. M.A. Green and S.P. Bremner, Nature Mater. 16, 23-34 (2017)

2. P.K. Nayak, S. Mahesh, H.J. Snaith and D. Cahen, Nature Rev. Mater., 4, 269-285 (2019)

3. W. Li et. al, Adv. Mater. 26(47), 7959-7965 (2014)

4. Z. Liu et. al, Sol. Energy Mater. Sol. Cells 179, 346-352 (2018)

5. Lumerical Solutions, Inc. URL: https://www.lumerical.com/products/fdtd-solutions/

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