Exploring materials for energy

Interview Dr. Li-Chyong Chen

The use of conventional fossil fuels has cast the landscape of convenient modern life. The accompanied carbon emission and related pollution nonetheless pose an increasing crisis on both the natural environment and the well-being of humankind. For decades, scientists have been searching for substitute energy solutions to reduce or inhibit these growingly severe environmental impacts. Despite being far from capable of resolving these issues, the following exemplifications, presented in the form of a Q & A interview by undergraduate students at the Department of Physics, represent our endeavor to address this outstanding problem in modern science.

1. What is the current status of energy-storage developments, in particular, Li-related technology?

Dr. Chen: The next-generation battery research largely focuses on the Li-S battery that displays a much higher theoretical energy density than that of the Li-ion counterpart. However, the Li-S battery is not immune from technical disadvantages, suffering the issues of volume expansion and contraction upon the respective charging and discharging processes caused by the low conductivity of sulfur; these issues substantially degrade the overall performance. One plausible solution to this drawback is the use of carbon composites to enhance the conductivity. The incorporation of a certain degree of porosity into the battery device to tolerate the expansion and contraction can also be an alternative. With such a battery-design principle in mind, the realization of practically useful Li-S batteries is indeed possible, and the associated development of *in situ* spectroscopic characterization technique, targeting at monitoring the molecular-scale change of the battery composite upon charging and discharging, would be equally important. These two points represent an important facet of the frontiers of Li-battery research and have attracted worldwide attention, thus promoting competition among research teams, among which our team in National Taiwan University could be considered as a rising force.

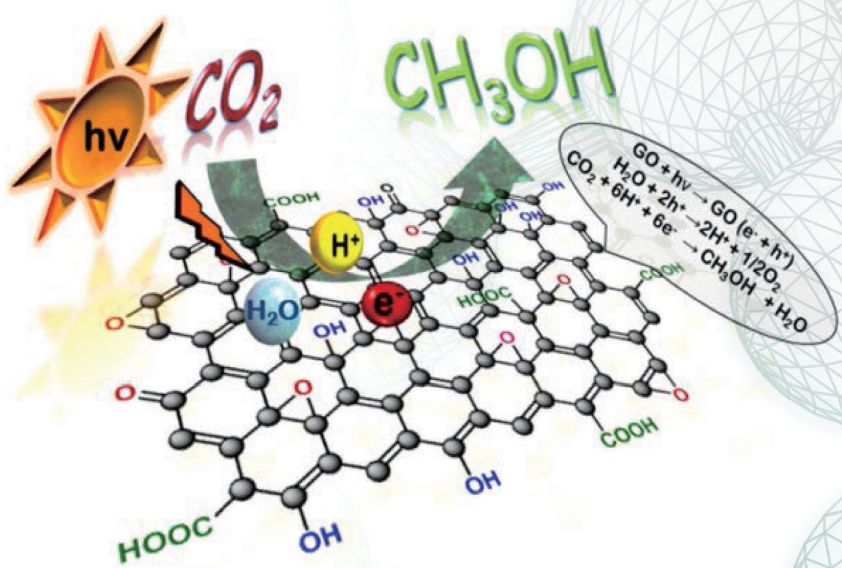

Figure 1. A research group led by Li-Chyong Chen has discovered an innovative approach for triggering the CO_2 conversion into solar fuels using synthetic two-dimensional (2D) graphene oxides (GOs) and hybrid GOs. This process, so-called artificial photosynthesis, mimics the way plants convert CO_2 and sunlight into glucose and paves the avenue to new energy solutions by 2D materials.

2. The so-called solution-process solar cell has been actively discussed. Would you please briefly summarize the background?

Dr. Chen: The modern solar cell with the highest efficiency is based on gallium arsenide (GaAs), typically used in space technology and famous for its high cost. For general applications, silicon-based technology is the most mature, with the advantages of relatively low cost and acceptably high efficiency of up to 20%. To more vividly depict the scale of cost, we take the example of Si-based solar cells, the cost of which is reduced significantly over years, but still much higher than the cost of fossil fuel. Therefore, there is room for exploring alternative materials for energy production with further reduced costs. The recent discovery of the so-called perovskite solar cell, based on solution-process hybrids of organic and inorganic species, turns out to be a game-changing material because of its notably low cost (one tenth of the Si counterpart) and optimally engineered efficiency of up to 12%~18%. However, note that this perovskite solar-cell system is not free from problems, for example, moisture sensitivity and lifetime. Indeed, there is much room for improvement regarding the development of perovskite solar cells; as a result, the material system has drawn much attention recently.

3. Display panels constitute a massive source of energy consumption. LCD and OLED displays have been frequently mentioned. What is the difference?

Dr. Chen: The well-developed liquid crystal display (LCD) has been the mainstream technology of display applications since the end of the 20th century.

On one hand, an LCD is a passive component, and one of its main issues is its small viewing angle. On the other hand, an organic light emitting diode (OLED) is an active component, i.e., it is able to emit light when current passes through it, and it does not have the viewing angle problem because it is deformable. The brightness of an OLED display is higher, and it has a better luminous efficiency, making it not as power consuming as an LCD. Nevertheless, OLED displays have their own issues, the main issue being that mass production techniques of OLED displays are still under development. OLED displays may become less expensive than LCDs someday, but to be honest, LCDs are already very inexpensive. Moreover, while progress has been made in the development of OLED displays, LCDs are also improving. For example, televisions using LCDs have increased their screen size to make up for the lack of viewing angle.

Although now it may seem like OLED displays do not have a clear advantage over LCDs, there is one clear advantage that OLED displays have over LCDs: flexibility. Flexibility is a property of soft matter. For example, although iPads and smart phones are not deformable, it would be much more convenient if we could roll them up like napkins. Such deformability can only be achieved by using OLEDs. The invention and discovery of new materials are mostly motivated by the urge to achieve capabilities that current materials cannot. LCDs are left with minor improvements, whereas the development of OLED displays can lead to many breakthroughs in technology. That potential gives OLED displays an edge over LCDs. Although techniques of mass production of OLED displays are yet to be developed, OLED displays can still be of good use in components of small sizes. In fact, nearly everything we bring with us outside can be considered as small components. Another aspect worth noticing is that OLED displays have a shorter lifetime than LCDs. In other words, LCDs are more durable. However, electrical components, such as smart phones, have high replacement rates, with new and upgraded products released every year or two. Therefore, the short lifetime of OLED displays is not really an issue for products with high development rates. Overall, OLED displays have much future potential, considering their advantages.

4. Cars, electronic devices, and home appliances all generate heat. Is there no way to make use of the waste heat?

Dr. Chen: Of course, a solution exists: thermoelectric materials can turn waste heat into useful electricity.

In reality, such materials have already been implemented in many industries, for example, rockets and satellites use these materials to convert radiation heat into electricity for energy-consuming operations. The effectiveness of energy transfer of thermoelectric materials is astonishing.

The current bottleneck of thermoelectric materials is related to cost again, such as the expensive thermoelectric silicon-germanium combination. An associated technical challenge is mass production. It is therefore vital to seek for new thermoelectric materials with high electric conductivity, low thermal conductivity, and ease of production. With decades of research efforts on the problem all over the world, it is unfortunately true that progress along the direction is still limited because of the fundamental limitations of physics. Finding new material(s) that address the bottleneck represents the holy grail of turning waste heat into precious resources.

5. What can we learn from Mother Nature to improve the other type of energy-storage device, namely, fuel cells?

Dr. Chen: Fuel cells definitely represent the cleanest energy solution, with water being the only "waste" substance during the power-generation process. However, the vital electro-catalyst component of platinum (Pt) renders the whole device too expensive to use in daily life. Seeking a non-precious metal electro-catalyst is therefore highly important; however, the progress had been frustratingly slow.

Very recently, scientists have reconsidered the reduction–oxidation principle of the cells by borrowing the fact that the same reaction occurs in a living body every second. The proof-of-concept exploitation of corrin and corrole in our blood circulatory system as the electro-catalyst in fuel cells has been demonstrated, paving the way toward affordable fuel cells; however, many improvements are required.

6. Can the broad spectrum of popular two-dimensional materials be used in energy applications?

Dr. Chen: The global climate change has been fundamentally entangled with carbon emissions, particularly CO_2, from the burning fossil fuel. The subsequent challenge is readily whether the emitted CO_2 could be transformed into hydrocarbons with low carbon-hydrogen ratios (such as CH_4 or CH_3OH) to reduce the greenhouse effect. To achieve this goal, one must find the proper catalyst to promote this chemical reaction. Although a plethora of catalyst materials have been tested, the conversion ratio is far from satisfactory.

With the birth of modern atomically thin two-dimensional materials (such as graphene, the Nobel Prize in Physics in 2010), an alternative approach emerging involves the use of graphene oxide (GO); I performed the first experimental trial of the idea. In fact, GO is a group of compounds with different functional groups (-OH, -COOH, etc.) connected to graphene that can provide better catalytic effect than the commonly used material of TiO_2. Honestly speaking, the physical and chemical mechanism behind this improvement is still an open question; nevertheless, we are confident that two-dimensional materials can indeed be useful in energy applications.

7. Could modern materials theory be helpful in searching for the appropriate materials?

Dr. Chen: It is very true that textbook examples are frequently not the appropriate materials for modern applications; as a result, we experimentalists are constantly busy searching for them. There always exist certain clues in the quest for appropriate materials, and theoreticians can be very helpful in selecting the most likely factor out of the various parameters via a modern theory framework in combination with sufficient computational power.

For example, several investigators in our center are now working on such primitive theoretical "guesses", starting from the basic construction unit of atoms in matter. Indeed, it is very entertaining to see from computer simulations how atoms assemble into materials and then exhibit their given properties.

Although the theoretical capturing of the property of a given material is an art and is still under development, the theoretical calculations by themselves could be a type of green research effort, considering that these calculations could reduce a significant number of unnecessary experiments. Of course, theoretical calculations cannot be performed without electricity, although this issue could be a separate issue on its own.

8. Would you please share some of your opinions on the difference between academia and industry to assist our future decisions in career life?

Dr. Chen: I have worked in the General Electric (GE) Company, which, despite being a company in the private industrial sector, still performs many basic research studies. One intriguing question raised during my GE days is whether one could fly across half the earth non-stop. Thinking about the technical and scientific challenges behind that task, first, one must develop the most efficient engine ever, let alone all the other details. This development calls for a thorough technical consideration of the engine design based on a new concept; such development would not only involve new and light materials but entire thermodynamics principles. This simple example outlines the high-standard research quality of GE, and such an approach has broadened my scope in considering how to conduct a research program.

It is a pity that most industrial companies in Taiwan target short- and/or mid-term profits, thereby limiting the possibility of undertaking truly challenging and high-impact technologies. For young talents such as you, this issue is an important consideration if your intent is to join industry in Taiwan. Compared to industry, academia in Taiwan offers you the possibility of trying new ideas that require long-term commitments. In this case, the questions are whether your idea is an attractive one across various research disciplines and whether your idea can be achieved without the accumulation of knowledge and experience in your academic career life. This latter aspect is also the most beautiful aspect of academic research.

Crowned the Taiwan Outstanding Women in Science Award in March 2017, Professor Li-Chyong Chen has been leading a group of researchers working on sustainable energy. There are more women in the sciences than ever before, as reported by Nature; however, the physical sciences are woefully behind regarding the number of women at all levels. Professor Chen's endeavors may shed light on plausible career paths of students longing to contribute their lives to physics.

Reference

Ramin Skibba. Women in physics face big hurdles — still persistent biases continue to affect the numbers of female physicists. *Nature*, 01 August 2016. *http://www.nature.com/news/women-in-physics-face-big-hurdles-still-1.20349*

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