

Laser Induced Graphene Hydrogen Technology

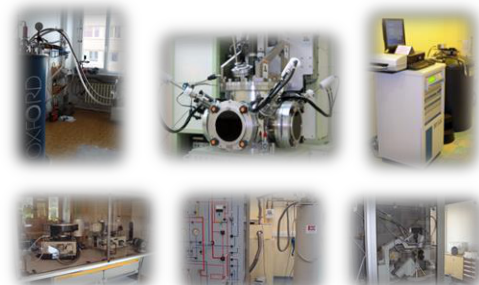
LIGHT



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POLISH ACADEMY OF SCIENCES
Okólna Str 2, 50-422 Wrocław, Poland



Graphene Innovations Laboratory



ILT&SR structure

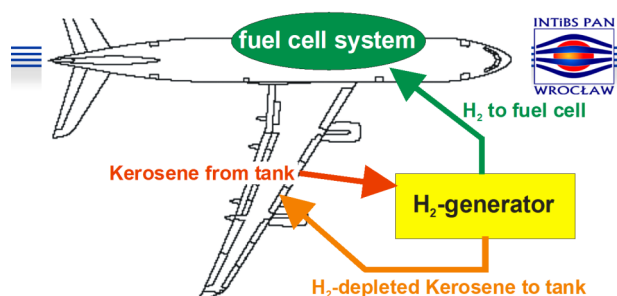
- Division of Nanomaterials Chemistry and Catalysis
- Division of Low Temperature and Superconductivity
- Division of Magnetic Research
- Division of Structure Research
- Division of Optical Spectroscopy



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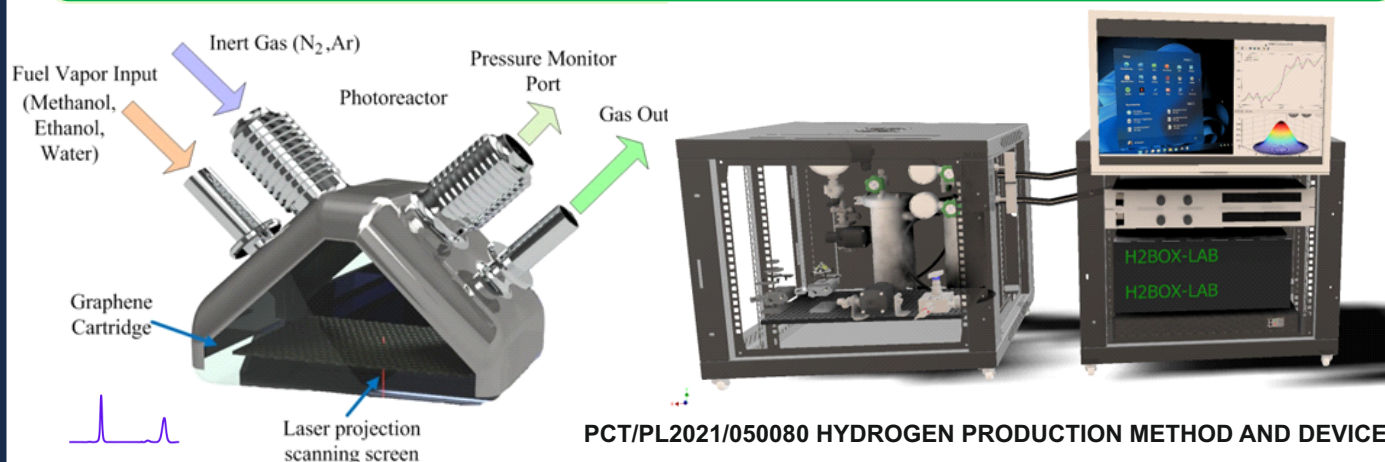
Hydrogen Laboratory

Experience in hydrogen projects



Designing of hydrogen generator based on Laser Induced Graphene Hydrogen Technologies (LIGHT)

Efficient Generation of Hydrogen by laser irradiation of Graphene in alcohols, water and their vapors in scalable broadband photocatalytic reactor (UV-VIS-IR) for renewable energy applications



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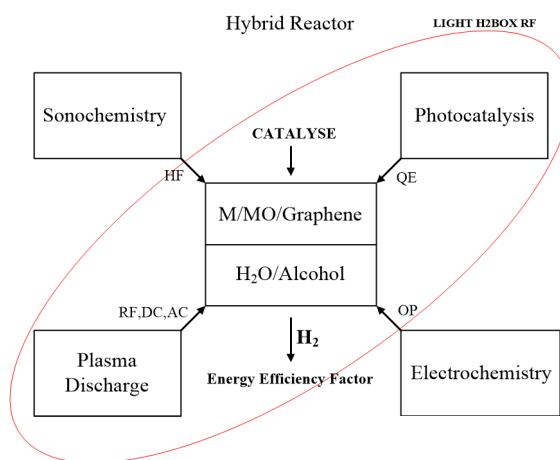
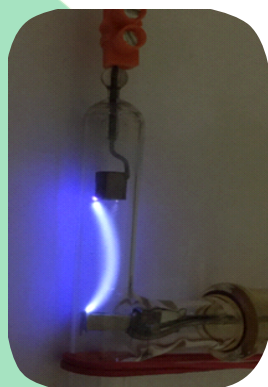
Wrocław 2024



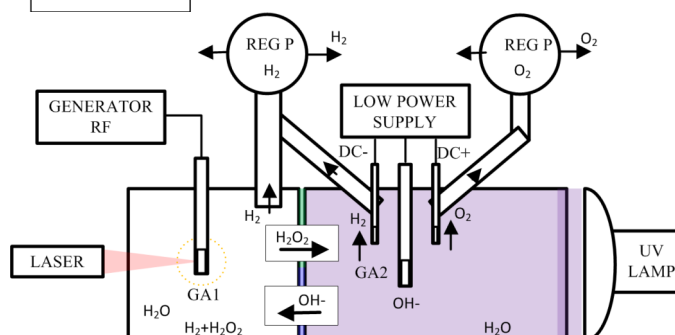
Hybrid LIGHT Photocatalysis



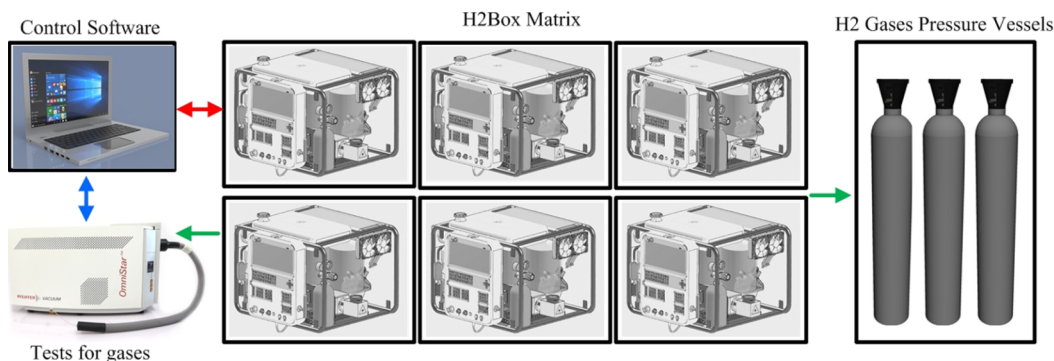
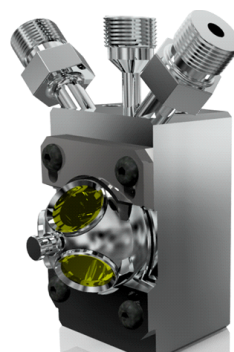
Due to the features of the Graphene material (flake in suspension, aerogel) and the available energy conversion techniques, the current work aims to achieve a synergy of optical, magnetic, electrical and catalytic phenomena specific to 2D materials.



The laser induced of hydrogen generation from water was investigated under influence of applied preionization condition. It was found that efficiency of the conversion process was significantly enhanced.



Scalable Hydrogen Production by LIGHT



The patent applications from of Hydrogen Laboratory at ILT&SR were filed at the following order

- Producing hydrogen by exposure to light on Graphene Aerogels in Methanol.
 - Producing hydrogen by exposure to light on Graphene Aerogel in Ammonia Water.
 - Generating electric current by converting CO₂ dissolved in water to Methanol using Graphene as a Photocatalyst.
 - Method and device for photo-induced conversion of Water to Oxy-Hydrogen mixture using Graphene as a Photocatalyst.
 - Converting light energy into thermal energy using Graphene-based Photolysis with hydrogen storage.
 - Photonic Device Microchip for Hydrogen generation based on Graphene Nanocatalyst.
- The full list of currently research and approved patents is available on the website: www.h2lab.com.pl

H₂ generation from methanol with Graphene Aerogel as the target



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Article

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

Wiesław Strek, Przemysław Wiewiórski, Włodzimierz Mista, Taras Hanulia, and Robert Tomala*

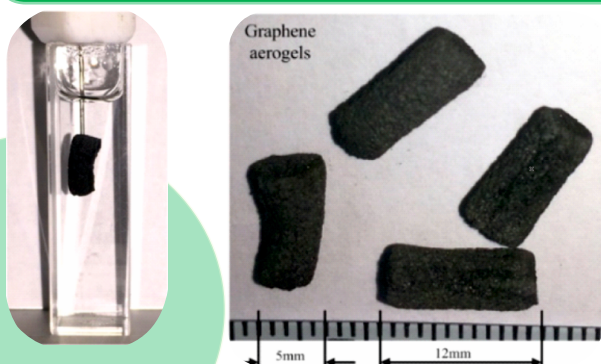


Cite This: ACS Omega 2021, 6, 3711–3716

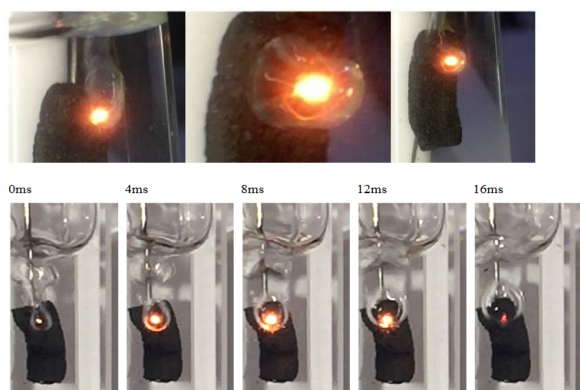


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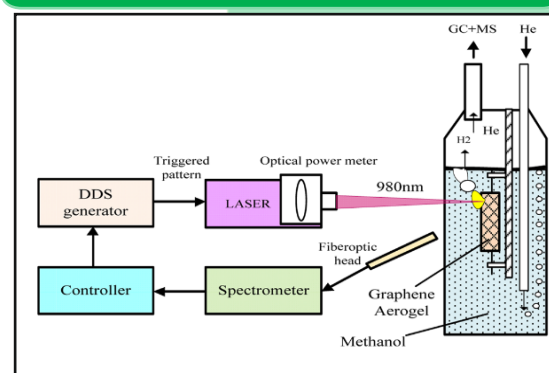
Graphene Aerogel scaffolds



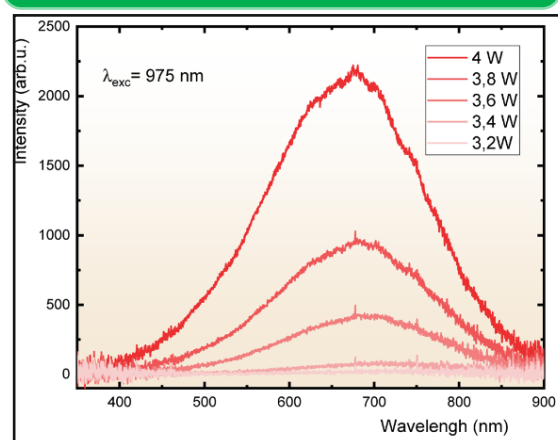
Evolution of a single bubble during CW laser excitation of Graphene Aerogel in the methanol



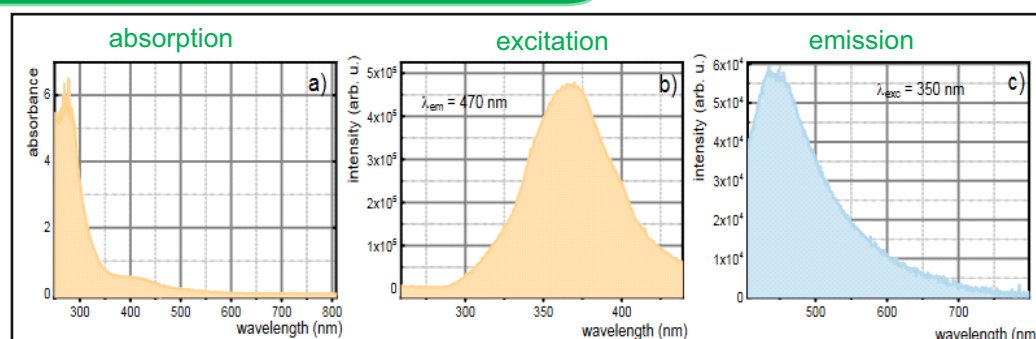
Scheme of the experimental setup



The emission spectra of LIWE on Graphene aerogel in the methanol



Graphene Quantum Dots as a result of irradiation with laser diode 975 nm

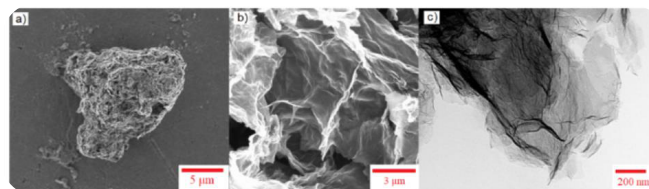


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H₂ generation from methanol with Graphene Aerogel as the target



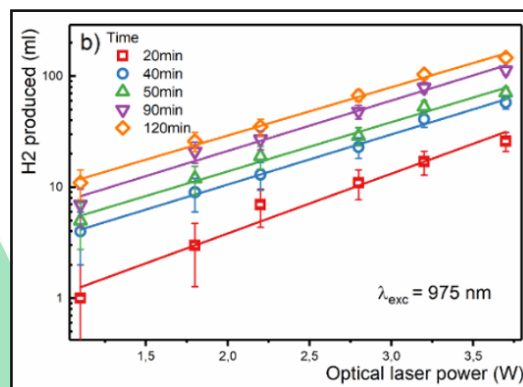
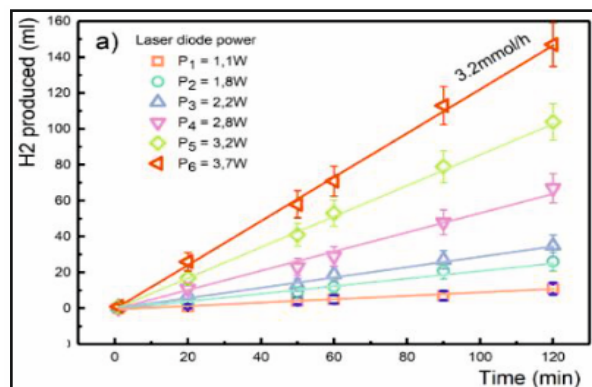
Next Synergy



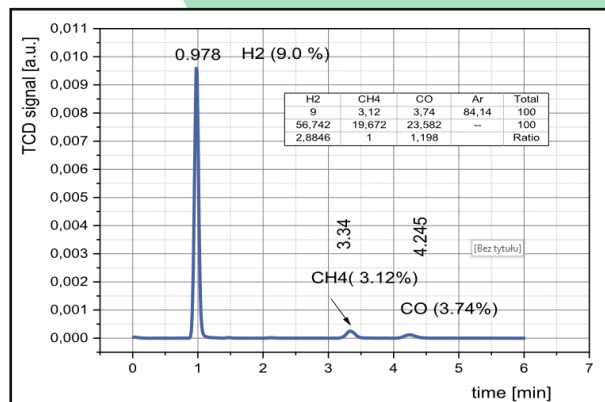
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The power dependence of H₂ volume generated from ethanol-graphene solution irradiated by CW 980 nm laser diode in different time intervals

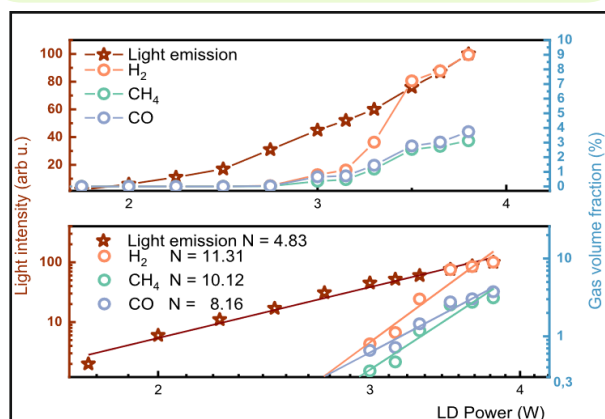


Gas products of laser-induced dissociation of methanol by using the GA scaffold as the target (in Ar flow 5 mL/min)

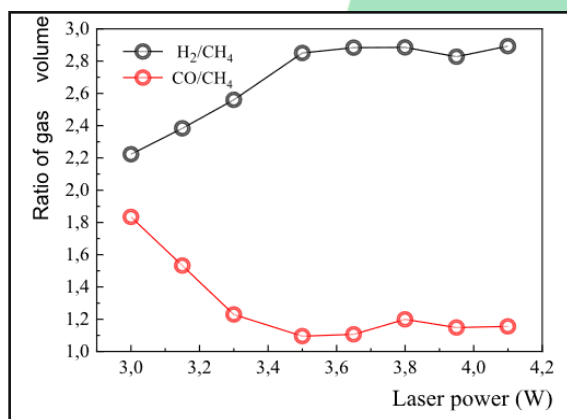


laser power P ₀ [W]	gas products		
	hydrogen H ₂ [%]	methane CH ₄ [%]	carbon monoxide CO [%]
2.50	43.96	19.78	36.26
2.75	48.48	20.35	31.17
3.00	53.45	20.88	25.66
3.15	57.63	20.22	22.14
3.30	57.79	20.04	22.17
3.50	56.75	19.67	23.58
3.65	56.82	20.1	23.08
3.80	57.30	19.81	22.89

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



Influence of excitation laser power on H₂ and CO gas products from CH₃OH with Graphene Aerogel as the photocatalyst



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H₂ generation from water with Graphene target



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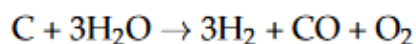
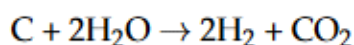
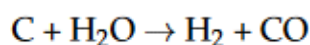
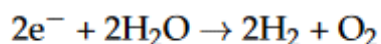
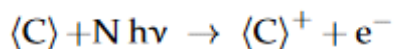
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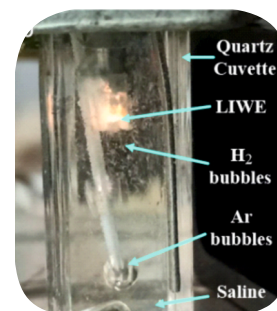
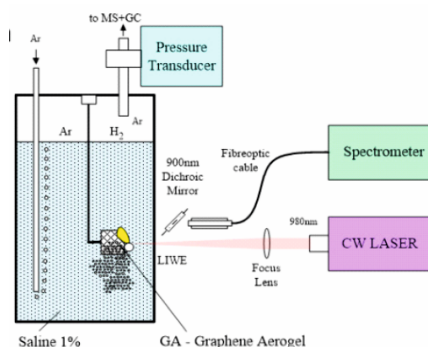
Laser-Induced Generation of Hydrogen in Water by Using Graphene Target

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

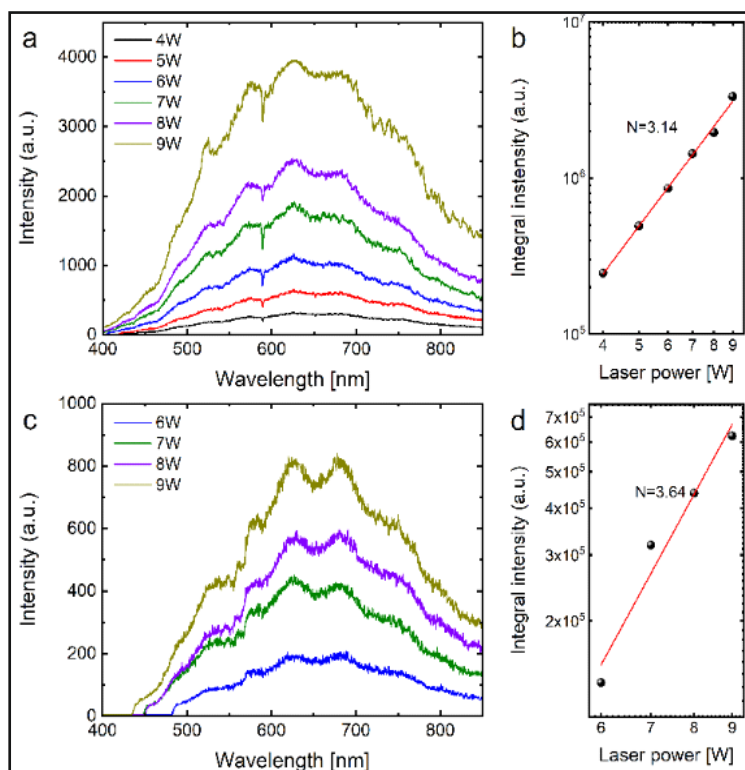
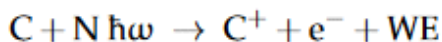
Laser-induced splitting of water
through Graphene Aerogel



Experimental set-up for hydrogen generation from water
using graphene as a photocatalyst



Multiphoton Absorption:



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.

Distilled water:

conductivity 10 μS/cm, pH=7

Saline:

conductivity 1.6 · 10⁴ μS/cm, pH=5.8

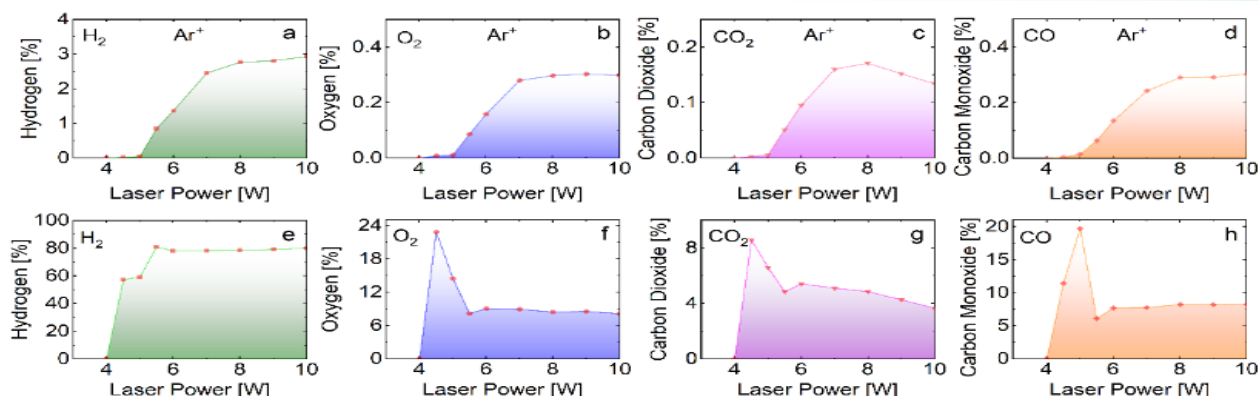
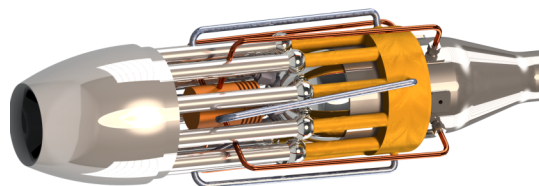
H₂ generation from water with Graphene target



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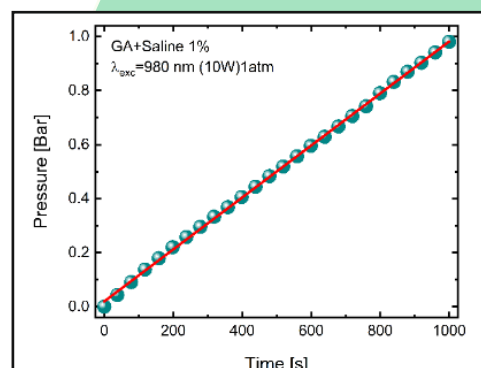
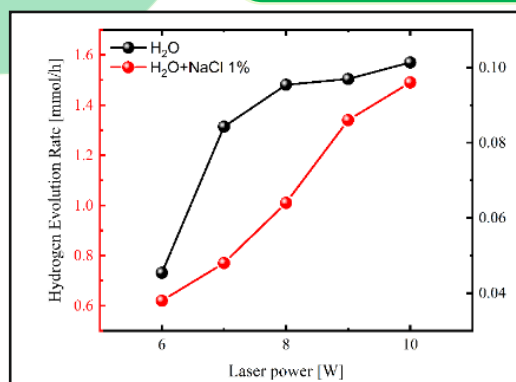


The power dependence of gas products in (a-d) and without (e-h) the presence of Ar, resulting from laser irradiation of H₂O+1% NaCl. The increase in total gas pressure during water splitting in the closed cuvette after long-time exposure

Ar 20 mL/min H ₂ O + 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

Ar 20 mL/min H ₂ O-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

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



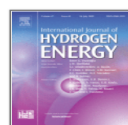
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H₂ generation from methanol vapor with Graphene Aerogel as the target



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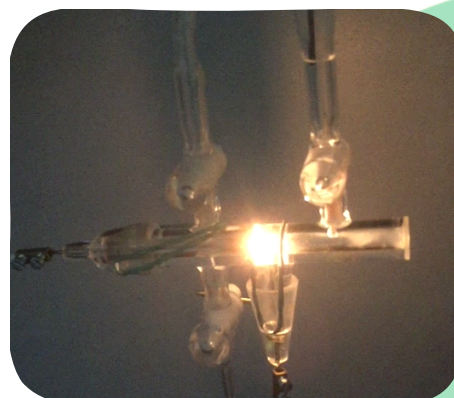
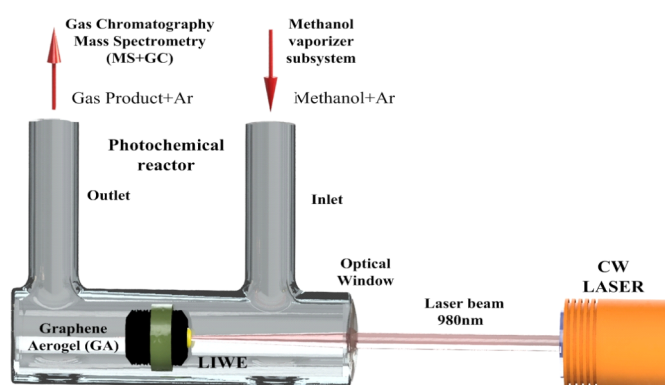


Short Communication

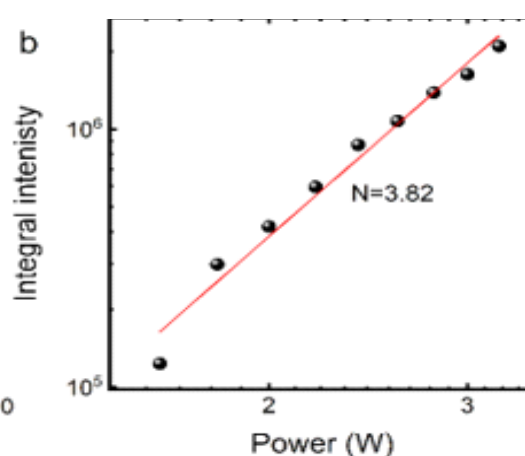
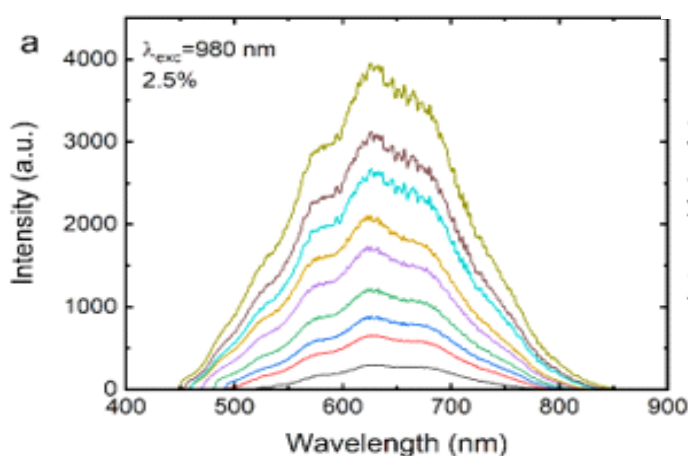
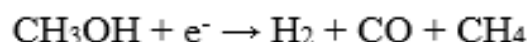
Laser-induced generation of hydrogen from methanol vapor

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

Generating of Hydrogen from LIWE on Graphene in Gas Phase



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



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).

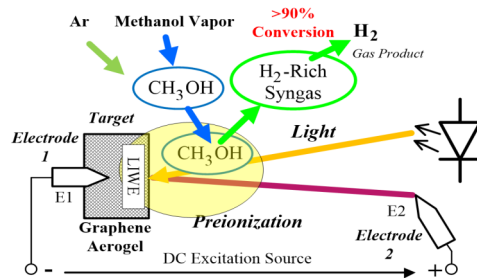
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H₂ generation from methanol vapor with Graphene Aerogel as the target



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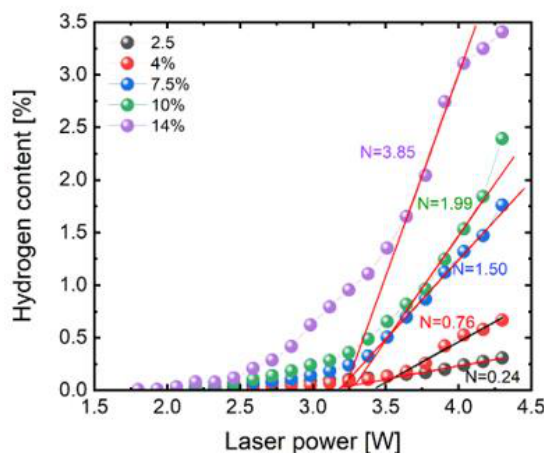
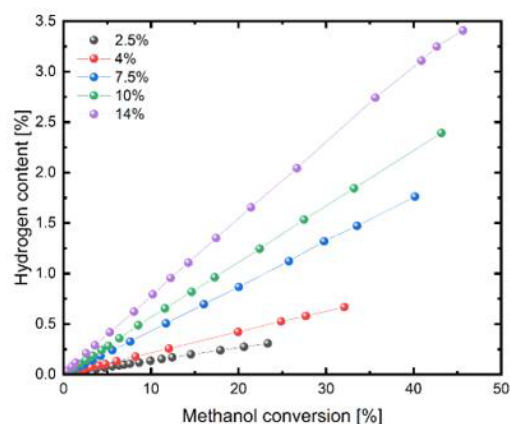
The total conversion hydrogen obtained for different amounts of methanol by irradiation with laser diode

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 ₃ OH [%]	
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

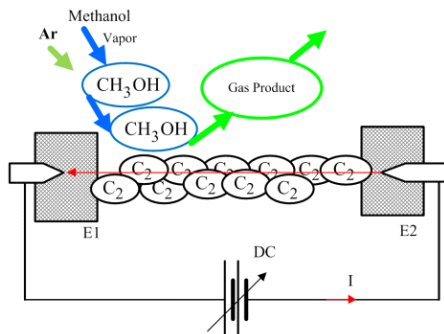
Table 2. The laser generated gas products obtained from vapor with different concentration of methanol for the highest applied laser power (4.3W).

Laser power [W]	Ar 20ml/min, methanol [%]	Gas products			Vapor	Methanol conversion [%]
		Hydrogen [%]	Carbon monoxide [%]	Methane [%]		
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

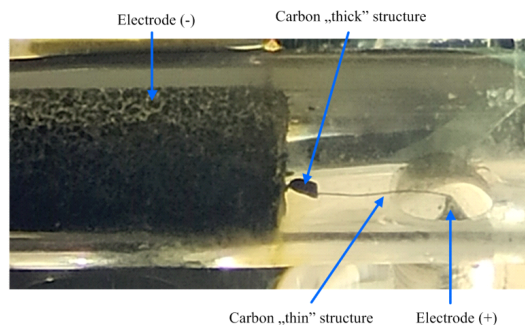


The novel method of Hydrogen generation from Methanol vapor by irradiation with CW laser diode of graphene aerogel as the target was developed. The Graphene upon laser irradiation has emitted intense White Light due to ionization of Graphene and served as source of Hot Electrons. The light emission has increased exponentially with a high increase of total Methanol Conversion in the process reaching almost 46%. LIGHT method is very perspective for industrial applications.

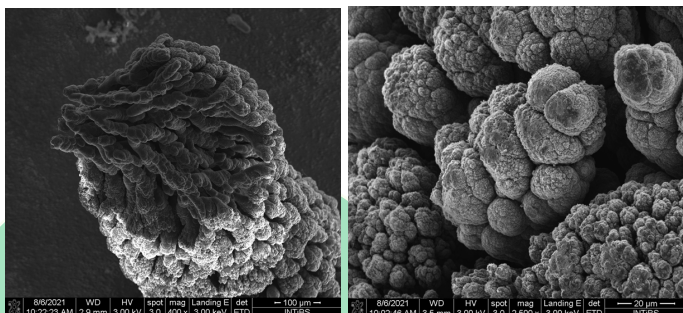
Mechanism of self-healing of electrode



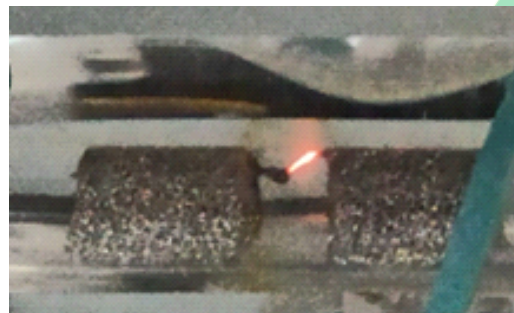
Initiation of growing of electrodes on Graphene



SEM photo of self-assembly structure

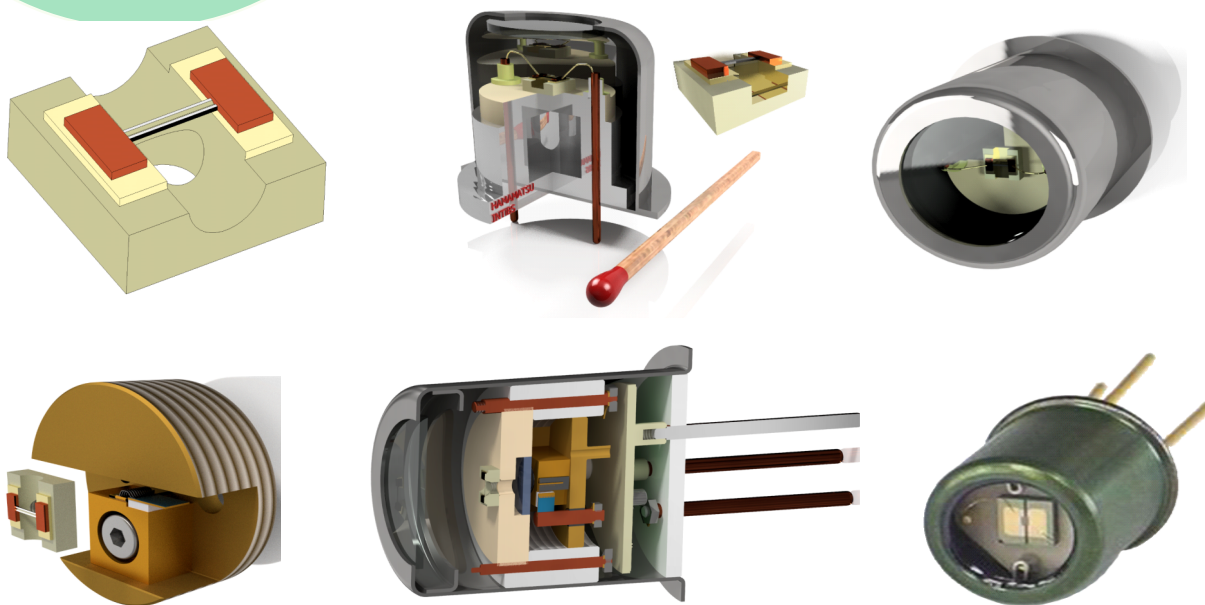


Current flow through self-assembly structure

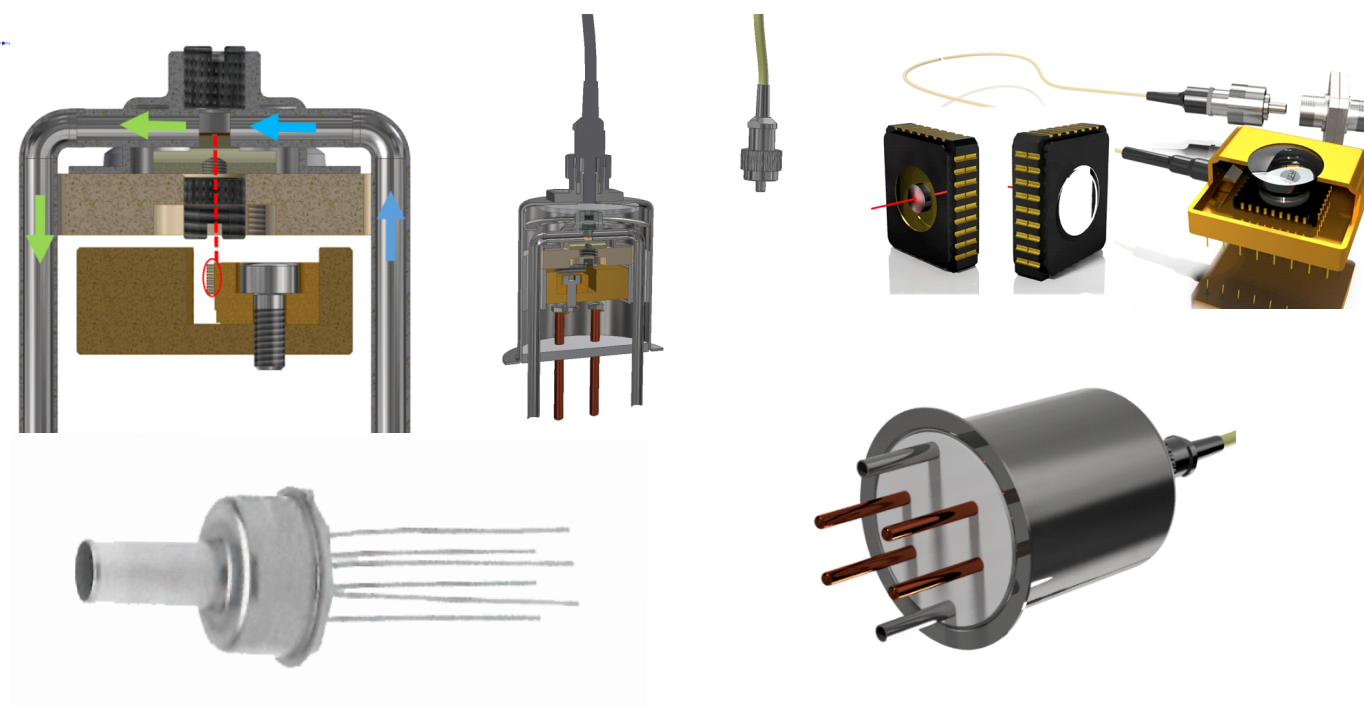


Graphene Microchips for Coherent Light Sources

Microchip hydrogen generator GL μ H₂ based on laser induction of white light (LIWE) on graphene dedicated for gas phase. The Microchip Hydrogen Generator involves a c-mount laser diode and Graphene in special configuration for best catalytic properties. Laser focal point was obtained at the contact of two mechanical high strength Graphene Aerogel rods.

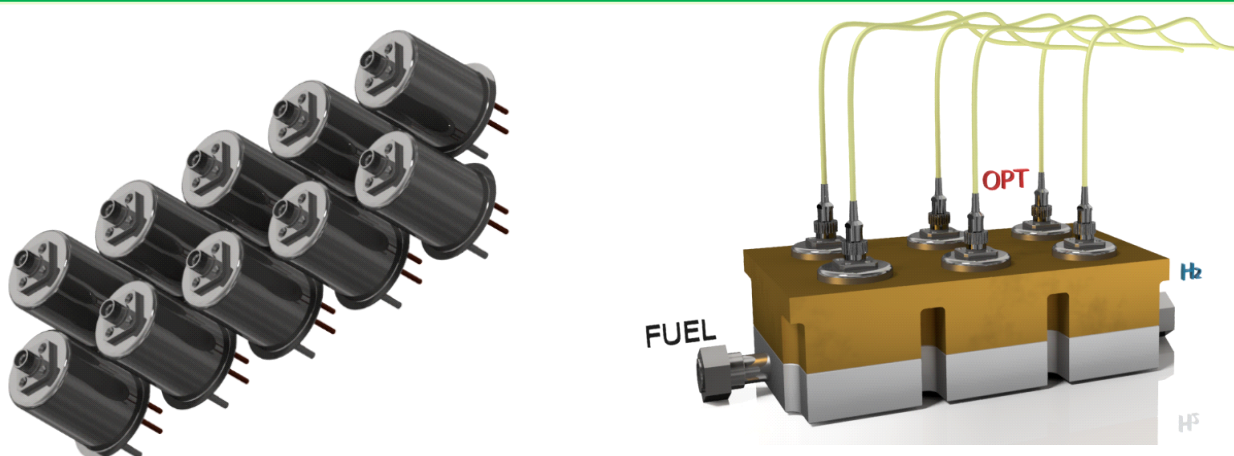


The Microchip Hydrogen Generator GL μ H2 is connected with laser Induced of white light (LIWE) on Graphene and is dedicated for gas phase application. GL μ H2 involves a C-mount laser diode and Graphene Core in special configuration for best catalytic properties. Laser focal point was obtained at the contact of two mechanical high strength Graphene Aerogel rods for better performance.

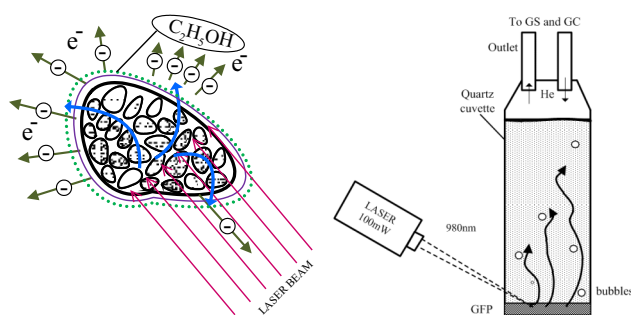


Scalability of the Microchip GL μ H2 by Multinode Hydrogen Generator Banks

The Hydrogen Generation Management System consists matrix-like configuration of GL μ H2 microchips. In case of faulty work each of node is monitored separately by fibreoptical unit.



The mechanism for laser light propulsion is proposed. Movement of Graphene Foam Particles dissolved in solution encapsulated in thin capillary is observed under light irradiation. The propulsion phenomenon is capable of transporting substances contained in Graphene in the direction of narrow stream of light.



Since Graphene Foam Particles has a huge effective surface area it becomes a reservoir (adsorber) for hydrogen. The GF particles with adsorbed hydrogen are characterized by lowered effective density and are transported to the gas phase located at the top of the vessel. When the concentration of hydrogen enhances to about 4% in the air there is initiated the high energetic explosive reaction leading to the fast vertical self-propulsion of the capsule.

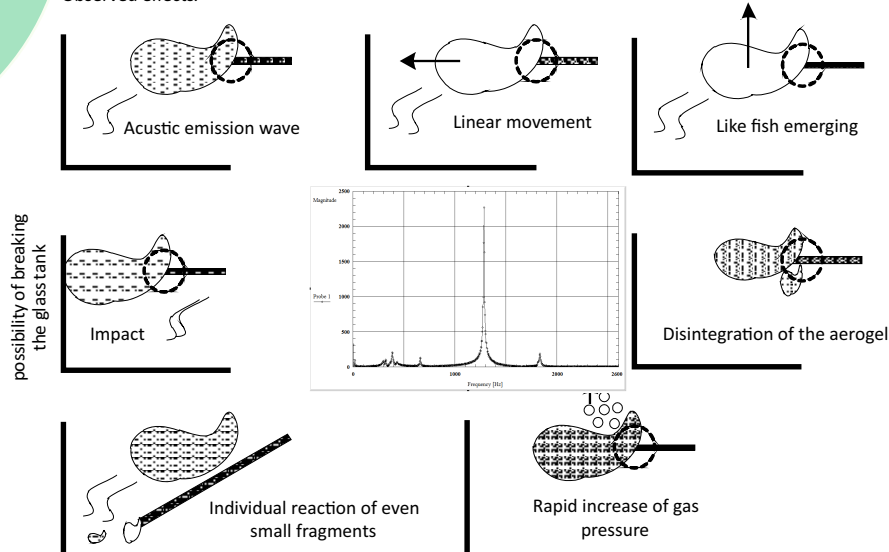


Graphene Particles inside liquid as giant-amplified electro-optical-actuator

The conversion of light in to the sound is one of the effect on 3D Porous Graphene in liquids. Additions of Graphene under the influence of light release high-energy collapsing bubbles.

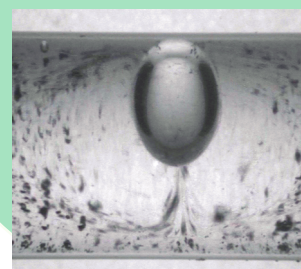
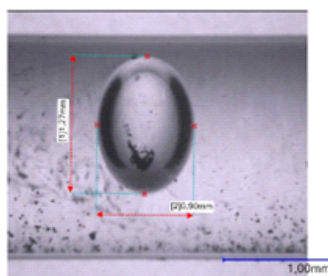
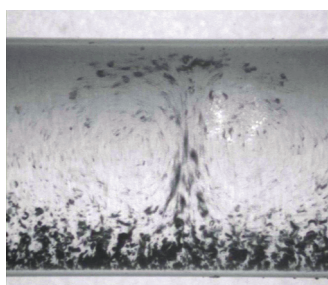


Observed effects:



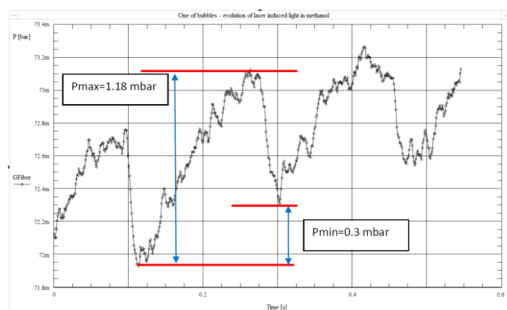
Laser-Driven Gas Transport inside liquids through Graphene Particles

Completely new approach to the problem of the Graphene Particles under the influence of unfocused coherent light was introduced. Graphene can initiate bubble transport in various solvents and increase the possibility of controlled reactions of hydrogen and oxygen bubbles.



Graphene Catalytic Interfaces for Nano-Bubbles Generation Technique

Concentration of Hydrogen Nano-Bubbles around Graphene in selected liquids and fuels during laser excitation of catalytic interfaces is one of the most fundamental problem to improve efficiency research. The multiphysics synergy is needed.



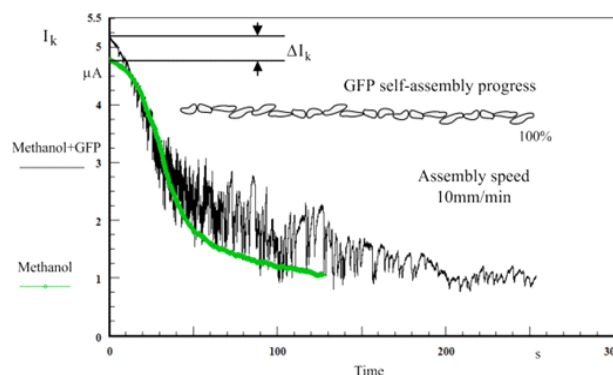
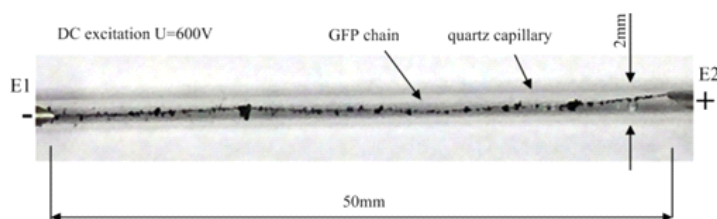
Thanks to the features of Graphene, it is possible to precisely detect and count separately of each gas bubbles using the measurement of liquid vibrations and pressure increase.



Electric Field Assisted Gas Transport via self-ordering of Graphene Particles

Self-assembling of single chain formed from Graphene Foam Particles in dielectric solvent (methanol) upon applied DC electric field can be used for uni-directional hydrogen transport.

Hydrogen filtration from photocatalysis process site to the reservoir without mixing of gas bubbles improved the efficiency of the hydrogen evolution from the base solution.



We welcome you to cooperate with Hydrogen Laboratory

