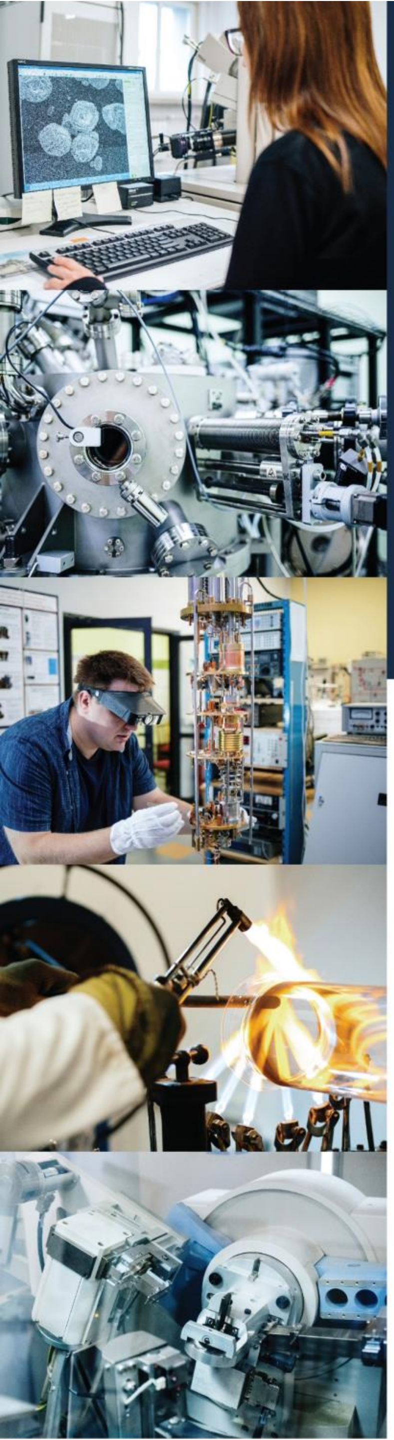

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Wieslaw Strek,
Przemysław Wiewiórski, Włodzimierz Miśta, Robert Tomala, Mariusz Stefanski

Laser induced generation of hydrogen from methanol, ethanol, water and methanol vapor by using graphene target

EcoPhotonics – Wildau, Germany

08.03.2022 | 13.00 – 16.00 UHR

EcoPhotonics – Photonik und künstliche Intelligenz für Nachhaltigkeit

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Laser-Induced Hydrogen Generation from Methanol with Graphene Aerogel as the Target

Wieslaw Strek, Przemyslaw Wiewiórski, Wlodzimierz Mista, Taras Hanulia, and Robert Tomala*

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Article

Laser-Induced Generation of Hydrogen in Water by Using Graphene Target

Wieslaw Strek, Przemysław Wiewiórski, Włodzimierz Miśta, Robert Tomala and Mariusz Stefanski *

Chemical Physics Letters 775 (2021) 138649

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Research paper

Laser induced hydrogen emission from ethanol with dispersed graphene particles

W. Strek, W. Mista, P. Wiewiorski, R. Tomala*

Institute of Low Temperature and Structure Research, Polish Academy of Science, Okolna 2, 50-422 Wroclaw, Poland

Laser-induced generation of hydrogen from methanol vapor

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H_2 generation from **methanol** with Graphene aerogel as the target

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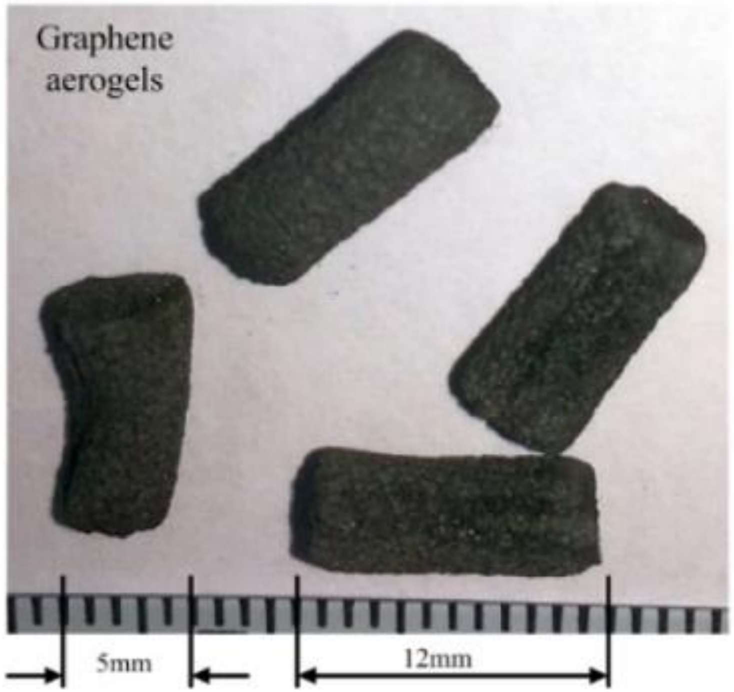
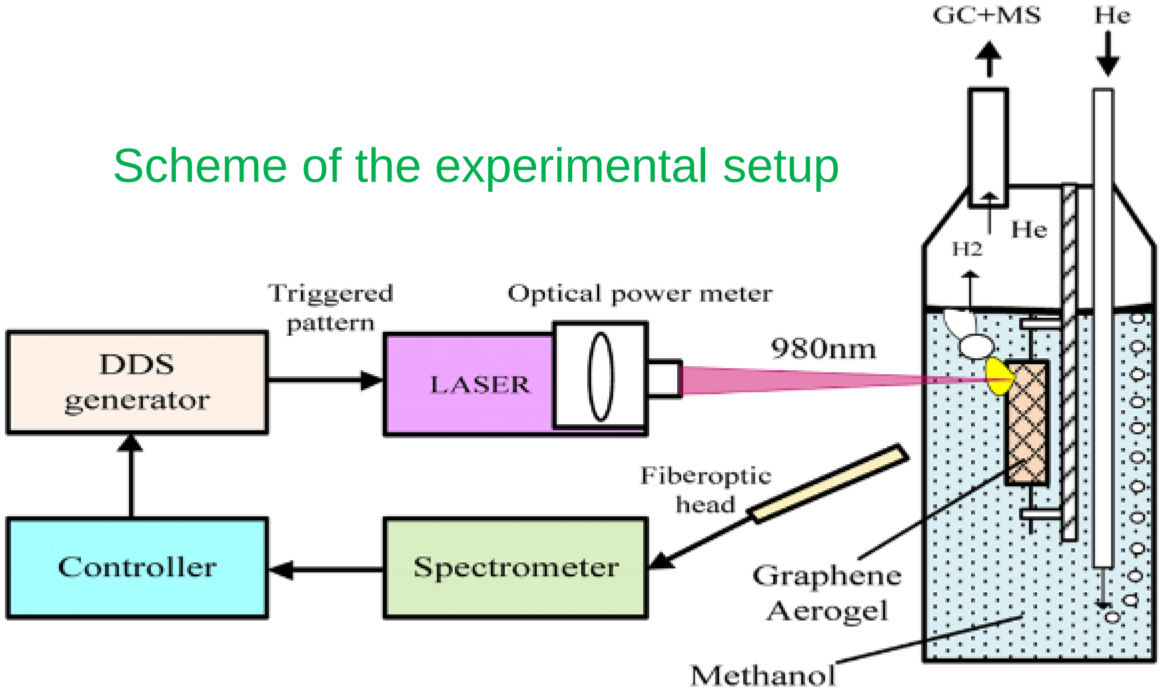
H_2 generation from **methanol** with Graphene aerogel as the target

Graphene areogel scaffolds

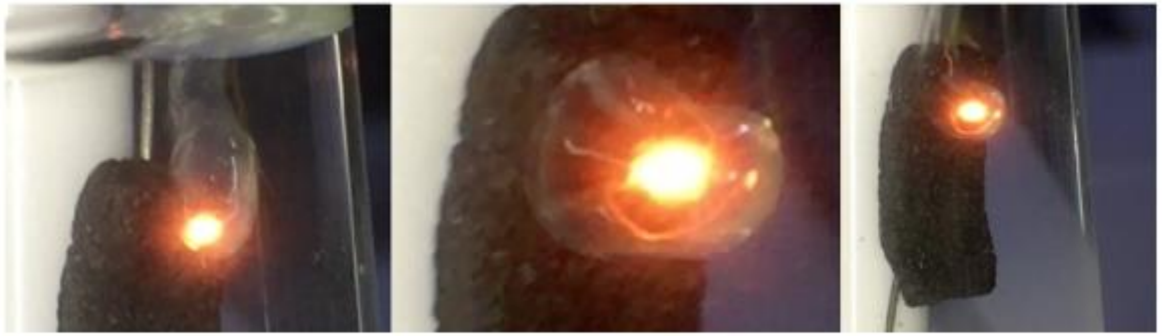


Scheme of the experimental setup

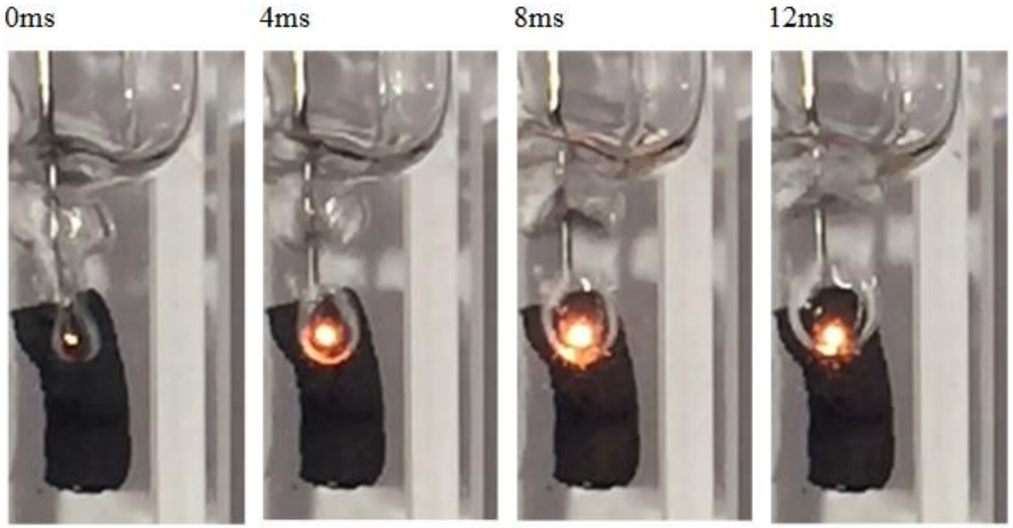


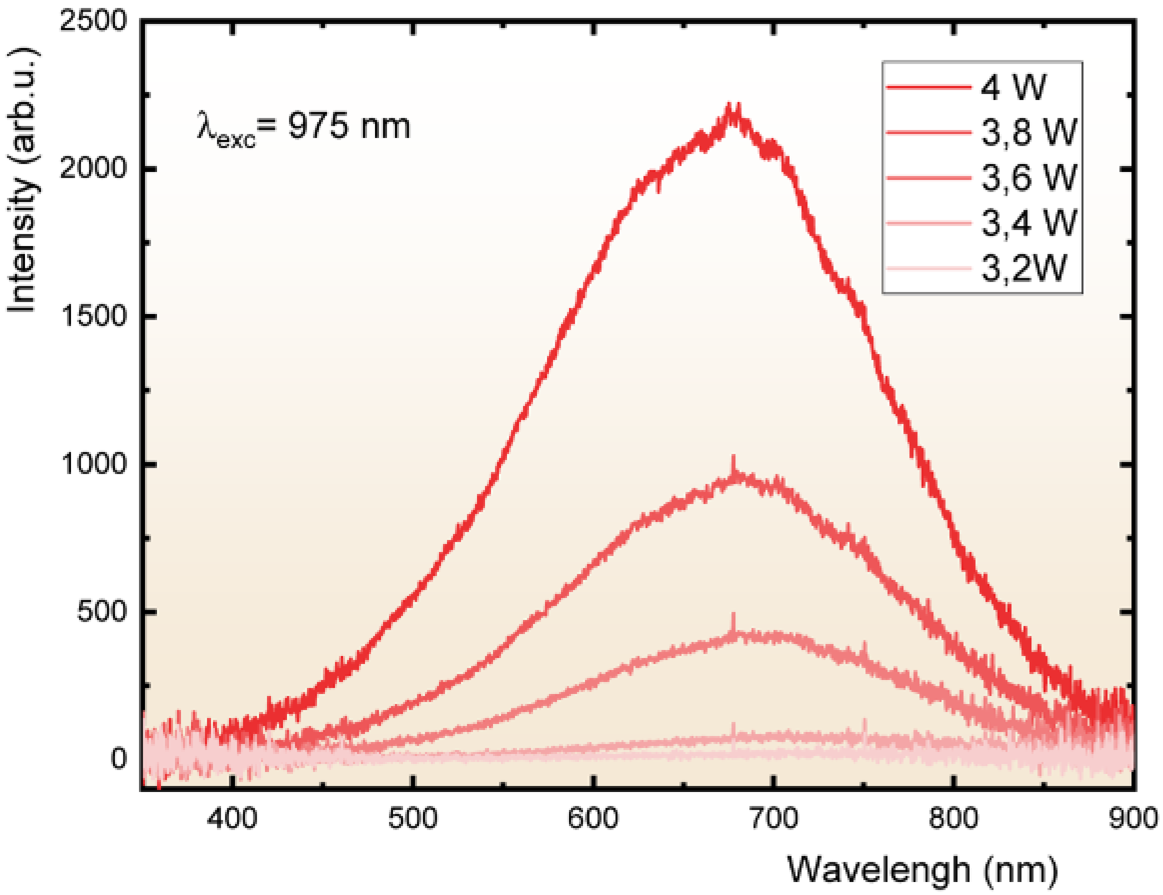
Cuvette of methanol with graphene foam scaffold after irradiation with laser diode 975 nm

H_2 generation from **methanol** with Graphene aerogel as the target

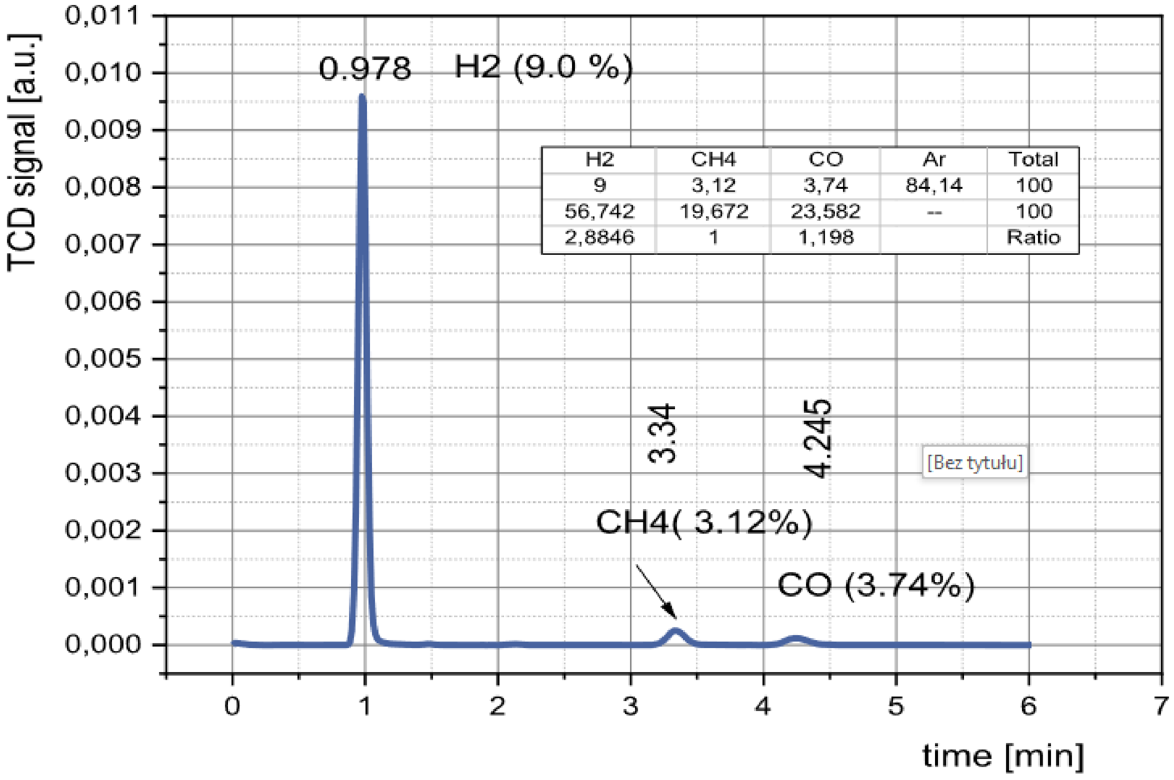


Evolution of a single bubble during continuous laser excitation of graphene aerogel in the methanol





H_2 generation from **methanol** with Graphene aerogel as the target

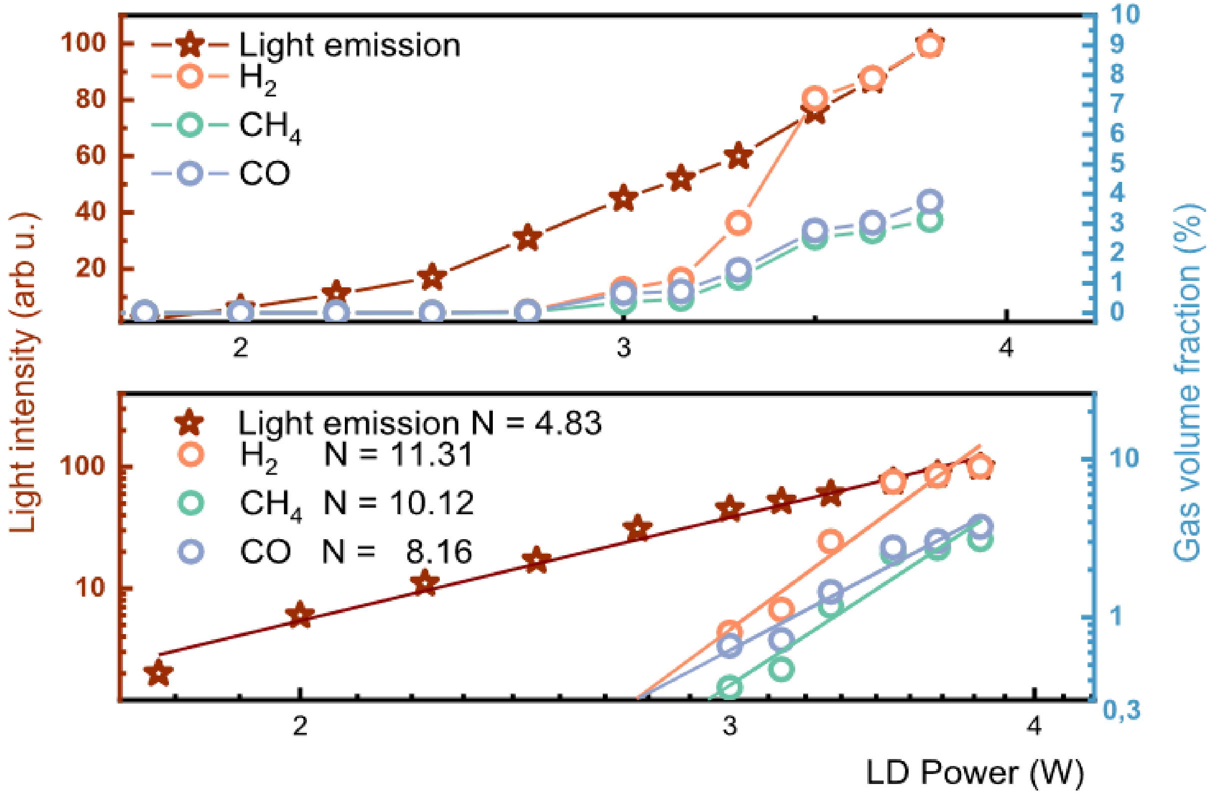


laser power P_O [W]	gas products: hydrogen H_2 [%]	methane CH_4 [%]	carbon monoxide CO [%]
2.50	43.96	19.78	36.26
2.75	48.48	20.35	31.17
3.00	53.45	20.88	25.66
3.15	57.63	20.22	22.14
3.30	57.79	20.04	22.17
3.50	56.75	19.67	23.58
3.65	56.82	20.1	23.08
3.80	57.30	19.81	22.89

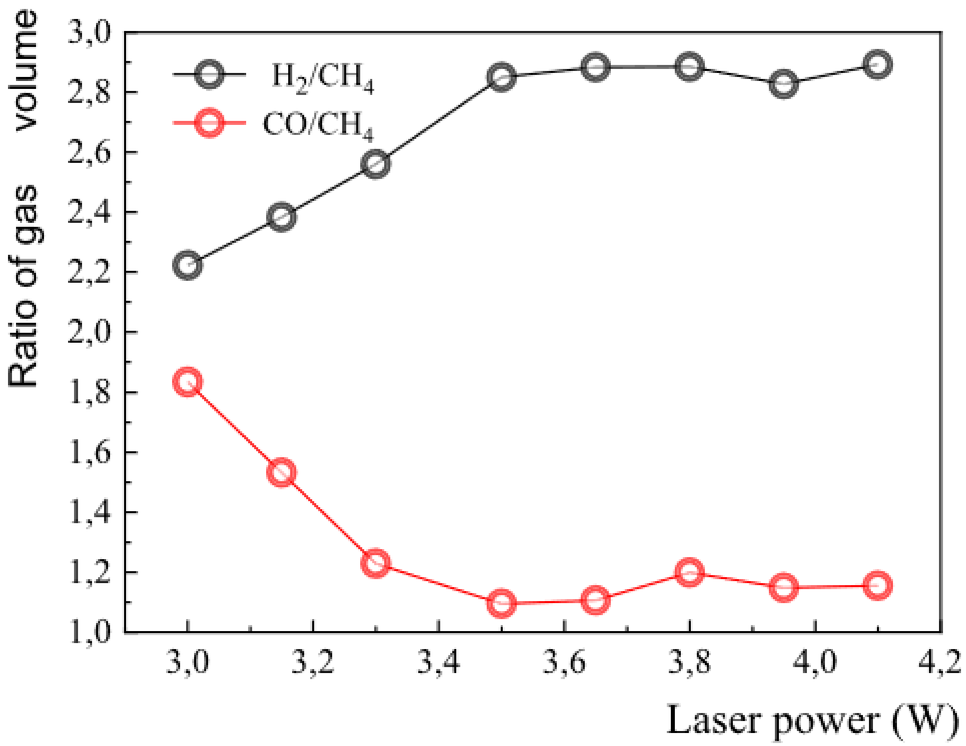
Gas products of LI dissociation of methanol by using the GA scaffold as the target (in Ar flow 5 mL/min)

H_2 generation from **methanol** with Graphene aerogel as the target

Influence of excitation laser power on light emission and the volumes of generated gases



Comparison of LI light emission intensity and emitted gas fractions (H2, CO, and CH4) of the GA scaffold on excitation LD power in log/log scale



Influence of excitation laser power on H_2 and CO gas products because of photoreformation of CH_3OH solution with graphene foam as the photocatalyst

H_2 generation from **methanol** with Graphene aerogel as the target

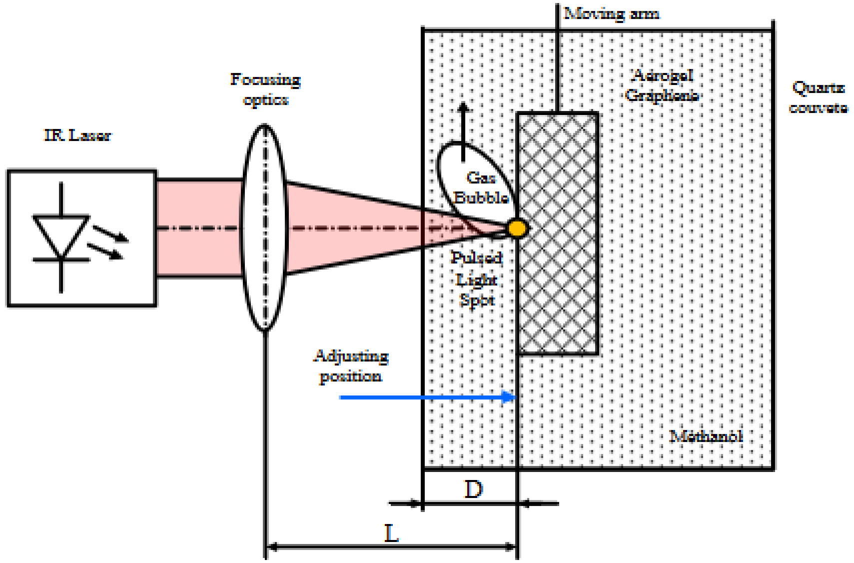
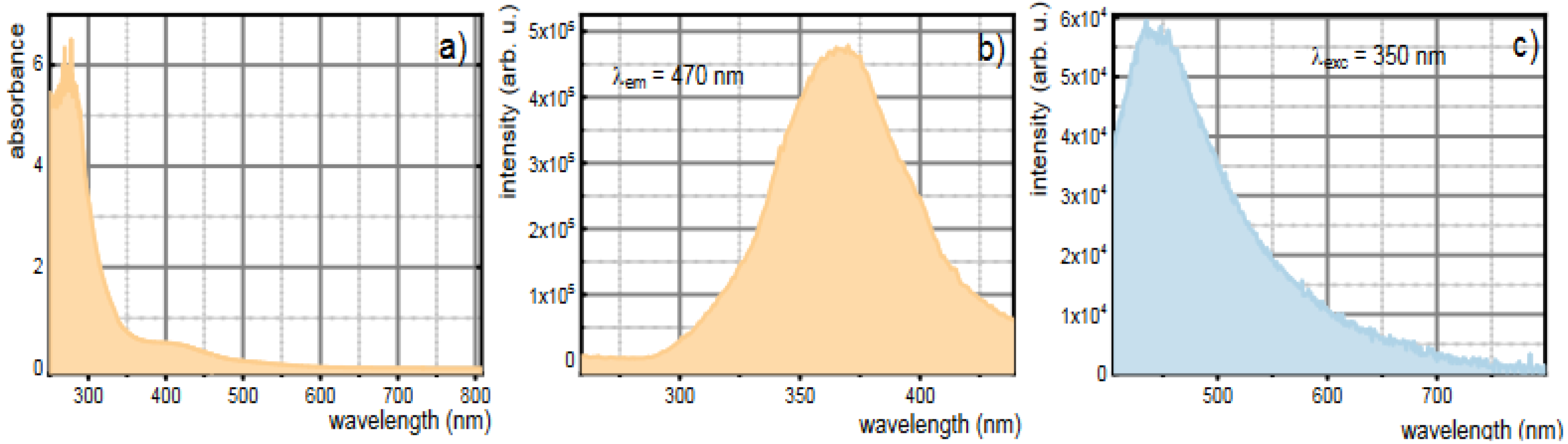


Diagram of measurement of emission spectra

absorption

excitation

emission



H_2 generation from **ethanol** with dispersed Graphene particles

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Research paper

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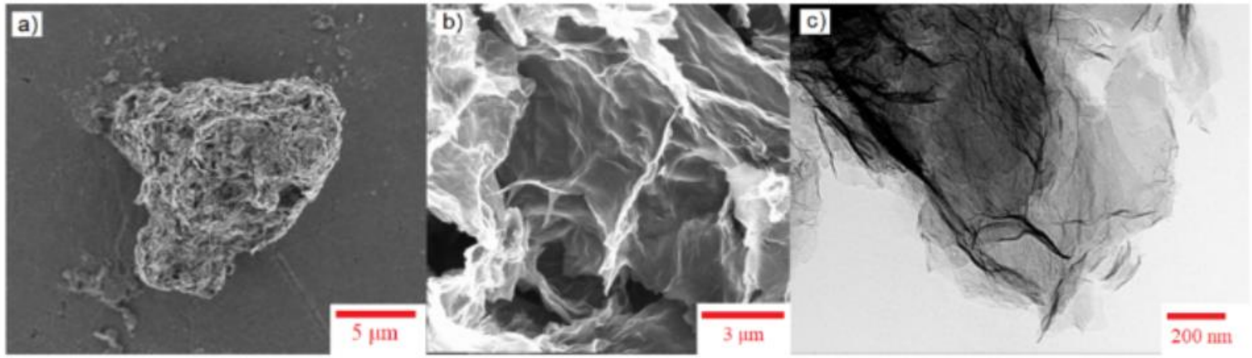
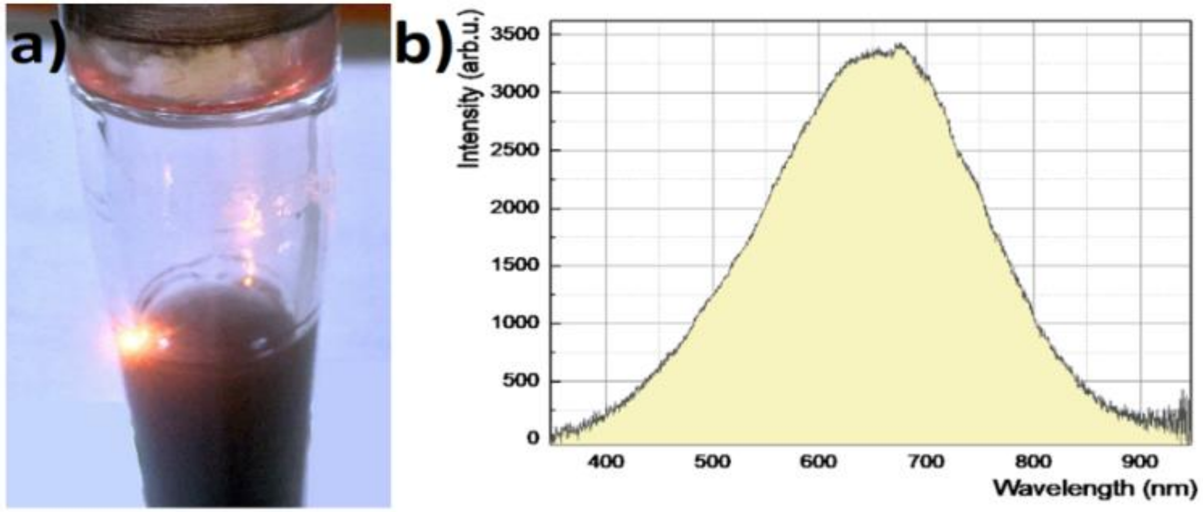
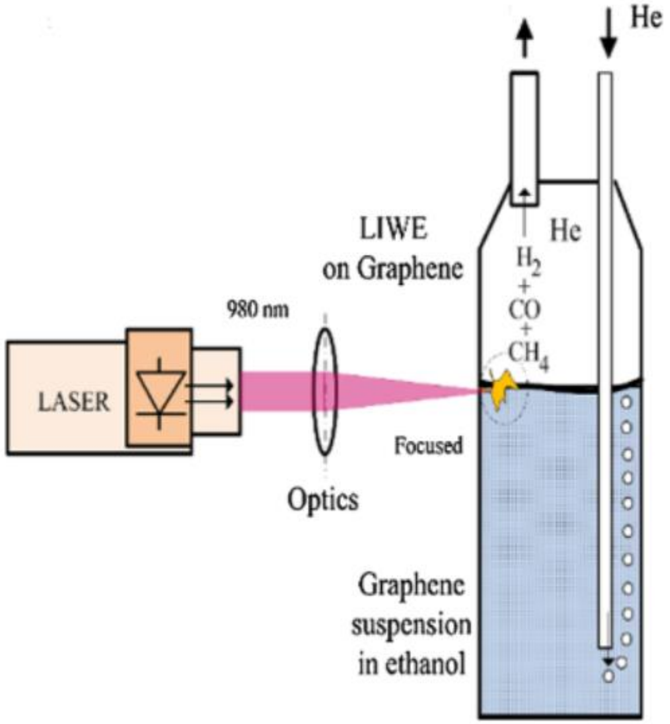
H_2 generation from **ethanol** with dispersed Graphene particles





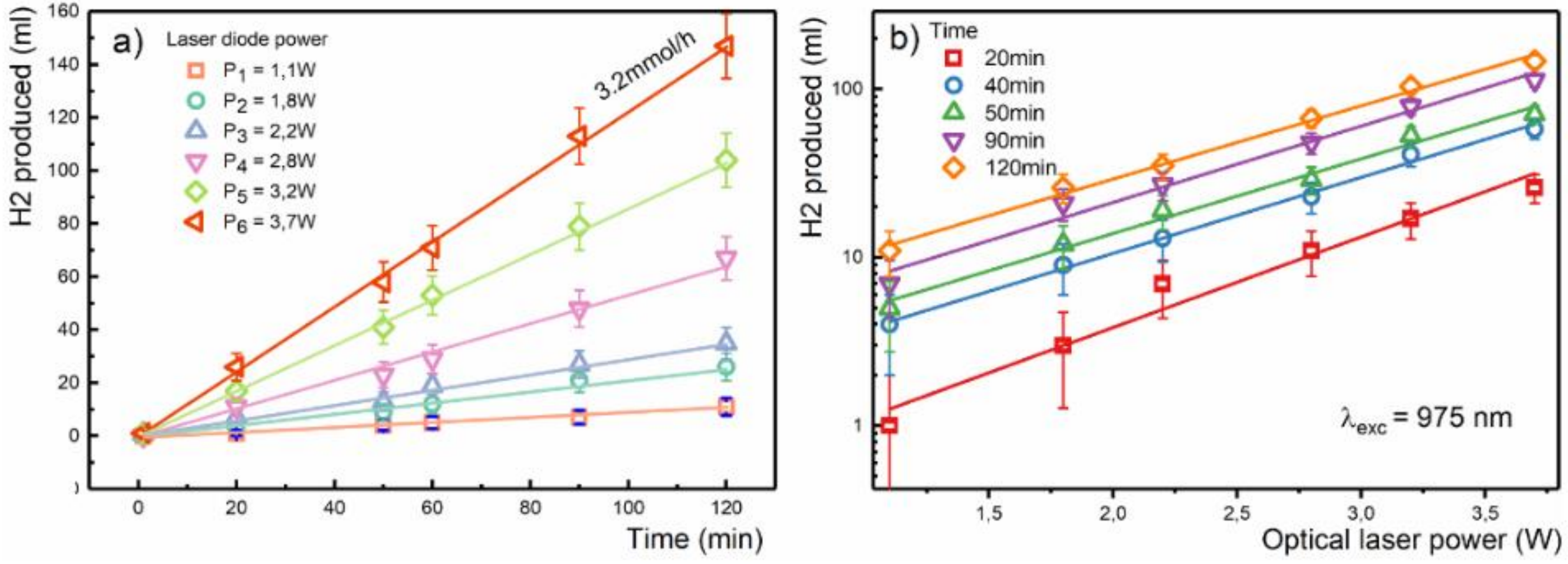


$$2C_2H_5OH + 4e^- \rightarrow 2C_2H_4OH^- + 2H^- \rightarrow 2C_2H_4O + H_2 + 4e^-$$

$$C_2H_4O + 2e^- \rightarrow CH_4^- + CO^-$$

$$CH_4 + CO + h\nu \rightarrow CH_3OH + C$$

H_2 generation from **ethanol** with dispersed Graphene particles



Time evolution of generated H_2 volume from ethanol + GP solution irradiated with CW 975 nm laser diode for different excitation power (a). The power dependence of H_2 volume generated from (ethanol + GP) irradiated with CW 980 nm laser diode in different time intervals (b)

H_2 generation from **water** with Graphene target

molecules

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Article

Laser-Induced Generation of Hydrogen in Water by Using Graphene Target

Wieslaw Strek, Przemysław Wiewiórski, Włodzimierz Miśta, Robert Tomala and Mariusz Stefanski *

H_2 generation from **water** with Graphene target

Saline: conductivity $1.6 \cdot 10^4$ μS/cm
pH=5.8

Distilled water: conductivity 10 μS/cm
pH=7

The splitting of water by electrolysis

$$2H_2O \rightarrow 2H_2 + O_2$$

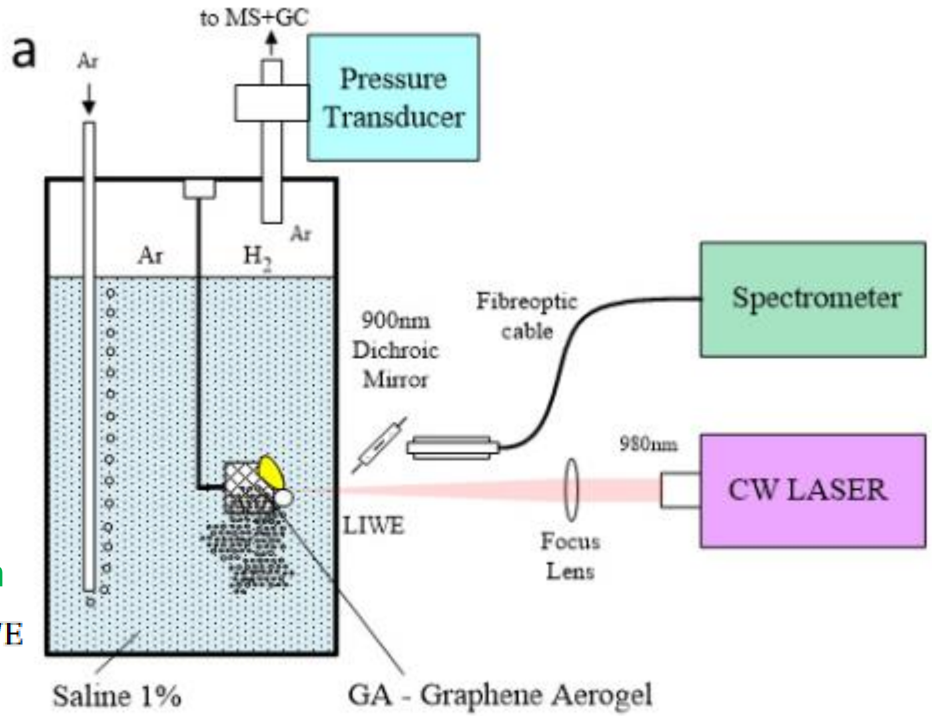
laser-induced splitting of water in the presence of graphene

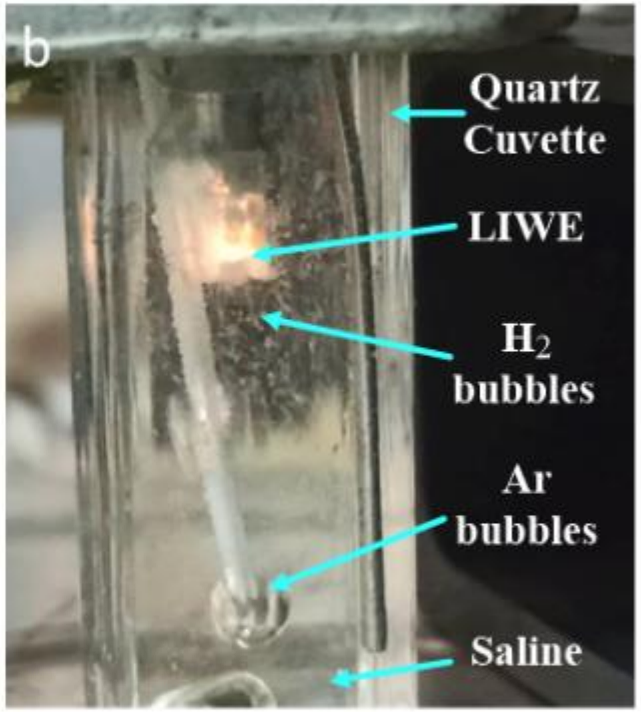
$$\langle C \rangle + N h\nu \rightarrow \langle C \rangle^+ + e^-$$

$$2e^- + 2H_2O \rightarrow 2H_2 + O_2$$

multiphoton absorption

$$C + N \hbar\omega \rightarrow C^+ + e^- + WE$$





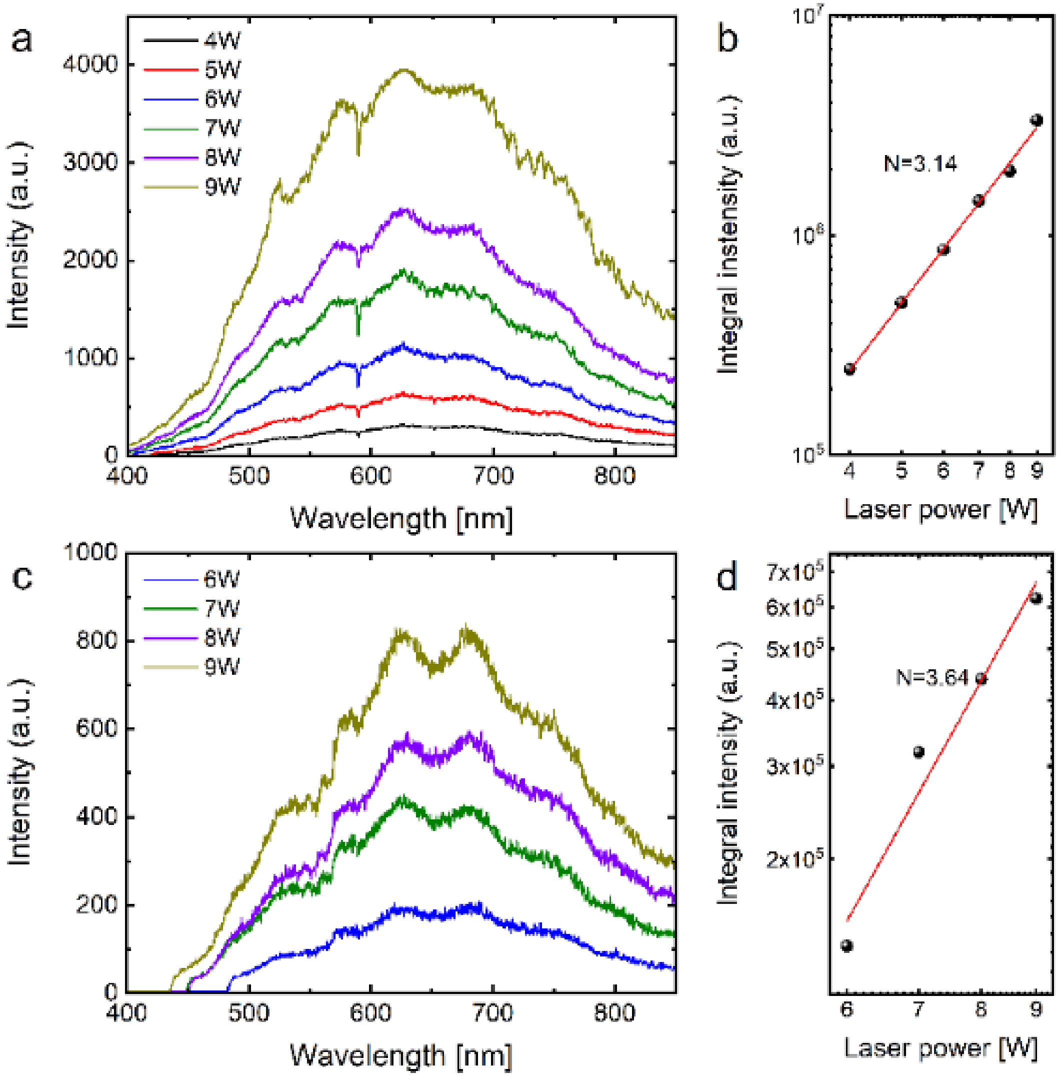
$$C + H_2O \rightarrow H_2 + CO$$

$$C + 2H_2O \rightarrow 2H_2 + CO_2$$

$$C + 3H_2O \rightarrow 3H_2 + CO + O_2$$

Experimental set-up for hydrogen generation from water, using graphene as a photocatalyst (a); Photo of the cuvette of water with immersed graphene scaffold irradiated with 980 nm laser beam (b)

H_2 generation from **water** with Graphene target



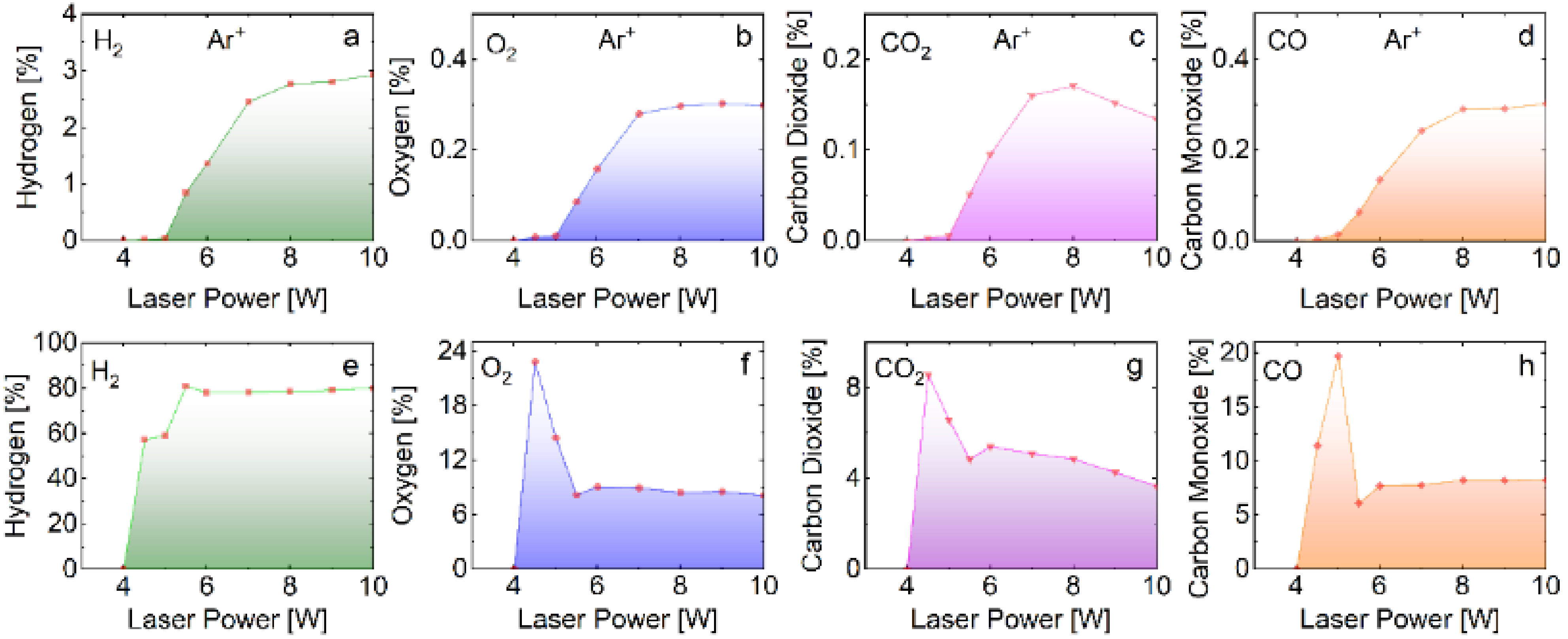
The emission spectra of laser-irradiated graphene foam with different excitation laser power in saline (a,b) and distilled water (c,d). The narrow dips observed at ~589 nm in the emission spectrum of saline water may be assigned to the Na^+ ions due to the dissociation of NaCl. They were not seen for distilled water.

H_2 generation from **water** with Graphene target

Ar 20 mL/min H_2O-Distilled Water				
Laser Power [W]	Gas Products			
	H_2 [%]	O_2 [%]	CO_2 [%]	CO [%]
10.0	47.00	10.44	11.23	31.33
9.0	54.42	6.80	11.56	27.21
8.0	54.30	9.05	9.50	27.15
7.0	53.25	11.83	11.24	23.67
6.0	55.56	7.94	12.70	23.81

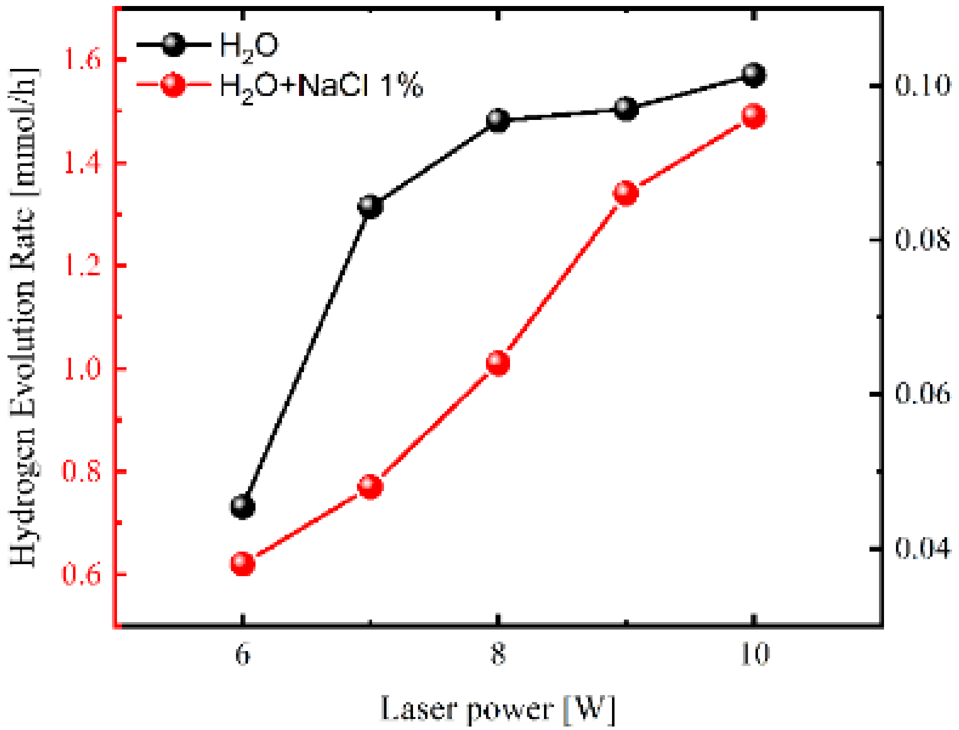
Ar 20 mL/min H_2O + 1% NaCl				
Laser Power [W]	Gas Products			
	H_2 [%]	O_2 [%]	CO_2 [%]	CO [%]
10.0	79.95	8.13	3.66	8.27
9.0	78.99	8.52	4.27	8.21
8.0	78.48	8.43	4.85	8.23
7.0	78.21	8.93	5.10	7.75
6.0	77.81	9.07	5.42	7.70
5.5	80.91	8.17	4.84	6.08
5.0	59.21	14.47	6.58	19.74
4.5	57.14	22.86	8.57	11.43

H_2 generation from **water** with Graphene target

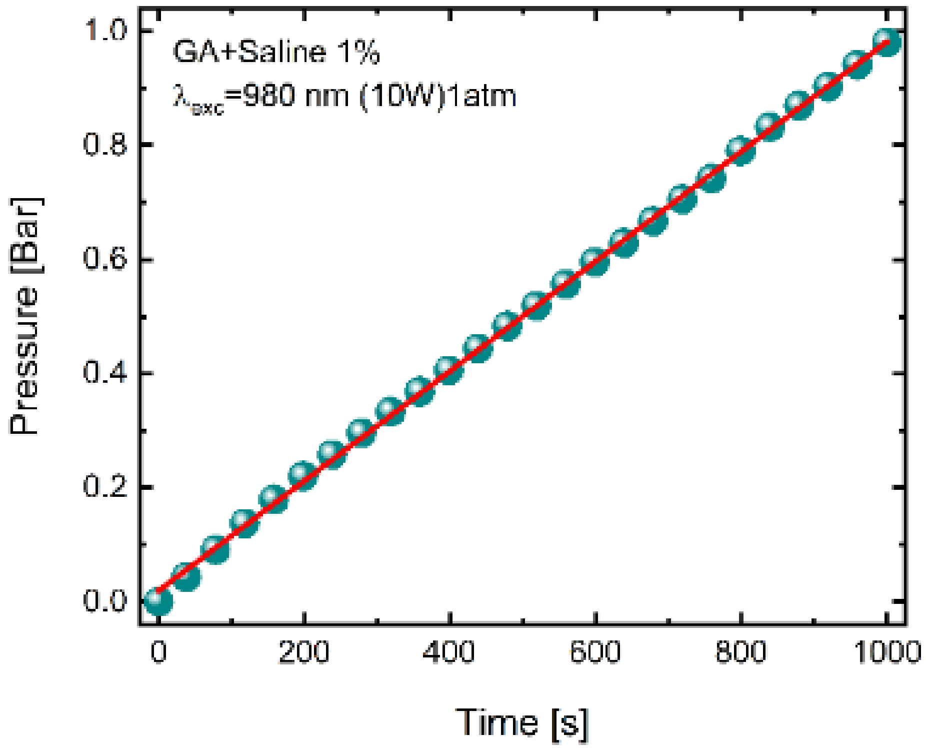


The power dependence of gas products in (a-d) and without (e-h) the presence of Ar, resulting from laser irradiation of H_2O+1% NaCl

H_2 generation from **water** with Graphene target



Hydrogen evolution rate from saline and distilled water by laser irradiation of graphene aerogel



The increase in total gas pressure during water splitting in the closed cuvette after long-time exposure

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H_2 generation from **methanol vapor** with Graphene target

Laser-induced generation of hydrogen from methanol vapor

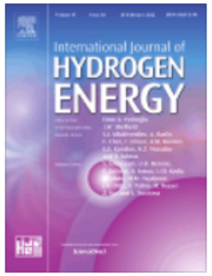
W. Strek, P. Wiewiórski, W. Miśta, R. Tomala, M. Stefanski

Institute of Low Temperature and Structure Research,

Polish Academy of Sciences, Wroclaw, Poland

**corresponding author*: m.stefanski@intibs.pl

Submitted



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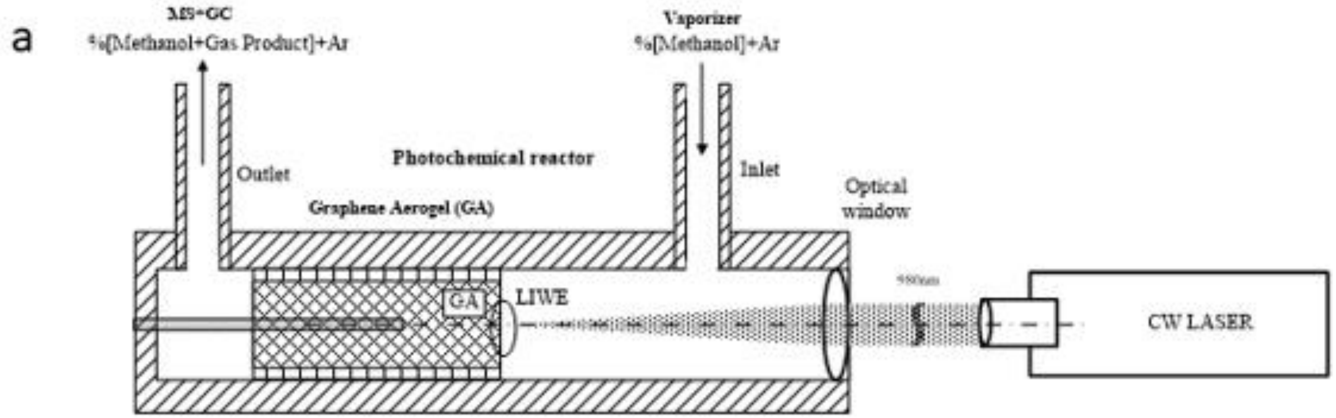
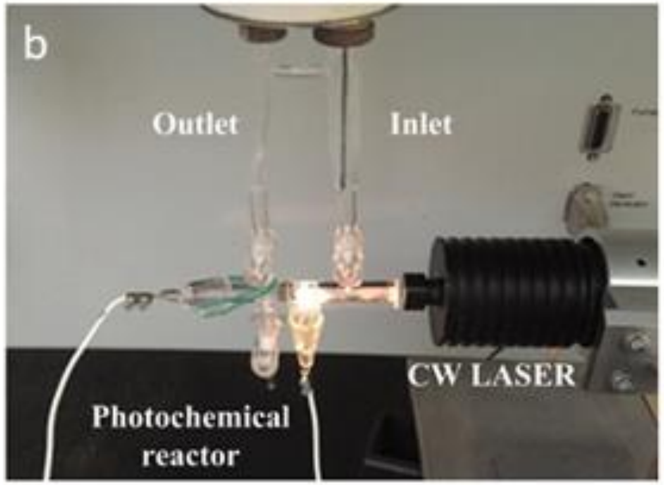
H_2 generation from **methanol vapor** with Graphene target

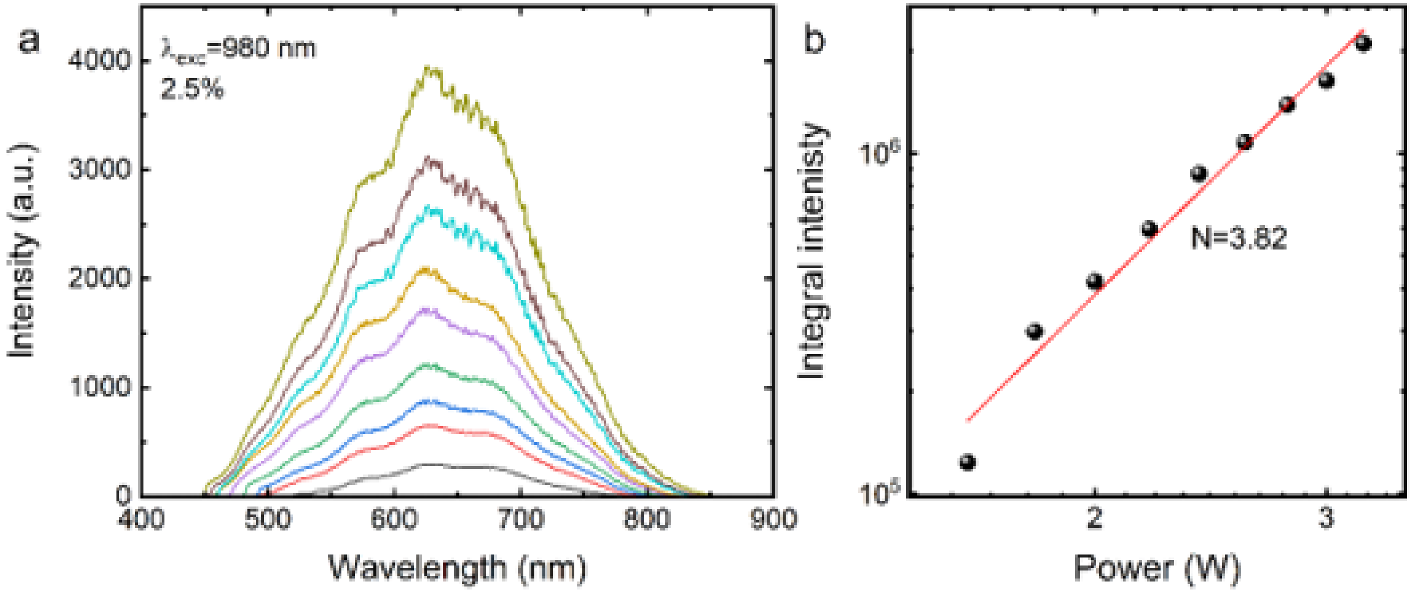


$$GA + N\hbar\omega \rightarrow GA^* + e^- + WLE$$



The experimental set-up of a laser driven photochemical reactor. LIWE means Laser Induced White Emission to hydrogen generation in methanol vapor by CW IR laser irradiation.

H_2 generation from **methanol vapor** with Graphene target



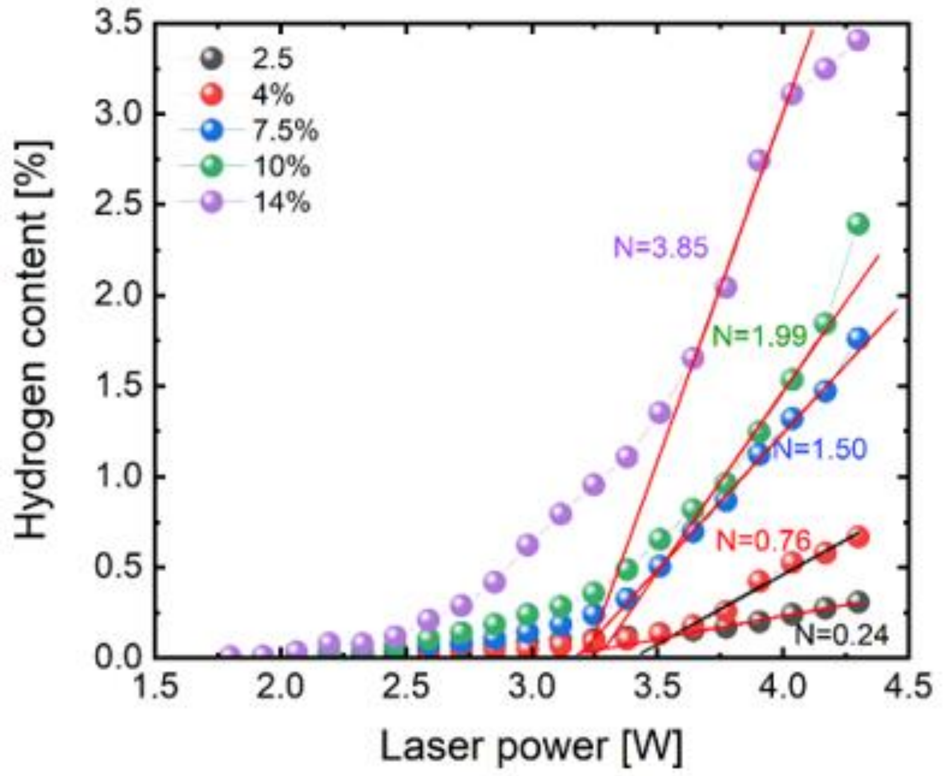
$$CH_3OH + e^- \rightarrow H_2 + CO + CH_4$$

The emission spectra of graphene aerogel in methanol vapor upon irradiation with focused beam of CW 980 nm laser diode (a). The power dependence of emission intensity in log/log plot (b).

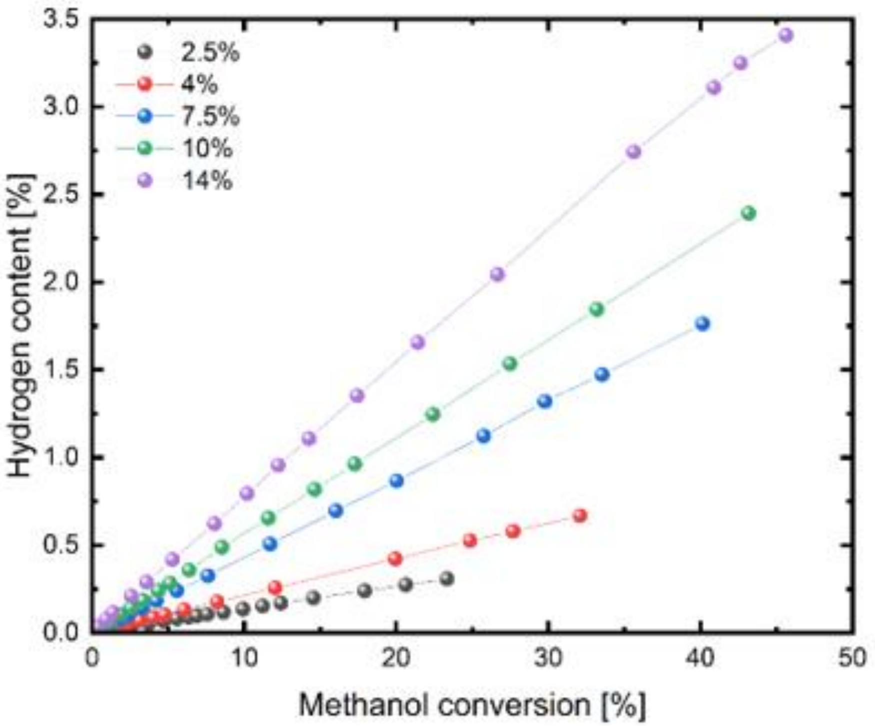
H_2 generation from **methanol vapor** with Graphene target

Table 1. Evolution of gas products on laser irradiation of 2.5% and 14% vapor concentrations of methanol.

Laser power [W]	Ar 20ml/min, methanol [%]							
	2.5	**14**	2.5	**14**	2.5	**14**	2.5	**14**
	Gas products						Vapor	
	Hydrogen H_2 [%]		Carbon monoxide CO [%]		Methane CH_4 [%]		Methanol CH_3OH [%]	
1.80	0.006	**0.008**	0.005	**0.007**	0.000	**0.001**	2.553	**13.750**
2.00	0.011	**0.012**	0.008	**0.008**	0.001	**0.002**	2.553	**13.744**
2.20	0.019	**0.072**	0.014	**0.059**	0.002	**0.009**	2.530	**13.626**
2.40	0.023	**0.096**	0.017	**0.059**	0.005	**0.012**	2.510	**13.599**
2.60	0.035	**0.218**	0.026	**0.135**	0.008	**0.029**	2.465	**13.385**
2.80	0.056	**0.336**	0.040	**0.209**	0.015	**0.045**	2.428	**13.176**
3.00	0.081	**0.647**	0.058	**0.430**	0.016	**0.094**	2.398	**12.595**
3.20	0.101	**0.900**	0.071	**0.565**	0.021	**0.134**	2.378	**12.167**
3.40	0.120	**1.132**	0.087	**0.735**	0.025	**0.157**	2.337	**11.742**
3.60	0.149	**1.529**	0.106	**0.995**	0.030	**0.206**	2.285	**11.035**
3.80	0.172	**2.121**	0.124	**1.393**	0.035	**0.312**	2.238	**9.940**
3.90	0.197	**2.724**	0.136	**1.771**	0.041	**0.384**	2.194	**8.888**
4.00	0.230	**3.070**	0.164	**2.060**	0.048	**0.442**	2.123	**8.194**
4.20	0.282	**3.282**	0.204	**2.189**	0.057	**0.466**	2.017	**7.829**
4.30	0.308	**3.408**	0.226	**2.389**	0.071	**0.494**	1.965	**7.475**



H_2 generation from **methanol vapor** with Graphene target



The total conversion hydrogen obtained for different amounts of methanol by irradiation with laser diode

Table 2. The laser generated gas products obtained from vapor with different concentration of methanol for the highest applied laser power (4.3W).

Laser power [W]	Ar 20ml/min, methanol [%]	Gas products			Vapor	Methanol conversion [%]
		Hydrogen [%]	Carbon monoxide [%]	Methane [%]	Methanol [%]	
4.3	2.5	0.30	0.23	0.08	1.93	23
	4	0.67	0.41	0.19	2.72	32
	7.5	1.76	1.01	0.26	4.50	40
	10	2.39	1.49	0.38	5.59	43
	14	3.41	2.39	0.49	7.56	46

Summary

- Methods of laser-induced hydrogen generation from graphene immersed in 4 different carriers (methanol, ethanol, saline, methanol vapor) are presented
- The generated volume of gases was assisted by the intense emission of white light from the irradiation spot at the graphene surface
- The H_2 generation process from graphene immersed in ethanol is free of O_2 and CO_2 gases emission
- This emission followed the photon driven ionization of graphene corresponding to the sp^2–sp^3 hybridization of carbon
- The ionization process is assisted by bright white light broadband emission and the efficient ejection of hot electrons leading to the dissociation of alcohol molecules
- The percentage of generated hydrogen for salted water reached nearly 81% compared to distilled water at 47%

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synthesis

chemical analysis

spectroscopy

optical spectra

x ray diffraction

materials properties

low temperatures

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general chemistry

hydrogen

crystals

chemical engineering

THANK YOU

crystal structure

diffraction

molecular structure

chemical structure

magnetic structure

chemistry

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