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Substantial Reduction of CO_2 Emission with Silicon Photonics Using in Data Center

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ABSTRACT

High temperatures in summer is more and more popular nowadays. This kind of unusual weathers come from the climate change due to the greenhouse gas emission. The politicians around the world are talking about the international cooperation to reduce the CO_2 emission. Scientists are paying great efforts to find clean energy to replace the current fossil fuels. In this paper, a technology named silicon photonics is introduced which consumes less energy compared to the tradition techniques. The data centers, consuming about 2.5% of the total electricity generation in United States of America, are taken as an example to analyze the reduced CO_2 emission. If the proportion of electricity consumption by data centers are assumed to be unchanged for the last 10 years and next 30 years, the total amount of the reduced CO_2 emission is predicted to be incredibly 6789.13 million tons for the year from 2021 to 2050. This work shows that the wide application of low-energy-consumption technology can do the substantial contribution to cool down our planet.

Introduction

In recent years, global warming attracts more and more attention, which has seriously affected our planet. The Arctic sea ice keeps on shrinking due to the greenhouse effect and it was only 3.74 million square kilometers on September 15, 2020, which is the second-lowest coverage in the past 40 years. The melted ice causes the sea level to rise, harming the island counties and low-lying coastal areas. The greenhouse effect possibly leads to extreme weathers. For instance, at the end of June 2021, the British Columbia (a Canadian province) met a historically high temperature of 47.9 Celsius degrees, threatening the survival of human beings. The main reason of global warming is excessive emissions of the greenhouse gases, including carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), etc. The CO_2 gas is the most important source among them. The newly made CO_2 can persist in the atmosphere for more than 200 years. CO2 mainly comes from the combustion of fossil fuels, including coal, oil and nature gas, to develop the modern industry. Electricity is the most important energy in the word. Applications of new technologies to reduce the electricity consumption give us the possibility to decrease the CO_2 emission to the atmosphere.

As an emerging technology, silicon photonics developed rapidly in recent years (M. Hochberg and T. Baehr-Jones 2010) Scientists around the world show great interests and do the research in this field. The components of silicon photonics include light source, waveguide, modulator, filter, detector and so on. To fabricate these devices needs the processing technology of photolithography, etching, ion implantation, etc. These fabrication techniques are also the basis of the traditional complementary metal oxide semiconductor (CMOS) components. Therefore, the technologies for silicon photonic and CMOS devices are compatible, which makes it easier for silicon photonic devices to be universally used when the technology is mature. Scientists in this area are optimistic about the opt-electronic integration due to the possibly vast applications in the near future. Low power consumption is another core feature for silicon photonic devices. As we know, traditional chips are based on the material of silicon, employing electron to do signal processing and transmission. Comparatively, silicon photonic chips use photon to process and transmit data.

Less energy is needed for silicon photonic chips to process signals, which is especially meaningful under current situation of global warming.

In this paper, the variation of CO_2 concentration was introduced firstly. Then the electricity generation in the world is discussed to give a direct concept about the energy structure contributing to the CO_2 emission. Finally, the data centers are taken as an example to calculate the possible reduction of CO_2 emission by using the chips based on silicon photonics. It shows that the reduced CO_2 emission can be 3 times of the CO_2 emission of Australia using this new technology in the year 2020. The total reduction for the year from 2021 to 2050 can be up to unbelievably 6789.13 million tons.

Materials and Methods

Data Analysis

1) The data of CO_2 concentration in the atmosphere for the past 40 years is from the website of Global Monitoring Laboratory of National Oceanic Atmospheric Administration (NOAA). The downloaded data is transformed to the Excel format and then copied to the software of Origin to draw Fig. 1.
2) The data of global electricity generation is from the website of the BP company. We take the data from the downloaded pdf file and copy it to the software of Origin to draw Fig. 2.
3) The calculations of Formula (1) and Formula (2) are executed in Excel. The reduced CO2 emissions from the year 2010 to 2020 are listed below:

Year	Electricity generation (TWh)	Reduced CO_2 emission (Million tons)
2010	21570.7	135.3915724
2011	22257	139.6992321
2012	22806.3	143.1469919
2013	23435.2	147.0943723
2014	24031.7	150.8383896
2015	24270.5	152.3372518
2016	24915.2	156.3838032
2017	25623.9	160.8320598
2018	26659.1	167.3296401
2019	27001	169.4756242
2020	26823.2	168.3596371

Then the first and third columns of are copied to the software Origin to draw a figure (The green points in Fig. 3). Linear functions are used to fit the green point. The fitted slope and intercept is used to estimate the reduced CO_2 emission from 2021 to 2050.

Results

The CO_2 in the atmosphere has increased substantially since the industrial revolution. Fig. 1 shows the CO_2 concentration in the last 40 years (N. O. A. A. N. E. S. R. Laboratories 2021). It can be seen that the CO_2 content is about 338 part per million (ppm) at the beginning of the year 1980. On April, 2021, it surprisingly increased to 416 ppm,

about 23.1% higher than that of 1980. It should be noted that this also is the maximum CO_2 concentration in the atmosphere for the last 400,000 years (J. R. Petit et al. 1999).

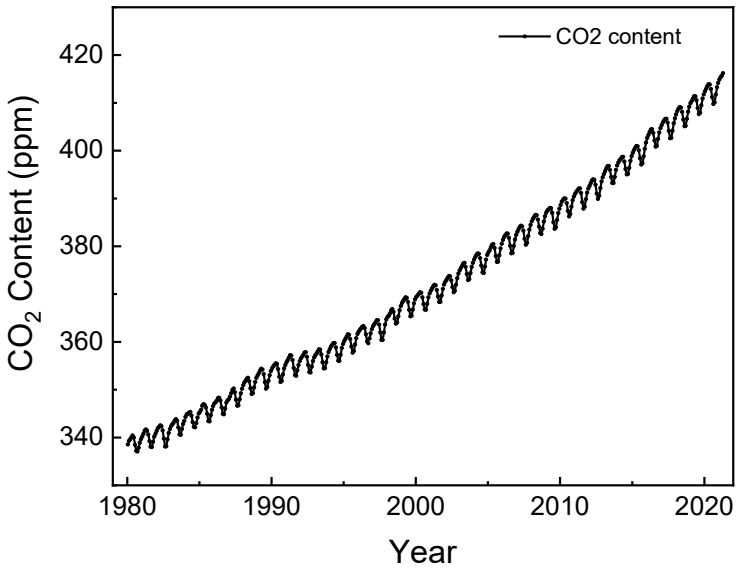

Figure 1. The CO_2 concentration in the atmosphere since 1980.

Lots of fossil fuels are consumed to produce electricity. Fig. 2 shows the trend of global electricity generation in the past ten years (B. Looney 2021). It shows that the electricity generation in 2010 is 21570.7 Terawatt-hours (TWh) and it is up to 27001 TWh in the year of 2019. Due to the effect of COVID-19 on industry, the amount of electricity generation slightly decreases to 26823.2 TWh in 2020, which is still 24.35% higher than that in 2010. The electricity generated in 2020 by burning coal, oil and nature gas are 758TWh、6268.1TWh and 9421.4TWh, which are 2.83%，23.37% and 35.12% of the total electricity generation in 2020. Huge amount of CO_2 is emitted to the atmosphere by combusting there three kinds of fuels to generate electricity. Reducing the electricity generation from these fossil fuels is essential to cool down our planet.

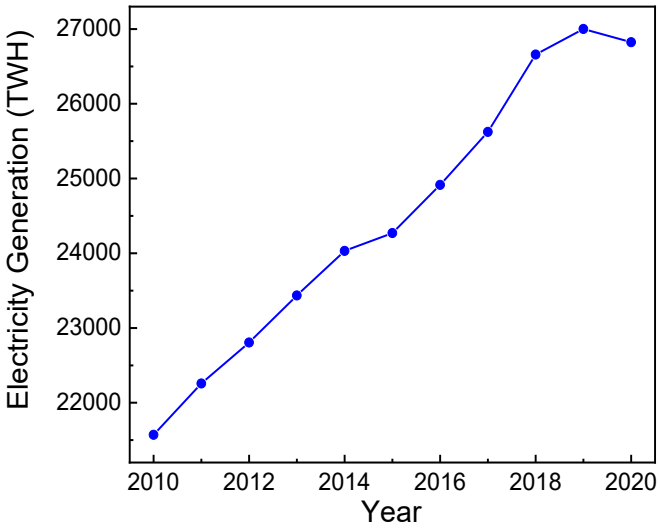

Figure 2. Global electricity generation from 2010 to 2020.

With the development of information technology, there are numerous data centers distributed around the world, executing rapid calculation and saving data. Multi-core architecture is commonly used for the computers or servers in the data centers. The energy consumption is about 11-16pJ/bit for the data transfer between chips (S. Pasricha and M. Nikdast 2020). Thought the value seems to be small, large quantity of electricity is consumed due to the huge workload in the data centers. For example, the data centers consume about 2.5% of the total electricity generation in United States of America (A. Lentine 2021). As mentioned above, the electricity generation around the world is 26823.2 TWh in 2020, implying an electricity consumption of about 670.58 TWh around the world by data centers, which is 16.06% larger than the annual electricity generation of Germany (571.9TWh). For silicon photonic chips, the energy needed for the signal transmission between chips varies from several to several hundreds of fJ/bit (Z. Zhou et al. 2015), which is about 1% of the energy consumed in current chips used in data centers. Under the help of silicon photonics technology, the annually reduced consumption of fossil fuels (coal, oil and nature gas) in 2020 can be calculated using the equation as follows:

$$M_i = E_s \times p_i \times \eta_i \quad (1)$$

The subscript i denotes coal, oil and gas. M_i is the quantity of the save fossil fuel, p_i is percentage of the generated electricity by the corresponding fuel, and η_i is the power generation efficiency.
According to the data from the Energy Information Administration (EIA) of United States of America (E. I. Administration 2021), η_{Coal}, η_{Oil} and η_{Gas} are 1.13 pounds/kWh, 0.08 gallons/kWh and 7.43 cubic feet/kWh, respectively. The saved coal, oil and gas are calculated to be 2.12×10^{10} pounds, 1.24×10^{10} gallon and 1.73×10^{12} cubic feet using Eqa.1 if silicon photonic chips are used in data centers. The reduced CO_2 emission R_{CO_2} can be derived from the following formula:

$$R_{CO_2} = \sum M_i \times C_i \quad (2)$$

Where, C_i is CO_2 emission coefficient burning fossil fuels. The values of C_i for coal, oil and gas are 4,631.50/short ton, 9.60/gallon and 117.10/thousand cubic feet (E. I. Administration 2021). Replacing the current electron-based chips by silicon photonic chips, the reduced CO2 emission is expected to be 3.71×10^{11}pounds (or 168 million tons), which is about 3 times of the CO_2 emission of Australia (55.3 million tons) in 2020. This means a reduced CO_2 emission of about 48.2 pound/people in the world based on an assumption of 7.7 billion's total population around the world.

Discussion

The percentage of electricity generated by fossil fuels p_i and the proportion of electricity consumption by data centers are assumed to be unchanged for the last 10 years and next 30 years. The reduced CO_2 emission from 2010 to 2050 is shown in Fig. 3. The discrete points are the calculated reduction of CO_2 emission by data center using silicon photonic chips for the year from 2010 to 2020. The solid line is a linear fitting of the calculated reduction. The dash line is the extension of the fitted line to predict the reduced CO_2 emission in the future. Replacing the current chips by silicon photonic devices, the reduced the CO_2 emission is up to 277.75 million tons in the year 2050. The total amount of the reduced CO_2 emission is predicted to be incredibly 6789.13 million tons for the year from 2021 to 2050.

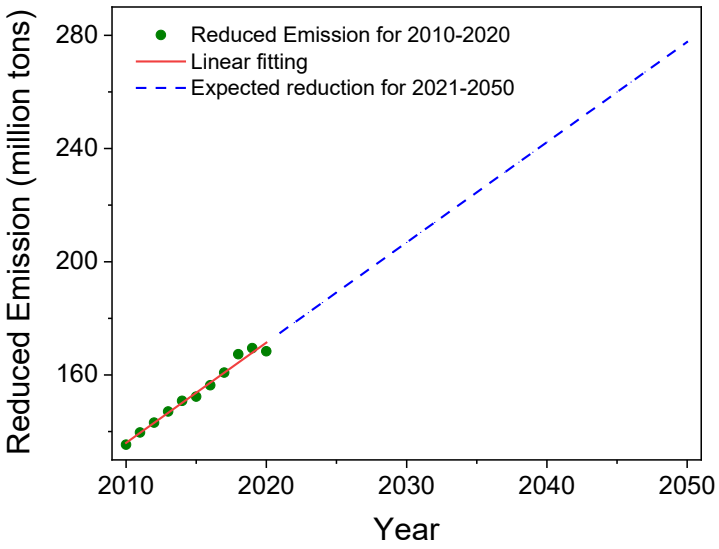

Figure 3. The reduced CO_2 emission from 2010 to 2050.

The above discussion only analyzes the data centers. It clearly shows that the technology of silicon photonics can substantially reduce the CO_2 emission and contribute greatly to slowing down the global warming.

Conclusion

In conclusion, the global warming threats the human beings. Reducing the CO_2 emission is probably the only way to "cool" our planet. As an emerging technology, silicon photonics shows a surprising merit of low electricity consumption. For example, the reduced CO_2 emission can be up to 168 million tons in 2020 if silicon photonic chips are used in data centers. The reduced CO_2 emission is up to unbelievably 6789.13 million tons for the next 30 years if the current chips are replaced by silicon photonic devices in data centers around the world. This new technique possibly does substantial contribution for us to fight against greenhouse effect.

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