

Study of Optical Specifications of $\text{HfO}_2/\text{Y}_2\text{O}_3$, $\text{Sc}_2\text{O}_3 + \text{MgO}$, and $\text{Ta}_2\text{O}_5 + \text{TiO}_2$ Used as Resonator Reflector for Nd:YAG Laser (1064 nm)

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Abstract

A theoretical design of a multi-layer for Nd:YAG mirrors resonator is described in this work. An output coupler was designed and fabricated by successive thin layers to achieve very high transmittance at optical wavelengths around 1064 nm for Nd:YAG mirrors resonator. The different film optical filters were used to control the transmittance and reflectance. The three samples of dielectric materials composed of $\text{HfO}_2/\text{Y}_2\text{O}_3$, $\text{Sc}_2\text{O}_3 + \text{MgO}$, and $\text{Ta}_2\text{O}_5 + \text{TiO}_2$ were used and compared with each other in transmittance, reflectance, full width at half maximum (FWHM), physical thickness, optical thickness, geometric thickness, and incident angles by the software [1].

Keywords

Optical Filters, Nd-YAG Laser Resonator, Multi-Layers Thin Films

1. Introduction

Nd:YAG crystal is the most widely used solid-state laser medium due to its excellent optical and mechanical properties. Generally, most of the researches on Nd:YAG lasers focused on ${}^4\text{F}_{3/2} - {}^4\text{I}_{11/2}$ transition at the 1064 nm wavelength and also focused on how to develop the Nd:YAG resonator in this wavelength [2].

2. Theory

The design of the thin film reflectors for 1064 nm are $\text{Air}/(\text{HL})^{45}/\text{substrate}$ where n is a real number. These reflectors consist of layers of two different materials

alternately deposited on a substrate. Each layer has a thickness of one-quarter of the reference wavelength (1064 nm) [3]. The large difference between the refractive indices of the materials can improve the optical characteristics of the filters. The materials used here were $\text{HfO}_2/\text{Y}_2\text{O}_3$, $\text{Sc}_2\text{O}_3 + \text{MgO}$, and $\text{Ta}_2\text{O}_5 + \text{TiO}_2$. **Table 1** gives full details of the transmittance spectrum for different materials with varying thickness and the results of the different reflectors which were designed by alternating dielectric multilayer films using H for a high index and L for a low index, to meet the requirements of the high reflection for 1064 nm, for full information of these dielectric materials [4].

Table 1. Main parameters for filters designed from dielectric materials as reflectors of dielectric materials 1064 nm.

Materials	Refractive index	Physical thickness (nm)	No. of layers	Filter design	Reflect. (%)
$\text{HfO}_2/\text{Y}_2\text{O}_3$	1.88867/1.77300	13,089.07	90	(HL) ⁴⁵	99.10
$\text{Sc}_2\text{O}_3 + \text{MgO}$	1.85000/1.70000	10,809.16	72	(HL) ³⁶	99.39
$\text{Ta}_2\text{O}_5 + \text{TiO}_2$	2.10000/2.2500	8697.78	70	H(HL) ³⁵	98.91

Figures 1-3 show the relationship between reflectance (%) and the wavelength in the range between 800 to 1400 nm for different reflectors materials with maximum reflectance at 1064 nm. We need to titrate these different materials to choose the best material for a back mirror of Nd: -YAG Laser (1064 nm).

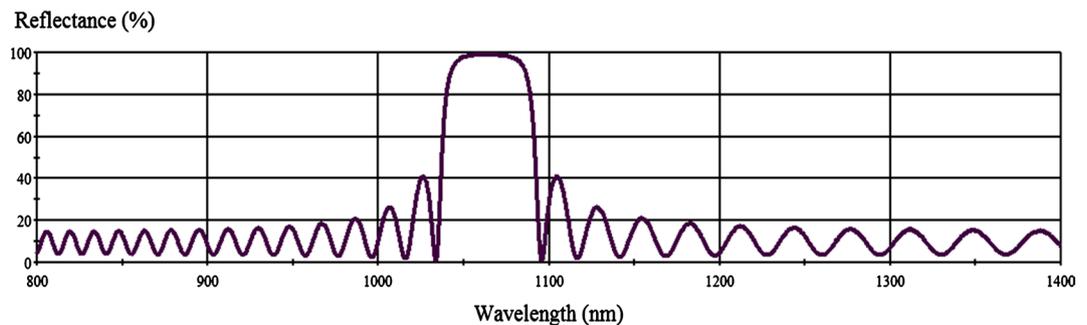


Figure 1. Reflectance (%) of $\text{HfO}_2/\text{Y}_2\text{O}_3$ in the range between 800 and 1400 nm.

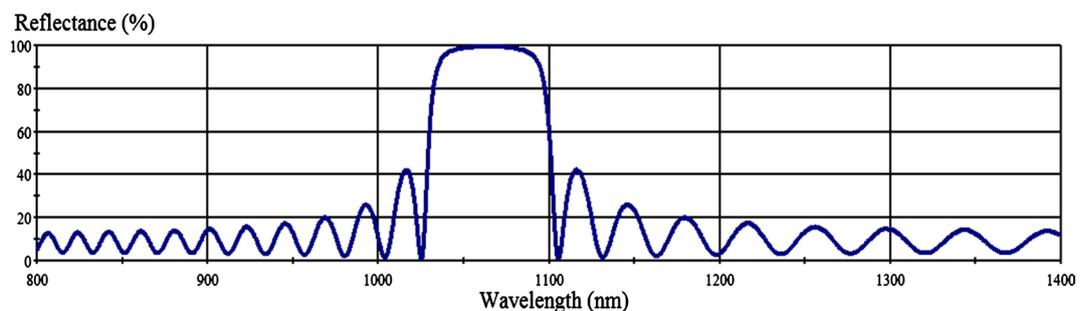


Figure 2. Reflectance (%) of $\text{Sc}_2\text{O}_3 + \text{MgO}$ in the range between 800 and 1400 nm.

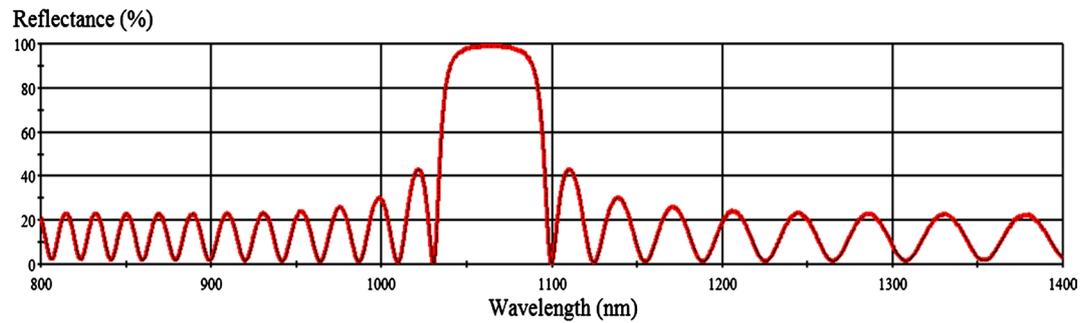


Figure 3. Reflectance (%) of $\text{Ta}_2\text{O}_5 + \text{TiO}_2$ in the range between 800 and 1400 nm.

Also, **Table 1** gives the full details of the reflectance spectra for the different materials chosen to design good reflectors for 1064 nm. The optimal design, with certain optical parameters, of the components using admittance loci analysis is simple, easy, and promising [5]. By using the thin-film account and the help of the program one can get good results for the reflector with various thicknesses. The results showed that the majority of these multi-layered dielectric materials are suitable for Nd-YAG back mirrors.

3. Titrations and Results of Three Dielectric Materials $\text{HfO}_2 + \text{Y}_2\text{O}_3$, $\text{Sc}_2\text{O}_3 + \text{MgO}$, and $\text{Ta}_2\text{O}_5 + \text{TiO}_2$

To examine the performance of the other oxides, different samples composed of $\text{HfO}_2/\text{Y}_2\text{O}_3$, $\text{Sc}_2\text{O}_3 + \text{MgO}$ and $\text{Ta}_2\text{O}_5 + \text{TiO}_2$ were used to design high reflectance and low transmittance mirrors for Nd-YAG laser (1064 nm) and titration them with each other in reflectance, Full width at half maximum (FWHM), physical thicknesses, optical thickness, geometric thickness, and incident angles.

The first titration: the reflectance (%) for materials.

Figure 4 shows the reflectance (%) for each dielectric material to the 1064 nm. The value of reflectance (%) is almost the same for all-dielectric materials with

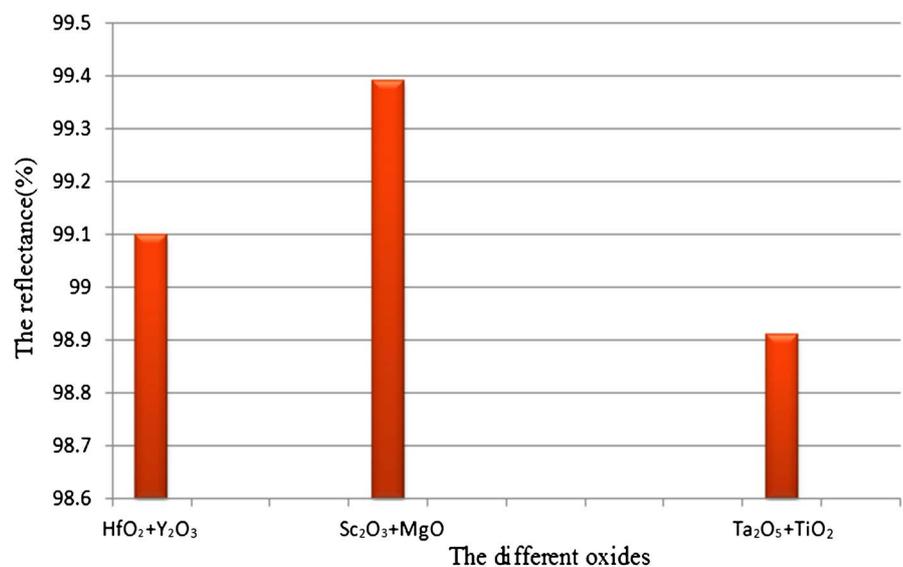


Figure 4. The reflectance (%) for different samples composed of different oxides.

no clear difference [6]. Because of this, we need other standards for choosing the best dielectric materials, which have better properties.

The second titration: the different dielectric materials with full width at half maximum (FWHM).

Figure 5 shows a Full width at half maximum (FWHM) for each dielectric material to the 1064 nm. The value of Full width at half maximum (FWHM) is nearly the same for all-dielectric materials with no difference. Because of this, we need other standards for choosing the best dielectric materials, which have better properties for Nd-YAG back mirrors [7].

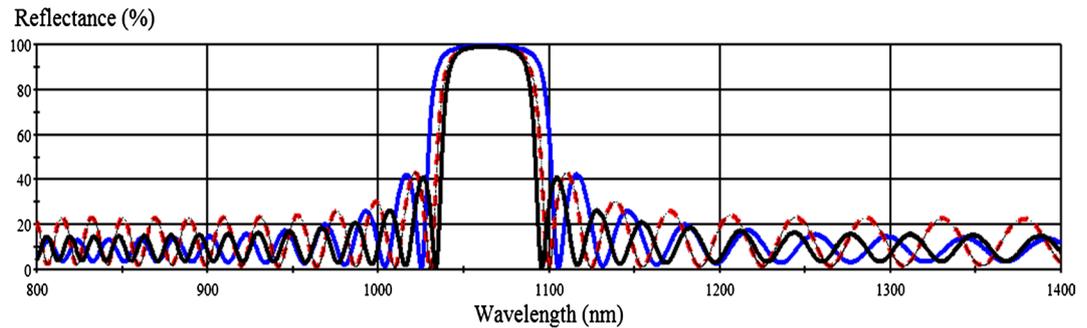


Figure 5. Comparison between the FWHM for three dielectric materials ($\text{HfO}_2 + \text{Y}_2\text{O}_3$, $\text{Sc}_2\text{O}_3 + \text{MgO}$, and $\text{Ta}_2\text{O}_5 + \text{TiO}_2$).

The third titration: the physical thickness (nm) for the materials.

The relationship between the total physical thickness [8] for thin-film coating and the types of material is shown in **Figure 6**. The thin film with the lowest physical thickness is $\text{Ta}_2\text{O}_5 + \text{TiO}_2$ which equals 8697.75 nm. The second one is $\text{Sc}_2\text{O}_3 + \text{MgO}$ which equals 10,809.16 nm. The third one is $\text{HfO}_2/\text{Y}_2\text{O}_3$, which equals 13,089.07 nm. The dielectric material ($\text{Ta}_2\text{O}_5 + \text{TiO}_2$) is the best in the manufacturing of mirrors because it has the lowest thickness. Directly one can suggest ($\text{Ta}_2\text{O}_5 + \text{TiO}_2$) as an aback mirror for 1064 nm.

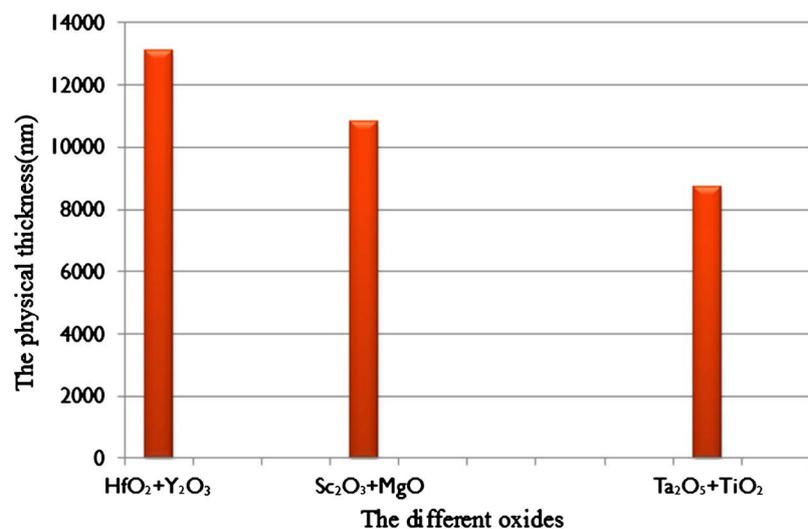


Figure 6. The physical thickness (nm) for different oxides mixtures.

The fourth titration: the geometric thickness for different oxides material.

Figure 7 shows the geometric thickness for different oxides material.

The smallest value of geometric thickness is for $Ta_2O_5 + TiO_2$ which equals 8.2 then for $Sc_2O_3 + MgO$ which equals 10.2 and finally is for HfO_2/Y_2O_3 , which equals 13.3. In thin-film coating, the smallest geometric thickness provides better coating [9]. Therefore, $Ta_2O_5 + TiO_2$ material is the best to act as a back mirror for 1064 nm.

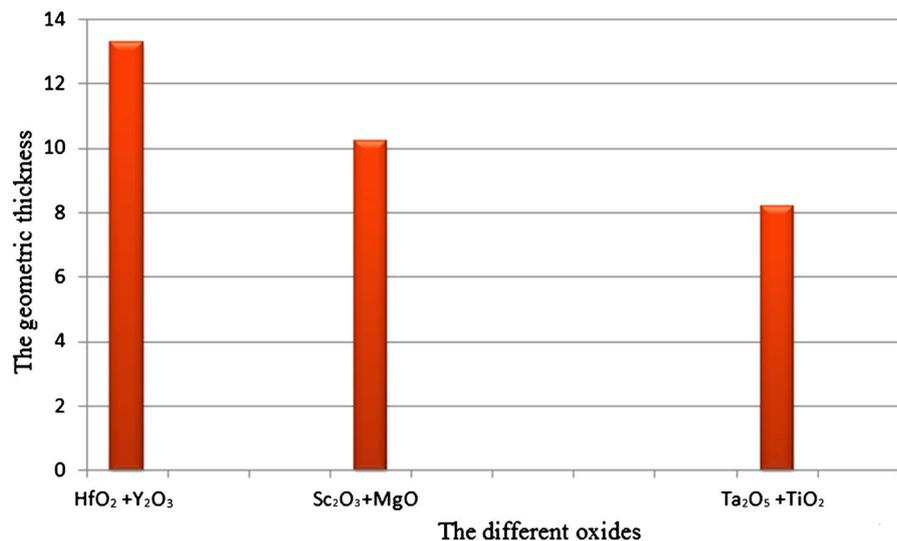


Figure 7. Relationship between the reflectance of different dielectric materials and total geometric thickness.

The fifth titration: the optical thickness for different oxide materials.

Figure 8 shows the optical thickness for different oxide materials.

The smallest value of optical thickness is for $Ta_2O_5 + TiO_2$, which equals 71 then for $Sc_2O_3 + MgO$ which equals 72 and finally is which is HfO_2/Y_2O_3 equals

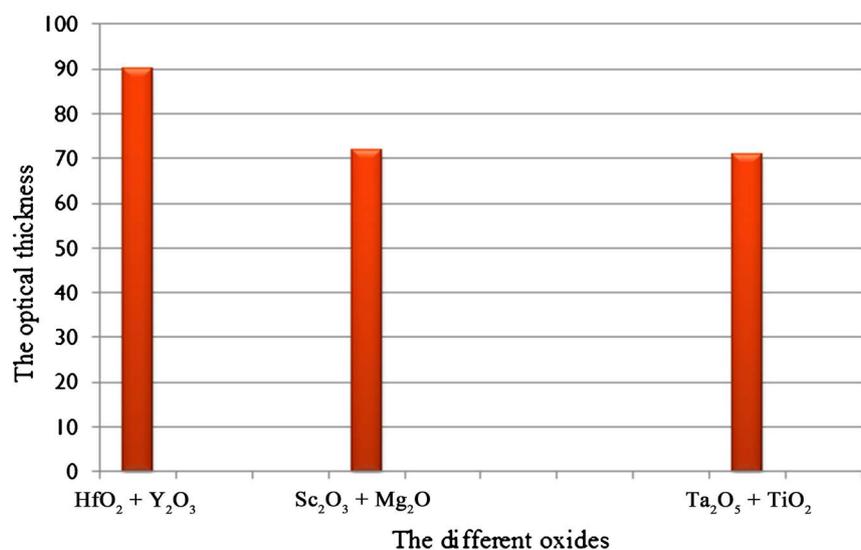


Figure 8. Relationship between different dielectric materials and total optical thickness.

90. In thin-film coating, the smallest optical thickness (depth thickness) provide better coating [10]. Therefore, $Ta_2O_5 + TiO_2$ material is the best to act as a back Nd-YAG Laser mirror.

The sixth titration: the relationship between the incidence angles and reflectance (%) for the oxides.

The materials $Ta_2O_3 + TiO_2$, $Sc_2O_3 + MgO$, and $HfO_2 + Y_2O_3$ with refractive indices 2.10000/2.25000, 1.85000/1.70000 and 1.88867/1.77300, respectively, were titrated with incidence angle. The filters designed of these oxides are ((LH)ⁿ) the wavelength reference was 1064 nm. Previous analyses showed that the reflectance (%), physical thickness, optical thickness, geometric thickness and Full width at half maximum (FWHM) of these three materials were almost similar in this demand. Therefore, the titration between the incidence angle and reflectance of oxide materials $Ta_2O_3 + TiO_2$, $Sc_2O_3 + MgO$ and $HfO_2 + Y_2O_3$ are needed. The results are listed in **Table 2** and **Table 3**.

Table 2. The incidence angles of dielectric materials in P-Polarized light and Reflectance (%) of the used materials.

$Ta_2O_3 + TiO_2$		$Sc_2O_3 + MgO$		$HfO_2 + Y_2O_3$	
Incidence angle	Reflectance (%)	Incidence angle	Reflectance (%)	Incidence angle	Reflectance (%)
0	98.91	0	99.40	0	99.10
5	98.90	5	99.39	5	99.00
10	98.81	10	99.31	10	98.95
15	98.54	15	97.52	15	98.31
20	97.62	20	79.23	20	93.90

Table 3. The incidence angles of dielectric materials in S-Polarized light and Reflectance (%) of the used materials.

$Ta_2O_3 + TiO_2$		$Sc_2O_3 + MgO$		$HfO_2 + Y_2O_3$	
Incidence angle	Reflectance (%)	Incidence angle	Reflectance (%)	Incidence angle	Reflectance (%)
0	98.91	0	99.40	0	99.10
5	98.92	5	99.40	5	99.11
10	98.92	10	99.40	10	99.10
15	98.80	15	99.30	15	98.70
20	98.40	20	98.60	20	96.50

From the two figures (**Figure 9** and **Figure 10**), we can see that the oxide materials $Ta_2O_3 + TiO_2$ have reflectance changed slightly with the incidence angle compared with the rest of the dielectric materials in P and S-polarized light. When we take into account all previous analyses and titrations of all oxide materials [11], we find that $Ta_2O_3 + TiO_2$ is the best compared to the rest of the dielectric materials. The results proved that this material is the best to be used as a back mirror for Nd:YAG Laser (1064).

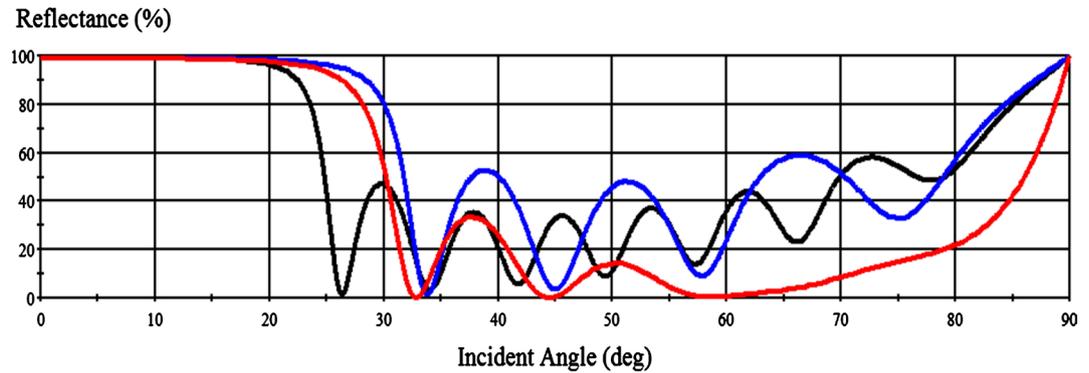


Figure 9. The reflectance of P-polarized light as a function of incidence angles for three dielectric materials ($\text{HfO}_2 + \text{Y}_2\text{O}_3$, $\text{Sc}_2\text{O}_3 + \text{MgO}$, and $\text{Ta}_2\text{O}_5 + \text{TiO}_2$).

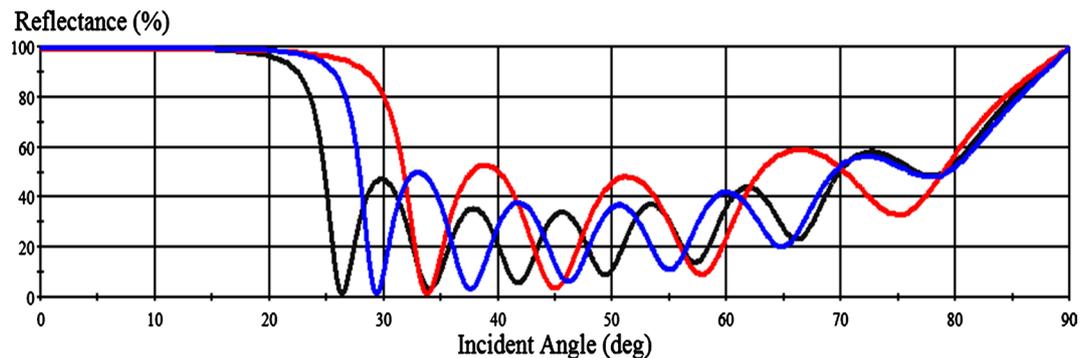


Figure 10. The reflectance of S-polarized light as a function of incidence angles for three dielectric materials ($\text{HfO}_2 + \text{Y}_2\text{O}_3$, $\text{Sc}_2\text{O}_3 + \text{MgO}$, and $\text{Ta}_2\text{O}_5 + \text{TiO}_2$).

4. Conclusions

From the obtained results, one can conclude that:

- 1) The best reflector among the chosen materials was $\text{Ta}_2\text{O}_5 + \text{TiO}_2$ with reflectivity for 1064 nm equal to 99.9%.
- 2) Among the chosen materials one can build Nd-YAG resonator composed of $\text{Ta}_2\text{O}_5 + \text{TiO}_2$ with 66 Layers as the back mirror.
- 3) By applying the one-quarter of the reference wavelength (1064 nm) in the calculations for thin film, the best results for Nd-YAG mirrors resonator were achieved.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

- [1] Choi, Y.J., Kim, J.Y., Nam, J.H., Lee, G.Y. and Kim, W.S. (2018) Clinical Outcome of 1064-nm Picosecond Neodymium-Doped Yttrium Aluminium Garnet Laser for the Treatment of Hypertrophic Scars. *Journal of Cutaneous Laser Therapy*, **21**, 91-98. <https://doi.org/10.1080/14764172.2018.1469768>
- [2] Schroeder, U., *et al.* (2018) Lanthanum-Doped Hafnium Oxide: A Robust Ferroelectric.

- lectric Material. *Inorganic Chemistry*, **57**, 2752-2765.
- [3] Balasingam, S.K., Lee, J.S. and Jun, Y. (2016) Freeze-Dried MoS₂ Sponge Electrodes for Enhanced Electrochemical Energy. *Dalton Transactions*, **46**, 2122-2128.
- [4] Qu, Y., Zoppi, G. and Beattie, N.S. (2015) Selenization Kinetic in Cu₂ZnSn (S,Se)₄ Solar Celles Prepared from Nanoparticle Inke. *Solar Energy Materials & Solar Cells*, **158**, 130-137.
- [5] Berner, U. and Widenmeyer, M. (2015) Solution-Based Processing of Cu(In,Ga)Se₂ Absorber Layers for 11% Efficiency Solar Cells via a Metallic Intermediate. *Progress in Photovoltaics: Research and Applications*, **23**, 1260-1266.
- [6] Kurdish, A.I. and Evseev, E.G. (2012) UVB Irradiance and Atmospheric Optical Depth at the Dead Sea Basin. *Renewable Energy*, **48**, 344-349.
<https://doi.org/10.1016/j.renene.2012.05.014>
- [7] Korkmaz, Ş., Elmas, S., Ekem, N., Pat, S. and Zafer Balbağ, M. (2012) Deposition of MgF₂ Thin Films for Antireflection Coating by Using Thermicnic Vacuum Arc (TVA). *Optics Communications*, **285**, 2373-2376.
<https://doi.org/10.1016/j.optcom.2011.12.095>
- [8] Angus Macleod, H. (2010) Thin-Film Optical Filters. 4th Edition, CRC Press, USA.
- [9] Chu, P.-J., Wu, S.-Y., Chen K.-C. and He, J.-L. (2010) Nano-Structured TiO₂ Films by Plasma Electrolytic Oxidation Combined with Chemical and Thermal Post-Treatments of Titanium, for Dye-Sensitised Solar Cell Applications. *Thin Solid Film*, **519**, 1723-1728. <https://doi.org/10.1016/j.tsf.2010.06.046>
- [10] Qi, Y., Zhu, X., Lou, Q., Ji, J., Dong, J. and Wei, Y. (2005) Nd:YAG Ceramic Laser Obtained a High Slope Efficiency of 62% in High Power Applications. *Optics Express*, **13**, 8725-8729. <https://doi.org/10.1364/opex.13.008725>
- [11] Xie, G., Tang, D., Kong, J. and Qian, L. (2007) Passively Q-Switched Nd:YAG Ceramic Laser with GaAs Saturable Absorber. *Pacific Rim Conference on Lasers and Electro-Optics*, Seoul, 26-31 August 2007, 1219-1220.
<https://doi.org/10.1109/cleopr.2007.4391698>