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Fundamentals of Photovoltaic Technology (PV): A Review

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Abstract: Energy demand in the world increases significantly as of industrial revolution and population growth. However, existing non-renewable sources are limited and depleting at a faster rate. Furthermore, burning of fossil fuel for energy recovery emits significant amount of CO_2 into atmosphere that leads to many environmental consequences especially global warming. World is therefore seeking renewable energy sources in order to mitigate problems encountered in the energy sector. PV technology is becoming popular in the world as of its freely available in nature. Many steps are taken to increase the efficiency of solar cells with minimum cost of manufacturing. Hence, this article provides an overview of world energy scenario, fundamentals of PV technology, growth and development of PV industry all over the world, techniques to increase the efficiency of solar cells, applications of PV technology and barriers on its way towards development. This review article helps the researchers for further research works of practical importance.

Key words: Basic concept · Renewable energy · Photovoltaic · Technology · Solar cell

INTRODUCTION

Photovoltaic (PV) systems convert sunlight into electricity. Once an exotic technology used almost exclusively on satellites in space, photovoltaic has come down to earth to find rapidly expanding energy markets. Many thousands of PV systems have been installed around the globe. PV devices can be made from many different materials in many different designs. The diversity of PV materials and their different characteristics and potentials demonstrate the richness of this growing technology. They also explained about PV effect. Because PV occurs through PV effect [1].

Primary unit of PV system solar cell, it is known as PV cell. PV effect was observed in 1839 by the French scientist Edmund Becquerel. Most PV cells in use today are silicon-based, cells made of other semiconductor materials are expected to surpass silicon PV cells in performance and cost and become viable competitors in the PV market place. PV technology uses the semiconductor materials to design the PV system. Solar cell is the basic unit of PV system, solar cells are collectively arranged into modules and modules are arranged together to form panels or arrays. Mainly three types of PV technology such as crystalline, thin film and nano-technology [2]. PV technology is and is suited to a broad range of applications and can contribute substantially to our future energy needs. The basic principles of PV were discovered in the 19th century. It was not before the 1950s and 1960s that solar cells found practiced use as electricity generators, a development that came about through early silicon semiconductor technology for electronic applications [3].

PV technology describes through the generations. First generation used crystalline silicon, second generation used the thin film and third generation uses nano-technology. Nano-technology uses the conductive organic molecules to design organic cell [4]. Concentrators are the one of the PV systems. Concentrators can be divided into three, such as Parabolic trough, Power towers and Dish-engine system. In this system energy from sunlight first converted into heat energy then after to electricity. This is an indirect conversion of solar energy into electricity [5].

The aim of continuous development of PV technology through the generations is not only to improve the efficiency of the solar cells but also to reduce the production cost of the modules and arrays. Moreover such variety in technology is needed to enhance the deployment of solar energy for a greener and clean environment.

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PV Effect: Semiconductors are used to produce solar cells and the characteristics of the semiconductor material make it easy for incoming photons of sunlight to release electrons from the electron hole binding. Leaving the holes behind them, the released electrons can move freely within the solid. However, these movements have no clear direction; to make use of the electricity, it is necessary to collect electrons. The semiconductor material is therefore polluted with ‘impure atoms. Two different kinds of atom produce an n-type and p-type region inside the semiconductor and these two neighboring regions generate an electrical field [6].

This field can then collect electrons and draws free electrons released by the photons to then n-type region. The holes move in the opposite direction, into the p-type region. However, not all of the energy from the sunlight can generate free electrons. There are several reasons for this. Part of sunlight is reflected at the surface of the solar cell, or passes through the cell. In some cases, electrons and holes recombine before arriving at the n-type and p-type regions [6].

Furthermore, if the energy of the photon is too low- which is the case with light at long wavelengths, such as infrared- it is not sufficient to release the electron. On the other hand, if the photon energy is too high, only a part of its energy is needed to release the electron and the rest converts to heat [6].

Type of PV Cell Materials/ Pv Technologies: PV cells are made of semiconductor materials and organic cell. The major types of semiconductor materials are crystalline thin film, which vary from each other in terms of light absorption efficiency, energy conversion efficiency, manufacturing technology and cost of production.

Crystalline Materials-1st Generation Technology

Single-Crystal Silicon: Cells are the most common in the PV industry. A single-crystal silicon has a uniform molecular structure. Compared to non-crystalline materials, its high uniformity results in higher energy conversion efficiency. The ratio of electric power produced by the cell to the amount of available sunlight power i.e. power-out divided by power-in. The higher the PV cell’s conversion efficiency, the more electricity it generates for a given area of exposure to the sunlight. The conversion efficiency for single-silicon commercial modules ranges between 15-20%. Not only are they energy efficient, single-silicon modules are highly reliable for outdoor power application [2].

Polycrystalline Silicon: Consisting of small grains of single-crystal silicon, polycrystalline PV cells are less energy efficient than single-crystalline silicon PV cells. The grain boundaries in polycrystalline silicon hinder the flow of electrons and reduce the power output of the cell.

The energy conversion efficiency for a commercial module made of polycrystalline silicon ranges between 10 to 14% [2].

Gallium Arsenide (GaAs): A compound semiconductor made of two elements. Gallium (Ga) and Arsenic (As). GaAs has a crystal structure similar to that of silicon. An advantage of GaAs is that it has high level of light absorptive. To absorb the same amount of sunlight, GaAs requires only a layer of few micrometers thick while crystalline silicon requires a wafer of about 200-300 micrometers thick. Also it has much higher energy conversion efficiency than crystal silicon, about 25-30% [2].

Thin Film Materials- 2nd Generation Technology: In a thin-film PV cell, a thin semiconductor layer of PV materials is deposited on low-cost supporting layer such as glass, metal or plastic foil. Since thin-film materials have higher light absorptivity than crystalline materials, the deposited layer of PV materials is extremely thin, from a few micrometers to even less than a micrometer.

Amorphous Silicon (a-Si): Used mostly in consumer electronic products which require lower power output and cost production, amorphous silicon has been the dominant thin-film PV materials. It is a non-crystalline form of silicon i.e. its silicon atoms are disordered in structure. A significant advantage of a-Si is its high light absorptivity, about 40 times higher than that of single-crystal silicon, a-Si still has two major roadblocks to overcome. One is the low cell energy conversion efficiency, about 5-9% and the other is the outdoor reliability problem in which the efficiency degrades within a few months of exposure to sunlight, losing about 10-15% [2].

Cadmium Telluride (CdTe): As a polycrystalline semiconductor compound made of cadmium and tellurium. CdTe has a high light absorptivity level-only about a micrometer thick can absorb 90% of the solar spectrum. Another advantage is that it is relatively easy and cheap to manufacture by processes such as high-rate evaporation, spraying or screen printing. The conversion efficiency for a CdTe commercial module is about 7% similar to that of a-Si [2].

Copper Indium Diselenide ($CuInSe_2$, or CIS): A polycrystalline semiconductor compound of copper, indium and selenium. The energy conversion efficiency is about 17.7%, being able to deliver such high energy conversion efficiency without suffering from the outdoor degradation problem [2].

Organic Cell- 3rd Generation Technology: Organic photovoltaic (OPV) solar cells aim to provide an Earth-abundant and low-energy production photovoltaic (PV) solution. This technology also has the theoretical potential to provide electricity at a lower cost than first and second generation solar technologies. Because various absorbers can be used to create colored or transparent OPV devices, this technology is particularly appealing to the building-integrated PV market. Organic photovoltaic have achieved efficiencies near 11%, but efficiency limitations as well as long-term reliability remain significant barriers [4].

The absorber is used in conjunction with an electron acceptor, such as a fullerene, which has molecular orbital energy states that facilitate electron transfer. Upon absorbing a photon, the resulting exciton migrates to the interface between the absorber material and the electron acceptor material. At the interface, the energetic mismatch of the molecular orbital provides sufficient driving force to split the exciton and create free charge carriers [4].

Concentrating Solar Power Technologies (CSP): Concentrating solar power technologies use mirrors to concentrate (focus) the sun's light energy and convert it into heat to create steam to drive a turbine that generates electrical power. CSP technology utilizes focused sunlight. CSP plants generate electric power by using mirrors to concentrate (focus) the Sun's energy and convert it into high-temperature heat. The heat is then channeled through a conventional generator. The plants consist of two parts: one that collects solar energy and converts it to heat and another that converts the heat energy to electricity. CSP technology utilizes three alternative technological approaches: Parabolic/Trough systems, power tower systems and dish-engine systems [5].

Trough Systems: These systems use large, U-shaped (parabolic) reflectors (focusing mirrors) that have oil-filled pipes running along their center, or focal point. The mirrored reflectors are tilted toward the Sun and focus sunlight on the pipes to heat the oil inside to as much as 750°F. The hot oil is then used to boil water, which makes steam to run conventional steam turbines and generators. [5]

Power-Tower Systems: These are also called central receivers, use many large, flat heliostats (mirrors) to track the Sun and focus its rays onto a receiver. The receiver sits on top of a tall tower in which concentrated sunlight heats a fluid, such as molten salt, as hot as 1050°F. The hot fluid can be used immediately to make steam for electricity generation or stored for later use. Molten salt retains heat efficiently, so it can be stored for days before being converted into electricity. That means electricity can be produced during periods of peak need on cloudy days or even several hours after sunset [5].

Dish-Engine Systems: These are use mirrored dishes to focus and concentrate sunlight onto a receiver. The receiver is mounted at the focal point of the dish. To capture the maximum amount of solar energy, the dish assembly tracks the Sun across the sky. The receiver is integrated into a high-efficiency "external" combustion engine. The engine has thin tubes containing hydrogen or helium gas that run along the outside of the engine's four piston cylinders. As concentrated sunlight falls on the receiver, it heats the gas in the tubes to very high temperatures, which causes hot gas to expand inside the cylinders. The expanding gas drives the pistons. The pistons turn a crankshaft, which drives an electric generator. The receiver, engine and generator comprise a single, integrated assembly mounted at the focus of the mirrored dish [5].

Solar Tracking Systems: Trackers direct solar panels or modules toward the sun. These devices change their orientation throughout the day to follow the sun's path to maximize energy capture. In photovoltaic systems, trackers help to minimize the angle of incidence (the angle that a ray of light makes with a line perpendicular to the surface) between the incoming light and the panel, which increases the amount of energy the installation produces. Concentrated solar photovoltaic and concentrated solar thermal have optics that directly accepts sunlight, so solar trackers must be angled correctly to collect energy. All concentrated solar systems have trackers because the systems do not produce energy unless directed correctly toward the sun. Single-axis solar trackers rotate on one axis moving back and forth in a single direction. Different types of single-axis trackers include horizontal, vertical, tilted and polar aligned, which rotate as the names imply. Dual-axis trackers continually face the sun because they can move in two different directions. Types include tip-tilt and azimuth-altitude. Dual-axis tracking is typically used to orient a mirror and redirect sunlight along a fixed axis towards a stationary

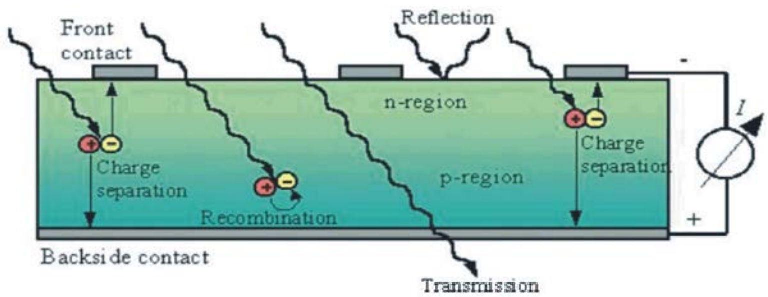

Fig. 1: Processing occurring in an irradiated PV cell [6].

Fig. 2: Single crystal silicon [9].

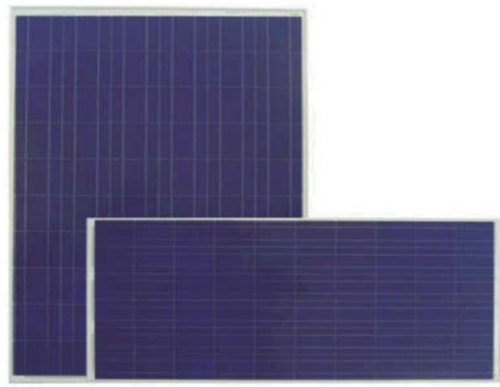

Fig. 3: Polycrystalline silicon [10].

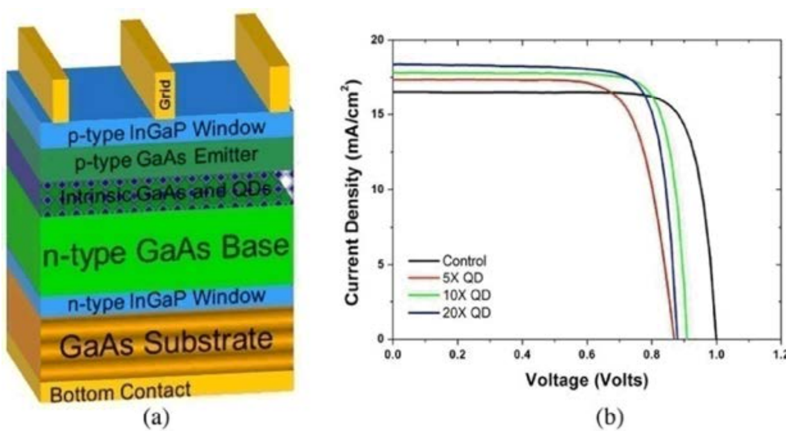

Fig. 4: Gallium Arsenide [11].

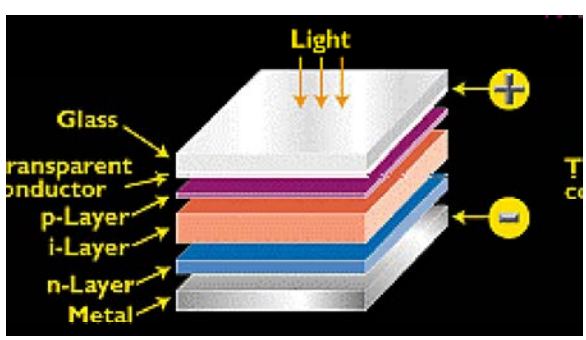

Fig. 5: Amorphous silicon (12).

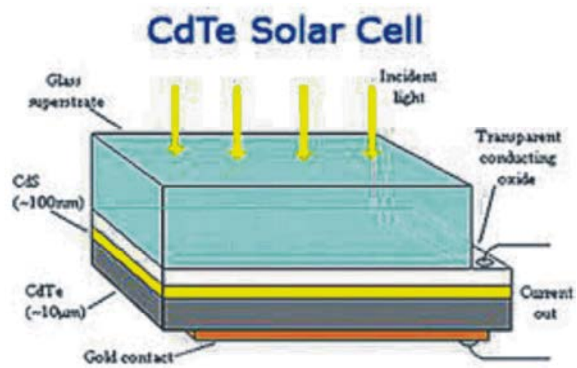

Fig. 6: Cadmium Solar cell [13].

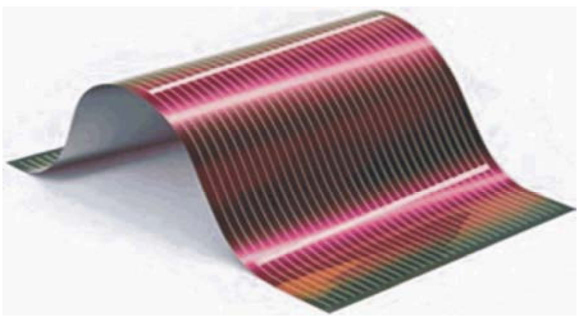

Fig. 7: Copper Indium Diselenide [14].

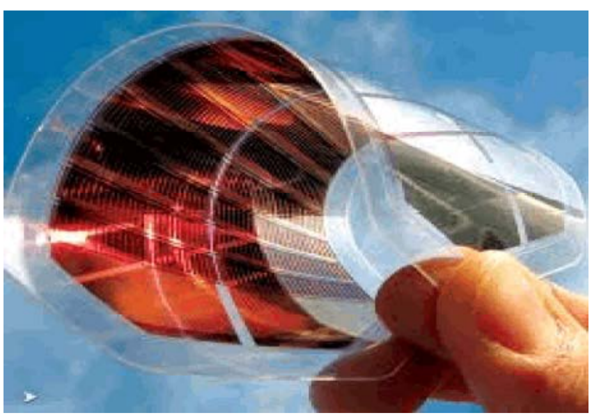

Fig. 8: Organic solar cell [15].

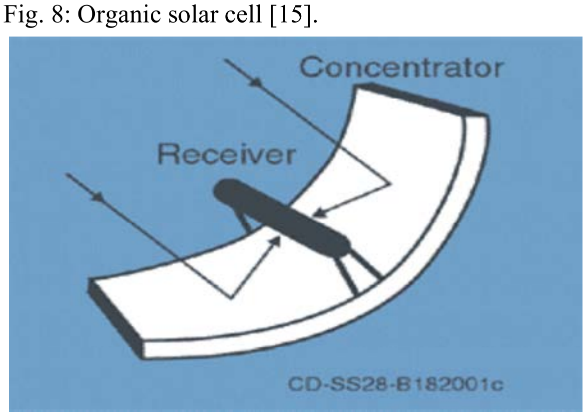

Fig. 9: Parabolic/trough system [5].

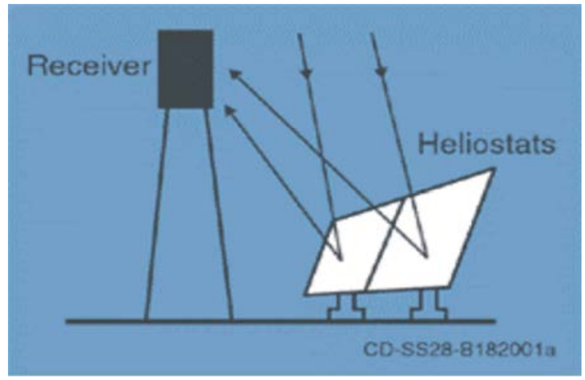

Fig. 10: Power Tower system [5].

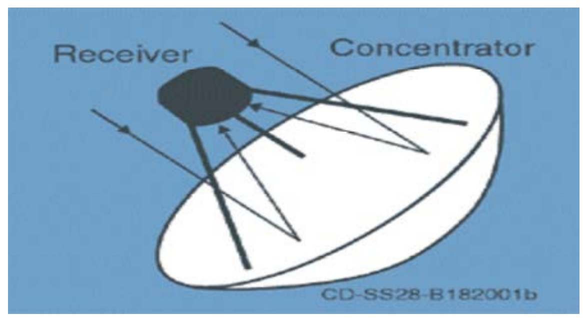

Fig. 11: Dish-Engine system [5].

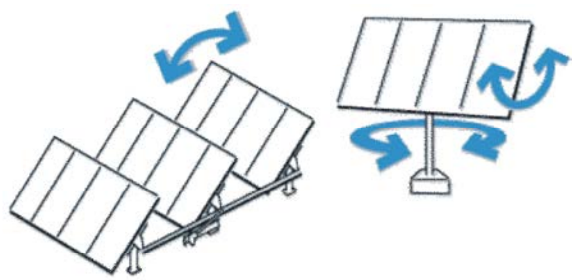

Fig. 12: Tracking system [16].

receiver. Because these trackers follow the sun vertically and horizontaly they help to obtain maximum solar energy generation [7].

There are also several methods of driving solar trackers. Passive trackers move from a compressed gas fluid driven to one side or the other. Motors and gear trains direct active solar trackers by means of a controller that responds to the Sun's direction. Finally, a chronological tracker counteracts the Earth's rotation by turning in the opposite direction [7].

Worldwide Pv Solar Growth: As can be seen from the chart (Fig. 2) the solar industry has seen remarkable growth. The blue bars represent the annual amount of PV solar systems installed by manufacturers in Giga-watts (1 GW=1 billion watts). One nuclear reactor produces

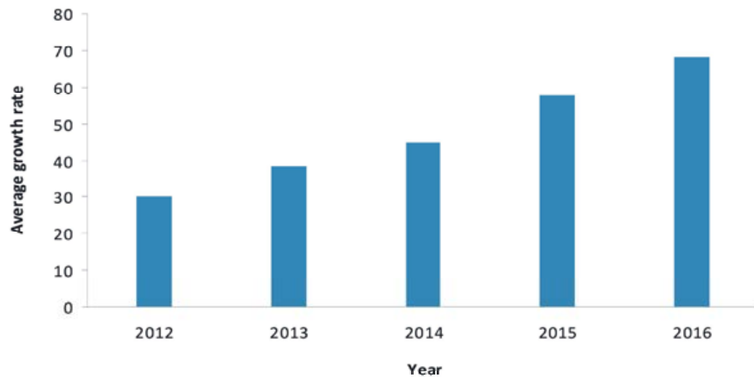

Fig. 13: Worldwide PV solar growth [8].

Table 1: PV solar installation by country [8]

Country	2012	2013	2014	2015
China	3.5	11.0	10.6	17.0
Japan	2.0	6.9	9.7	9.5
United States	3.4	4.8	6.2	8.0
UK	0.9	1.5	2.0	3.0
India	1.0	1.1	0.9	2.2
Germany	7.6	3.3	2.0	1.9
ROTW	11.7	9.8	13.6	16.2
Total Market	30.1	38.4	45.0	57.8

about 1.3 GW of electricity per year. The 5 years average growth rate from 2012 to 2016 is about 22% per year. The growth in 2013 was 28% and 2014 was 17%, which averages out to be 22.5% for the two years. The growth in 2015 was also 28% and 2016 is projected to be 18%. The 2013 and 2015 growth spurts of 28% were mainly due to increases in China, Japan and the US which have continued throughout this period [8].

PV Solar Installation by Country: The char in Fig. 3, megawatts of PV solar installed by country, shows that Germany back in 2012 had been the leader in solar power. China is now the world leader in PV solar and will likely remain so for the foreseeable future [8].

CONCLUSIONS

Solar power is considered to be an attractive energy force in terms of both business and power generation. Significant improvements have already been accomplished by numerous international, governmental and non-governmental organizations including the funding and development of projects involving renewable energy systems for various developed as well as developing nations. This progress is transforming uninhabitable conditions into quality living spaces and providing new luxuries to those who were once lacking. Ecosystem, developing societies and the solar energy market will only benefit from an increase in solar PV system installations. A review of major PV technologies comprising of PV power generation or PV effect, types of PV materials, performance and reliability of PV system, PV technologies & global scenario and statistics of PV will help to carryout meaningful resource to meet future renewable energy needs.

Crystalline silicon has been the workhorse of the PV cells for the past two decades. However, recent progress in the thin-film technology and nanotechnology have led many industry experts to believe that thin-film PV cells and organic cell will eventually dominate the market place one day and realize the goals of PV- a low price and reliable source of energy supply.

REFERENCES

1. Gary Cook, Lynn Billman and Rick Adcock, 1995. Photovoltaic Fundamentals, National Renewable Energy Laboratory, a DOE national laboratory, U.S.
2. Olivia Mah, 2007, Fundamentals of Photovoltaic materials, National Solar Power Research Institute, Inc, Washington.
3. European Photovoltaic Technology 2007, A strategic Research Agenda for Photovoltaic Solar Energy Technology, Science, technology and application, European.
4. Department of Energy, 2016. Organic Photovoltaic Research, viewed 19 September 2016, http:/www.energy.gov/eere/sunshot/organic-photovoltaics-research
5. 'Solar Energy Development Programmatic EIS' 2012, Concentrating Solar Power Technologies, viewed 19 September 2016, http:/ www.solaries.anl.gov/ guide/ solar/ csp

6. Quaschning, V, 2010, Renewable Energy and Climate Change. John Wiley & Sons Ltd Chichester, Germany.
7. Kathie Zipp, 2013. How does a solar tracker work, Solar Power World, Japan.
8. Four peaks technologies, 2011. Solar Market, viewed 19 September 2016, http:/ www.solarcellcentral.com/ index.html.
9. http:/www.pveducation.org.
10. http:/ www.jg-solar.com/ en/product-list.php?cid=3.html.
11. http:/www.spie.org/newsroom/2553-boosting-solar-cell-efficiency-with-quantumdot-based-nanotechnology.
12. AZoM, 2002, Photovolatic materials-Amorphous silicon, Department of energy photovolatics program, U.S.
13. http:/www.solarcellcentral.com/companies.page.html.
14. http:/www.solarcellcentral.com/solar-page.html
15. http:/www.supersmartenergy.com
16. http:/www.solartracking.com