

MATERIALS, MANUFACTURING METHOD AND DEVICE FOR CONVERTING AMBIENT HUMIDITY TO ELECTRICAL ENERGY AND USES THEREOF

TECHNICAL FIELD

[0001] The present disclosure relates to converters configured to convert water vapor/moisture into electrical energy, preferably ambient water vapour into electrical energy.

BACKGROUND

[0002] Ambient humidity is a huge reservoir of low-potential energy contained in gaseous water molecules which can be used as an alternative source of electrical energy. Recently, the problem of energy independence, which requires the creation of miniature and spaced energy sources for energy applications, has simultaneously arisen. These issues can be solved by using alternative energy sources (piezo-, frequency converters, etc.). Humidity to electricity converters are one of possible type of devices for creation of the alternative energy sources that may power IoT devices, smart homes, energy storages, etc.

[0003] The most probable mechanism that leads to charge separation of generally neutral gaseous water molecules is their dissociation into protons and OH-groups both spontaneously and during their adsorption on the surface of a solid. Water droplets and ice can transfer some of these ions to other particles during melting, freezing and collisions. Faraday found that the presence of a sufficient amount of condensed water droplets in steam immediately generated electricity. The effect was caused by the fact that condensed water became a good conductor and ions were transferred to the metal or any other body due to friction.

[0004] Studies have shown that some metals can spontaneously accumulate an electrical charge when exposed to conditions of high relative humidity (>50%). Different metals are charged with different polarity due to the selective adsorption of water ions (OH^- and H^+) in accordance with the acid-base characteristics of the metal surface. The determination of the acid-base characteristics of the surface by Kelvin force microscopy confirmed that depending on the type of Brönsted characteristics of the surface of the sample (acidic or basic), it will selectively adsorb more OH^- or H^+ depending on the relative humidity. It was shown that charge transfer occurs

through the metal surface via an oxide film with active centers on the surface. The mechanism of charge exchange by means of Lewis and Brønsted centers on the surface of the oxide film is indicated. Therefore, not a metal, which can drastically change its properties during oxidation in a humid atmosphere, but stable oxide materials can be used as a converter material. Consequently, the dissociation of water molecules into ions and their selective adsorption on the surface centers of a solid can be used to separate the charges in an initially neutral water vapor molecule. The implementation of a device operating on this principle will allow accumulation of electrical energy in the most environmentally friendly and simple way. The implementation of such device in countries with a high level of humidity is especially promising.

[0005] Humidity-to-electricity converters have a very low specific power ($0.01 - 4 \mu\text{W}/\text{cm}^2$) (see Table below), but when using simple and cheap materials in large area converters, it can give good overall results.

[0006] Table 1. Electric characteristics of humidity-to-electricity converters (according to literature)

Material	V_{oc}, V^*	$I_{sc\text{max}}^*, \mu\text{A}/\text{cm}^2$	t_0^*, s	Type/optimal thickness, μm
sponge-like graphene oxide	0.012	6.2	60	-
graphene oxide frameworks	0.26	3200	2	Planar/50
TiO ₂ nanowires	0.52	8	400	Planar/15
protein nanowires	0.5	0.25	-	Planar/7
ZrO ₂ +1wt%PVA	0.08	0.1	600	Planar
$*V_{oc}$ — open circuit potential I_{sc} — short circuit current t_0 - time of generation, where $V_{oc} > 0$				

[0007] It was found that some non-metallic materials can generate electricity directly when exposed to moisture. These are protein nanofibers, carbon nanoparticles, and graphene materials which are expensive and difficult to manufacture. It was shown that existing humidity-to-electricity converters can only generate intermittent, pulsed power. This is due to the presence and absence of a concentration gradient of water molecules in the thickness of the sample (between contacts), caused by the saturation of the sample with moisture from one side at the beginning of the generation process and its complete saturation with time when the

concentration gradient of water molecules in the thickness of the sample disappears.

[0008] Also known are planar devices made of titanium dioxide (TiO₂) nanofibers for generating electricity from ambient moisture. Spin-coated fibers deposited on glass generated a constant voltage as the ambient humidity increased (>~70%RH). However, the output voltage of the TiO₂ nanofiber device is highly dependent on the ambient humidity and quickly decreases to zero (in 400 s) non-constant humidity conditions. This inconsistent power output is due to the fact that these converters have a sandwich structure closed on one side and a continuous flow of water molecules from the atmosphere cannot be maintained. Once the film is saturated with water, the gradient disappears, and the generation of the electric potential stops. Therefore, the disadvantages of these elements, which hinder their introduction into scale commercial use, are:

- the periodicity of generating process of the electrical power, namely the presence of a drying cycle, associated with the design features of the film technology for manufacturing the converter and the need to maintain a moisture gradient along the sample,
- with an unstable humidity gradient on the sides of the converter and/or with a change in the rate of evaporation/saturation of the sample with water molecules on one of the sides of the converter, the humidity gradient and, therefore, the sign of the generated potential may change to the opposite.

[0009] There is therefore a need for a converter that allows continuous conversion of ambient moisture into electric power using simple and cheap materials.

[0010] Currently, converters of the state of the art that are made of oxide materials uses a planar design placed on a substrate and only generate intermittent, pulsed power due to an unstable humidity gradient.

[0011] These facts are disclosed to illustrate the technical problem addressed by the present disclosure.

GENERAL DESCRIPTION

[0012] The present disclosure to converters configured to convert water vapour into electrical energy, preferably ambient water vapour into electrical energy.

[0013] An aspect of the present disclosure relates to a modular converter for continuous

conversion of water vapor into electricity comprising:

- a porous matrix comprising compressed metal oxide nanopowder;
- a functional layer for causing a concentration gradient of proton and OH-groups in the matrix;
- a carbon electrode layer;
- a layer of metal electrode for providing a Schottky contact with the matrix, wherein the metal electrode is selected from: Au, Ag, Al, Cu, Fe, Zn, Mg, Li, Ni, Co, Ti, Zr, Sn, Cr, Y, Nb, Mo, Pd, Pt, Cd, Hf, Ta, W, C or their alloys.
- metal or carbon current collector.

[0014] In an embodiment, the modular converter for continuous conversion of water vapor into electricity comprises:

- a porous matrix comprising yttrium oxide stabilized zirconia nanopowder;
- a functional layer for causing a concentration gradient of protons and OH-groups in the matrix, on a first surface of the porous matrix;
- a layer of carbon electrode layer on the functional layer;
- metal or carbon current collector on the first surface of the converter;
- a metal electrode layer on a second surface of the converter for providing a Schottky contact, wherein the metal electrode is selected from: Au, Ag, Al, Cu, Fe, Zn, Mg, Li, Ni, Co, Ti, Zr, Sn, Cr, Y, Nb, Mo, Pd, Pt, Cd, Hf, Ta, W, C or their alloys; metal or carbon current collector on the second surface of the converter; wherein the second surface of the converter is directly opposite the first surface of the converter.

[0015] In an embodiment, wherein the current collectors are selected from Au, Ag, Al, Cu, Fe, Zn, Mg, Li, Ni, Co, Ti, Zr, Sn, Cr, Y, Nb, Mo, Pd, Pt, Cd, Hf, Ta, W, C or their alloys.

[0016] In an embodiment, the porous matrix further comprises an additive, preferably the additive is 1 – 20 wt% activated carbon.

[0017] In an embodiment, the functional layer is a phosphate layer, preferably a layer of aluminium phosphate.

[0018] In an embodiment, the carbon electrode layer is preferably a graphite layer.

[0019] In an embodiment, the porous matrix comprises porous channels arranged perpendicular to the layer of electrodes.

[0020] In an embodiment, the compressed metal oxide nanopowder is selected from: aluminium oxide, magnesium oxide, nickel oxide, iron oxide, calcium oxide, titanium dioxide, zirconia dioxide, preferably zirconia-based metal oxide, more preferably yttrium oxide stabilized zirconia.

[0021] In an embodiment, the compressed metal oxide nanopowder comprises compressed yttrium oxide stabilized zirconia nanopowder ranging from 0 mol% - 20 mol%, preferably 0 mol% - 10 mol%, even more preferably 8 mol%.

[0022] In an embodiment, the layer of aluminium phosphate has a thickness ranging from 0.001 mm - 5 mm, preferably 0.02 mm - 0.2 mm, even more preferably 0.05 mm.

[0023] In an embodiment, the porous matrix has a density ranging from 1g/cm^3 - 4g/cm^3 , preferably $2.00\text{-}3.5\text{ g/cm}^3$, even more preferably 2.5g/cm^3 .

[0024] In an embodiment, the current collector is a gold current collector or a gold-plated current collector.

[0025] In an embodiment, the converter is in cylindrical form, rectangular cuboid form, or square cuboid form.

[0026] In an embodiment, the converter has a surface with a surface area ranging from 1 cm^2 to 1000 cm^2 , preferably from 3 cm^2 to 100 cm^2 , more preferably 11.3 cm^2 .

[0027] Another aspect of the present disclosure relates to a building article comprising the converter of the present disclosure, wherein the article is a building cladding article, a building roofing article, or a building tile article.

[0028] Another aspect of the present disclosure relates to use of the converter of the present disclosure as a building article, wherein the article is a building cladding article, a building roofing article, or a building tile article.

[0029] Another aspect of the present disclosure relates to a device for continuous conversion of water vapor into electrical energy comprising at least 2 converters of the present disclosure, wherein the converters are connected in series, parallel, or combinations thereof.

[0030] Another aspect of the present disclosure relates to a method of continuous conversion of water vapor into electrical energy using the converter of the present disclosure or the device of

the present disclosure, comprising the steps of: subjecting the converter or the device to humidity, preferably at least 20% relative humidity.

[0031] An aspect of the present disclosure relates to a converter for continuous operation without the presence of a water vapour gradient in the atmosphere on two opposite sides of the converter. To solve this problem, one side of the converter is covered with a thin layer of material that has adsorption characteristics different from the converter material and/or is a generator of charged ions (protons or OH-groups) when interacting with water molecules in the atmosphere. In this case, the converter can have a densely packed structure in the form of 3D-plate(s) and generate electrical power at any point in space with a relative humidity level starting at least 20%.

[0032] An aspect of the present disclosure relates to a modular converter configured to operate continuously based on the continuous movement of ions of adsorbed water molecules along porous channels in the absence of an external water vapour gradient.

[0033] In an embodiment, the converter comprises a porous matrix with chaotic and/or structured distribution of porous channels, (capillaries) channels formed from pores between powders particles of materials.

[0034] In an embodiment, the walls of the porous channels (or particles surfaces) have a specified centres (Lewis and Brønsted) with the specified force that allows water molecules to be adsorbed and desorbed without formation of stable links with the walls of the porous channels.

[0035] In an embodiment, the porous matrix comprises nanopowders obtained by compaction methods such as uniaxial, cold isostatic pressure conditions, etc.

[0036] In an embodiment, the size of the nanopowder particles range from 4 -50nm, preferably 7-25nm, more preferably 7-13 nm. Particle size refers to particle size obtained by visual inspection using SEM or TEM of a particle sample, typically referring to the largest observable particle dimension of individual particles.

[0037] In an embodiment, the converter has a thickness of 0.1mm– 12mm, preferably 7 mm.

[0038] In an embodiment, the converter further comprises a functional layer of phosphate on one surface of the converter.

[0039] In an embodiment, the thickness of the phosphate functional layer ranges from 0.001 - 5 mm, preferably 0.02 - 0.2mm, more preferably 0.05mm.

[0040] In an embodiment, the phosphate functional layer interacts with ambient water vapour that has been adsorbed onto the surface of the converter. This interaction changes the equilibrium density of water ions (protons and OH-groups) between covered and opposite sides of the converter thus leading to the creation of an internal moisture gradient along the converter, independent on external conditions.

[0041] In an embodiment, the phosphate functional layer produces charged ions (protons) during its interaction with water molecules adsorbed on the surface of the converter thus causing a moisture gradient in the converter. This unambiguously determines the direction of the generated current that is independent of external adsorption/desorption conditions on both sides of the converter.

[0042] In an embodiment, the converter of the present disclosure is modular and can be connected with more converters to form a group of converters in series, parallel, or combinations thereof.

[0043] In an embodiment, the converter is able to operate in the absence of an external water vapour gradient. This has the advantage that the converter can be assembled as a modular device to obtain a tight pack of converters without a spontaneous sign change of one or more converters during operation.

[0044] In an embodiment, the converter comprises pressed metal-oxide powder (zirconia, aluminium oxide, titanium oxide, zirconia with dopants, etc) preferably zirconia-based powder, more preferably yttria stabilized zirconia powder, even more preferably 8 mol% yttria stabilized zirconia nanopowder ($\text{ZrO}_2\text{-8mol\%Y}_2\text{O}_3$, hereinafter 8YSZ).

[0045] In an embodiment, the converter further comprises a functional layer of phosphate on one surface of the converter and inert conductive contacts one surface of the converter, preferably, the contact is deposited on the phosphate layer.

[0046] In an embodiment, the inert conductive contacts are carbon contacts.

[0047] In an embodiment, the converter has an electrode area the of size one surface of the converter. Preferably, the inert contact covers the whole area of one of the surfaces of the converter.

[0048] In one embodiment, the converter has current collectors made of one type of inert metal contacts, preferably gold or gold plated.

[0049] In one embodiment, the converter has current collectors made of different type of metal or carbon contacts, preferably gold on a side of converter covered by a phosphate functional layer.

[0050] In one embodiment, the converter has contacts on a second surface of the converter for providing Schottky contact, wherein the converters on the second surface is made from different type of metals or carbon, preferably selected from: Ag, Al, Cu, Fe, Zn, Li, Mg or other p-, d- or f-elements from the periodic table of elements.

[0051] In an embodiment, the converter has a thickness of 0.1mm– 12mm, preferably 7 mm.

[0052] In an embodiment, the converter has a mass of 0.5g – 20g, preferably 12g.

[0053] In an embodiment, the converter has a density of 1.7-3.0, preferably 2.5 g/cm³.

[0054] In an embodiment, the converter has a form as cylindrical, rectangular or other form, with the butt area from 1 cm² to 1000 cm², preferable from 3 cm² to 100 cm², more preferable 11.3 cm².

[0055] In an embodiment, the converter is able to convert ambient water vapour into electrical energy when placed in relative humidity of 20%-100%.

[0056] In an embodiment, the converter with a surface area of $1.1 \cdot 10^{-3}$ m² is capable of continuous electrical power generation of $11 \cdot 10^{-3}$ W at a load of 100 Ohm. The open circuit voltage is up to 2.8V, short circuit current is up to 23mA. These values 400 - 1000 times greater than the values obtained in current prior art.

[0057] In an embodiment, the converter of the present disclosure can generate energy of up to 39.6J for a characteristic time of 1 hour.

[0058] The present disclosure shows that the particle size, the acidity of the particle surface and the porosity (density) of the porous converter material affects the energy conversion efficiency of the converters.

[0059] In one embodiment, the converter comprises compressed oxide powder, preferably zirconia-based powder, more preferably yttria stabilized zirconia powder, even more preferably 8 mol% yttrium stabilized zirconia nanopowder (ZrO₂-8 mol% Y₂O₃, hereinafter 8YSZ) to which is added from 0.1 to 15 weight percent of coal (in the form of graphite, exfoliated graphite, graphene, activated carbon, etc.). The maximum amount of coal is limited by the fragility properties of the converter.

[0060] These types of humidity to electricity converters made from oxide powders can be used as building materials, while simultaneously performing the functions of generating electrical energy and building products (wall cladding, panels, etc.).

BRIEF DESCRIPTION OF THE DRAWINGS

[0061] The following figures provide preferred embodiments for illustrating the disclosure and should not be seen as limiting the scope of invention.

[0062] **Figure 1** shows X-ray diffraction pattern (**Fig. 1a**), transmission electron microscope images (**Fig. 1b**) and scanning electron microscope (**Fig. 1c**) images of 8YSZ nanopowder and pressed converter material.

[0063] **Figure 2a** shows a converter design, **Figure 2b** shows a converter circuit diagram, Figure 2c shows an illustration of the converter.

[0064] **Figure 3** shows a scheme of testing.

[0065] **Figure 4** shows time dependence of output voltage 8YSZ converter during continuous generation in the compartment with the humidity level of 60% RH with and without a functional layer of phosphate.

[0066] **Figure 5** shows time dependence of output voltage (open circuit and on load) 8YSZ converter with a functional layer of phosphate.

[0067] **Figure 6** shows dependence of open circuit and load voltage for 8YSZ converter with a functional layer of phosphate and magnesium. Figure 6 shows time dependence of output voltage of converters obtained from aluminium oxide of α (Figure 6a) and γ (Figure 6b) modifications, titanium oxide (Figure 6c), zirconia with nickel dopant (Figure 6d) on level of ambient humidity.

[0068] **Figure 7** is a schematic representation of electric potential generation in the porous oxide material.

[0069] Reference list

1. Metal current collector for providing a Schottky contact with the matrix
2. Functional layer for causing a concentration gradient (protons and OH-groups) in the matrix
3. Porous matrix

4. Water vapor
5. Channels in the porous matrix
6. Walls of the channels
7. Proton
8. OH-group

DETAILED DESCRIPTION

[0070] The present disclosure relates to converters configured to convert water vapour into electrical energy, preferably ambient water vapour into electrical energy.

[0071] In an embodiment, the converter of the present disclosure comprises zirconia nanopowder, preferably zirconia nanopowder stabilized with 8 mole% of yttrium oxide ($\text{ZrO}_2\text{-8mol\%Y}_2\text{O}_3$, hereinafter 8YSZ). The advantage of using $\text{ZrO}_2\text{-8mol\%Y}_2\text{O}_3$ is that this material is in a stable cubic (Fm3m) crystalline modification, thus excludes the possibility of phase transformations of this material when it interacts with water vapour.

[0072] In an embodiment, the $\text{ZrO}_2\text{-8mol\%Y}_2\text{O}_3$ (8YSZ) nanopowder were obtained by co-precipitation. Nanopowders were synthesized by co-precipitation using $\text{ZrOCl}_2\cdot n\text{H}_2\text{O}$ and $\text{Y}(\text{NO}_3)_3$ salts. After the last filtration, the sediments were dried in a microwave furnace with an output power of 900 W and at a frequency of 2.45 GHz. The calcination of dried zirconium-yttrium hydroxide was carried out in an electrical resistance furnace at 400°C for 2 hours [14].

[0073] In an embodiment, synthesized nanopowders are used for creating the porous matrix with different dimensions. The nanopowder are subjected to compaction in metallic die at 30 MPa to 300 MPa or in metallic die at 30 MPa and then pressed isostatically (CIP) in a rubber shell in VG32 oil at 100-400 MPa.

[0074] In an embodiment, a functional layer for causing a moisture gradient in the convert was produced from aluminum phosphate deposited on one side of the converter. The layer has a thickness ranging from 0.001 - 5 mm, preferably 0.02-0.2 mm. The aluminum phosphate functional layer was allowed to interact with the zirconia converter material by heating the converter at 400 °C for 1 hour.

[0075] In an embodiment, the nanopowder and pressed matrix were characterized by X-ray

diffraction analysis (XRD) by means of a Dron-3 diffractometer (IC “Bourestnik”, USSR) with Cu-K α radiation.

[0076] In an embodiment, the nanopowder were also evaluated by transmission electron microscopy (TEM). The porous structure of converter materials was analyzed by scanning electron microscopy (SEM). The density and porosity of materials for converters were measured by the Archimedes method.

[0077] In an embodiment, the dominant charge of the nanopowder porous matrix surface is determined from the dependence of the integral acidity of the suspension over time ($\text{pH} = f(t)$) which was based on pH method. A “pH 700” (Eutech Instruments, Singapore) was used as the pH meter-analyzer. The method of estimating the integral acidity of the surface is as follows: 40 ml of distilled water was added to the flask ($\text{pH} = 6.1$). After stabilizing the potential of the glass electrode, a powder sample (0.02 g) was added to the water. Measurements were continued until the pH stabilized and equilibrium was established in the system. Data collection were performed every 10 sec during first minute and every 1 min during 10 minutes then every 5 min. The hydration of oxide nanopowder surface occurs during measurements when surface active sites interact with water vapour. The change of pH during the first minute allows the prevailing kind of active centers on air-drying surface of nanopowder which determines nature of surface to be determined. Further dependence of pH of the suspension against time indicates the water saturated condition of powder in suspension. If the pH of the suspension increases relative to the pH of distilled water (level of neutrality), then such a medium is basic, if it decreases it is acidic.

[0078] In an embodiment, according to TEM and XRD data, the average particle size of ZrO₂-8 mol%Y₂O₃ nanopowders obtained by a co-precipitation technique range from 6 to 50 nm, preferably 8 ± 2 nm (**Fig. 1a, 1b**). The nanopowder was represented by a cubic phase Fm3m. The observed X-ray reflections exhibit good agreement with the ICDD standard card No. 01-071-4810.

[0079] **Figure 1** shows X-ray diffraction pattern (**Fig. 1a**), transmission electron microscope images (**Fig. 1b**) and scanning electron microscope (**Fig. 1c**) images of 8YSZ nanopowder and pressed converter material.

[0080] In an embodiment, the converter of the present disclosure has different dimensions which is determined by the possibilities of production process and constructive strength of converter. For example, the cylindrical pellet with diameter 15 mm and 1 mm height, the rectangular samples with dimensions 50*80*2 mm, etc (**Fig. 2**).

[0081] **Figure 2a** shows a converter design, **Figure 2b** shows a converter circuit diagram.

[0082] In an embodiment, the functional phosphate layer was deposited onto one side of the convert either by tape casting or by other methods.

[0083] The inert graphite contacts were deposited on one of the surfaces of the converter. The Au-plated current collectors connect the converter to the measuring device - DMM7510 (Keithley, USA) (**Fig. 3**). The AM2302 digital capacitive sensor with accuracy to 0.1% RH controlled the humidity level in the chamber. The testing device was located in the grounded Faraday grid.

[0084] **Figure 3** shows a scheme of testing and a schematic representation of the converter of the present disclosure.

[0085] The technical effect of the converter of the present disclosure is that it allows continuous conversion of water vapor, preferably ambient humidity, to electrical energy and the specific characteristics of adsorption-type electrical energy converters.

[0086] **Figure 4** shows time dependence of output voltage 8YSZ converter during continuous generation in the compartment with the humidity level 60% RH with and without a functional layer.

[0087] In an embodiment, that when the humidity changes from 20 to 95%, the potential generate by the converter of the present disclosure is non-linearly dependent on the ambient humidity level.

[0088] **Figure 5** shows time dependence of output voltage (open circuit and on load 100 Ohm) 8YSZ converter with a functional phosphate layer.

[0089] **Figure 6** shows time dependence of output voltage of converters obtained from aluminium oxide of α (Figure 6a) and γ (Figure 6b) modifications, titanium oxide (Figure 6c), zirconia with nickel dopant (Figure 6d) with a functional phosphate layer on level of ambient humidity.

[0090] **Figure 7 shows** the scheme of creation of the electric potential on the converter sides in the humidity gradient

[0091] **Table 2** shows electrical characteristics of humidity-to-electricity converters obtained from different metal oxides.

[0092] **Table 2.** Electrical characteristics of humidity-to-electricity converters from metal oxides

Material	V_{oc}, V^*	$I_{scmax}^*, \mu A/cm^2$
Magnesium oxide	0.35	0.005
Iron oxide	0.4	0.005
Nickel oxide	0.2	0.02
Titanium oxide (TiO ₂)	0.03	-
Aluminum oxide (Al ₂ O ₃)	0.01	-
YZS +8wt% Nickel	0.02	-
* V_{oc} — open circuit potential I_{sc} — short circuit current		

[0093] In an embodiment, increase in voltage and current can be obtained by connecting multiple converters of the present disclosure in series or parallel or combination thereof.

[0094] It can be argued that:

- the generation of an electric potential by a porous sample made of oxide powder occurs when it is placed in a humidity conditions (the concentration of water molecules in the atmosphere);
- the increase in the value of the generated electric potential occurs over time, with subsequent stabilization at a certain level;
- the time dependence of the electric potential of the converter correlates with the time dependence of the water adsorption of the porous sample;
- the use of a functional layer (phosphate layer) on one side of the converter leads to active generation of protons due to the dissociation of "aluminum phosphate" on this side when interacting with adsorbed water molecules, and an unambiguous determination of the sign of the electric potential, regardless of the change in external conditions. Thus, allowing continuous power generation;
- the magnitude of the generated electric potential is determined by the type of material and the properties of the surface of the particles during their interaction with water molecules;
- the use of a functional layer (phosphate layer) on one side of the converter leads to a difference in the adsorption properties of the sides of the converter, which determines the direction of the concentration of protons and OH-groups along the converter.

[0095] The process of generating an electric potential by a porous oxide material occurs due to the adsorption of water molecules on the surface of porous channels formed between oxide

particles and their diffusion through the channels in the direction of decreasing of related humidity. The adsorption of water molecules on the surface of oxide particles depends on the type of surface charges and their strength. It is also known that in water a certain amount of dissociated water molecules, which depends on the value of acidity (pH), is present. On the walls of porous channels, a Stern layer and a diffusion layer of a certain sign, which prevents diffusion through the channels of dissociated water molecules (protons and OH-groups) of the same sign, are formed. Thus, only ions of the same sign diffuse along the channels, which determines the process of charge separation along the sample (along the concentration gradient of water molecules) and the value of the electric potential on opposite sides of the converter (Fig. 7).

[0096] A humidity gradient along the sample leads to the flow of water molecules in the porous structure. Due to water self-ionization, this streaming carries an uncompensated charge and generates a streaming current or potential. Charge accumulates at the inlet and outlet, and a streaming potential develops across the channel. Since the walls of the microchannels are charged (positively or negatively), oppositely charged ions in an aqueous solution (for example, positive protons or negative OH-groups) are attracted to the channel walls and form a double electric layer, which prevents further flow of ions of the opposite sign. In this case, a separation of charges occurs, and a potential arises, the sign of which is determined by the sign of the charge on the surface of the channel walls.

[0097] **Figure 7** is a schematic representation of electric potential generation in the porous oxide material.

[0098] The effect of electric potential generation may be explained in terms of a capacitor with a variable dielectric constant, which, in turn, depends on the flow of water molecules along the porous channels. The potential on this capacitor may be calculated as a sum of streaming potential and standard potential on the capacitor.

$$V = V_{sp} + \frac{qd}{\epsilon\epsilon_0 S}, \quad (1)$$

Where V_{sp} – streaming potential (Eq. 2), q – charge, d – separation between the plates, $\epsilon\epsilon_0$ is the permittivity of the capacitor dielectric, S – area of capacitor.

$$V_{sp} = \frac{8\epsilon\epsilon_0\zeta L}{\pi K R^4} Q, \quad (2)$$

where R is the radius of the channel, ζ is the zeta potential of the channel walls, $\epsilon\epsilon_0$ is the

permittivity of the solution, and Q is the volumetric flow rate, K is the conductivity of the solution, L is the length of the channel.

[0099] When the water vapor does not penetrate in the porous channels the streaming potential and charge on the capacitor equal to zero. The value of the streaming potential increases due to the water molecules flow rate due to the humidity gradient along the converter. The continuous adsorption of water molecules on the wetter side of the converter and their continuous evaporation on the drier side determines the continuous flow of water molecules in the porous channels of the converter.

[00100] Zeta potential value and dielectric properties of material determine the sign and value of the streaming potential. In this request the sign of the surface charge of the ZrO_2 -8mol% Y_2O_3 powder particles is positive ($\Delta pH < 0$). Consequently, OH-groups will move along the porous channels in the converter based on ZrO_2 -8mol% Y_2O_3 .

[00101] In an embodiment, the specific surface area of the porous structure of the converter material based on nanopowder is several times greater than the area of a planar heterojunction, thus making it possible to significantly increase the conversion efficiency compared to planar analogs of current prior art.

[00102] In an embodiment, the thickness of the converter of the present disclosure is determined, on the one hand, by the structural strength of the tablet, and, on the other hand, by a decrease in the magnitude of the electric potential.

[00103] The embodiments described above are combinable.

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C L A I M S

1. A modular converter for continuous conversion of water vapor into electricity comprising:
 - a porous matrix comprising compressed metal oxide nanopowder;
 - a functional layer for causing a concentration gradient of protons and OH-groups in the matrix;
 - a carbon electrode layer;
 - a layer of metal electrode for providing a Schottky contact.
2. The converter according to the previous claim further comprising a metal or carbon current collector.
3. The converter according to the previous claim, wherein the converter comprises:
 - a porous matrix comprising yttrium oxide stabilized zirconia nanopowder;
 - a functional layer for causing a concentration gradient of protons and OH-groups in the matrix, on a first surface of the porous matrix;
 - a layer of carbon electrode layer on the functional layer;
 - metal or carbon current collector on the first surface of the converter;
 - a metal electrode layer on a second surface of the converter for providing a Schottky contact, wherein the metal electrode is selected from: Au, Ag, Al, Cu, Fe, Zn, Mg, Li, Ni, Co, Ti, Zr, Sn, Cr, Y, Nb, Mo, Pd, Pt, Cd, Hf, Ta, W, C or their alloys;
 - metal or carbon current collector on a second surface of the converter.
4. The converter according to the previous claim, wherein the second surface of the converter is directly opposite the first surface of the converter.
5. The converter according to any of the previous claims, wherein the porous matrix further comprises an additive, preferably the additive is 1 – 20 wt% activated carbon.
6. The converter according to any of the previous claims, wherein the functional layer is a phosphate layer, preferably a layer of aluminum phosphate.
7. The converter according to any of the previous claims, wherein the carbon electrode

- layer is preferably a graphite layer.
8. The converter according to any of the previous claims, wherein the porous matrix comprises porous channels arranged perpendicular to the layer of electrodes.
 9. The converter according to any of the previous claims, wherein the compressed metal oxide nanopowder is selected from: aluminium oxide, magnesium oxide, nickel oxide, iron oxide, calcium oxide, titanium dioxide, zirconia, preferably zirconia-based metal oxide, more preferably yttrium oxide stabilized zirconia.
 10. The converter according to any of the previous claims, wherein the compressed metal oxide nanopowder comprises compressed yttrium oxide stabilized zirconia nanopowder ranging from 0 mol% - 20 mol%, preferably 0 mol% - 10 mol%, even more preferably 8 mol%.
 11. The converter according to any of the previous claims, wherein the layer of aluminum phosphate has a thickness ranging from 0.001 mm - 5 mm, preferably 0.02 mm - 0.2 mm, even more preferably 0.05 mm.
 12. The converter according to any of the previous claims, wherein the porous matrix has a density ranging from 1g/cm^3 - 4g/cm^3 , preferably $2.00\text{--}3.5\text{ g/cm}^3$, even more preferably 2.5g/cm^3 .
 13. The converter according to claim 2, or claim 2 and any of the claims 3-12, wherein the current collector is a gold current collector or a gold-plated current collector.
 14. The converter according to any of the previous claims, wherein the converter is in cylindrical form, rectangular cuboid form, or square cuboid form.
 15. The converter according to the previous claim, wherein the converter has at least one surface with a surface area ranging from 1 cm^2 to 1000 cm^2 , preferably from 3 cm^2 to 100 cm^2 , more preferably 11.3 cm^2 .
 16. A building article comprising the converter according to any of the previous claims 1-15, wherein the article is a building cladding article, a building roofing article, or a building tile article.

17. Use of the converter according to any of the previous claims 1-15 as a building article, wherein the article is a building cladding article, a building roofing article, or a building tile article.
18. A device for continuous conversion of water vapor into electrical energy comprising at least 2 converters according to any of the previous claims 1-15, wherein the converters are connected in series, parallel, or combinations thereof.
19. Method of continuous conversion of water vapor into electrical energy using the converter according to any of the previous claims 1-15 or the device according to claim 18 comprising the steps of: subjecting the converter or the device to humidity, preferably at least 20% relative humidity.