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Communication

A Preliminary Anti-Glare System for Traffic Vehicles Using Polarizing Filters and a Polarizing Flip Plate

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Abstract: In the past, polarizing filters were attached to cars' halogen headlights to reduce glare for other vehicles. However, the filters absorbed a significant amount of light and made it difficult for drivers to see properly. Coupled with overheating issues and numerous technical and logistical limitations, polarized automotive lighting systems have not become widespread. In this research, we propose using a polarized LED lighting system to improve drivers' visibility. Our results demonstrated an illuminance reduction of up to 97.5% when simultaneously using a polarized headlight filter and flip plate. Additionally, our system's lower operating temperatures resulted in a lifespan increase of approximately 120 times compared to a conventional halogen lighting system.

Keywords: polarization; flip plate; anti-glare; traffic vehicles; lifespan

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1. Introduction

One of the biggest problems that drivers face on the road is glare from other vehicles, which could temporarily blind and lead to dangerous accidents. According to Stanke et al. [1], most surveyed participants experienced traffic glare at least once a week or almost daily. Furthermore, 60% of respondents expressed the sources of the glare. Because of this dilemma, car manufacturers have come up with various solutions [2–14], including attaching polarizing filters to the headlight system, to reduce illuminance while maintaining adequate visibility. The use of polarized filters stems from the physics of how light interacts with polarized media; specifically, most of the approaching light will pass a filter if they are polarized in the same direction. In contrast, most of the incoming light will be blocked by a filter if their polarization angles are perpendicular [15]. In practice, when both vehicles are equipped with the same polarized system and travel in opposite directions, most of their emitted light will be blocked by each other due to the perpendicular polarization angles of one's headlight and the other's flip plate (attached to a regular sun blocker), therefore eliminating glare. Many companies have also utilized this special characteristic to make products such as polarized sunglasses and spectacles to eliminate sun glare [16–18].

In the past, some companies used polarized headlights to reduce glare for traffic vehicles, especially from 1968 to 1980 [19–21]. The earliest known discussion was in 1920 [16], which was followed by an implementation method by Edwin Land in 1938. Land's method utilized a combination of polarized headlights and windscreen to reduce the glare from vehicles traveling in opposite directions [20–22]. This system has several benefits such as improved visibility and drivers' safety margin [19,20,23]. However, later studies detected depolarization in laminated and toughened windscreens, two prevalent types of glass used in windshields, when using Land's approach [24,25]. In most cases, the depolarization in the former is tolerable, with some exceptions for the latter. Additionally, it was determined that dust and grime buildup on windshields does not significantly affect the detection distance of incoming vehicles [20]. Nevertheless, additional studies on the impact of dust accumulation on both the windscreen and headlights are needed to ascertain the effectiveness of the polarized lighting system.

Recent approaches to reduce traffic lights' glare have employed some novel approaches, such as using linearly polarized windshields in combination with Glan–Thompson prisms, half wave plates, on the headlights to reduce the light intensity from other vehicles by 50% while maintaining similar visibility [26]. Another method employs smart headlights to configure light distribution for optimal illumination with minimal glare [27]. However, we believe Land's system can simply be improved with modern lighting and polarized film technology.

With advancements in lighting technology, today's LEDs have a high luminescence efficiency (up to 150 lm/W) [28] and this will continue to increase in the future [29]. In this study, 25–30 W LEDs were used, but with the development of higher-efficiency diodes, the power required to attain the same efficiency will surely be reduced. Compared to halogen lamps with more than twice the power, LED lamps are much more energy efficient; therefore, the latter is expected to be more widespread in the future. In addition, LEDs have longer lifespans and almost similar light quality (color rendering index) compared to halogen lamps, customizable light colors, etc. [30]. Therefore, LED lights will likely become the standard lighting for cars in the future, such as the application of LEDs in street, office, and home lighting.

Currently, polarized film technology is highly developed, and films can be produced on a large scale and with good quality. However, the transmission coefficient (TC) limit is difficult to overcome. Optimal commercial films possess a TC of 0.45 compared to the ideal theoretical value of 0.50. Therefore, at least 55% of the incoming light energy is absorbed and converted into thermal energy, which makes applying polarized filters in halogen systems inefficient due to low transmittance-induced overheating.

Therefore, we propose using efficient LEDs in combination with Land's method to achieve improved lighting and thermals. We determine that the use of LEDs results in better visibility in poor lighting conditions using the high-beam mode as well as an increased life span for the headlights. Additionally, a polarizing flip plate, attached to the sun blocker in a car, enhances versatility as the driver could deploy the plate to remove glare when required. Furthermore, this approach is more cost-effective since the windscreen is not polarized. The use of polarized headlight systems for all cars is widely accepted as a valid solution to mitigate nighttime traffic accidents due to its simplicity and effectiveness. There have even been proposals for polarized headlights to be incorporated nationwide in Sweden in 1970 due to their apparent benefits over conventional systems [17]. In this study, various experiments were conducted to ascertain the effectiveness of our system in glare mitigation and lifespan enhancements of the polarizing filters.

2. Experimental Methods

To accomplish the research objectives in this article, we constructed a system such that the headlights of each vehicle are attached with polarizing filters, with polarization angles at 45° relative to the horizontal. Furthermore, our test vehicle is equipped with a polarizing flip plate, attached to the sun blocker, with the same polarization angle as the headlight filters'. This study was carried out using the halogen headlights of a Toyota Corolla Altis car with a length of 83 mm and diameter of 12 mm. Additionally, it is rated at 12 V, 60 W, with a luminous flux of 1700 lm and color temperature of 3200 K. Our LED bulbs have the same dimensions and are rated at 12 V, 25–30 W, with a luminous efficacy and color temperature of 120 lm/W and 6000 K, respectively. In particular, they are C6-25 W from Daylead (25 W), H6-BA20D from QLEE (28 W), and TS-LED-H4 from Tinsin. These lamps are commercially available and were found to be in line with their manufacturer's stated specifications. Additionally, linear polarizing films (XP44-40) were acquired from Edmund Optics, with transmission coefficients of 0.44, and affixed onto PVA (polyvinyl alcohol) to create polarized filters for the flip plate and headlights. Illuminance and luminance measurements were completed using a Tenmars TM-201 light meter and a Konica Minolta LS-110 luminance meter, respectively. Both measurements were made at 2.5 m from the center of the headlights using a custom clamping apparatus to hold the equipment in place. Additionally, temperature measurements were performed using a KIMO TK62 digital thermometer. It should also be noted that this study focuses on the high-beam mode of the headlights as it is responsible for the majority of glare observed by other vehicles. Furthermore, regular drivers would experience less illuminance and luminance due to traveling in different lanes.

3. Results and Discussion

3.1. Experimental Results and Discussion

Figure 1 illustrates our adjustable polarizing flip plate and headlight filters. Figure 2 shows the LED headlights on the left, which presented significant glare, whereas the headlight on the right was attached with a set of polarizing filters and thus exhibited much less observable glare. Figure 3 presents the polarizing equipped headlights, observed with and without the polarizing flip plate, demonstrating a further reduction in glare when using the flip plate. From Figures 2 and 3, we can see a drastic diminishing of glare. This is a satisfactory result, albeit qualitative.

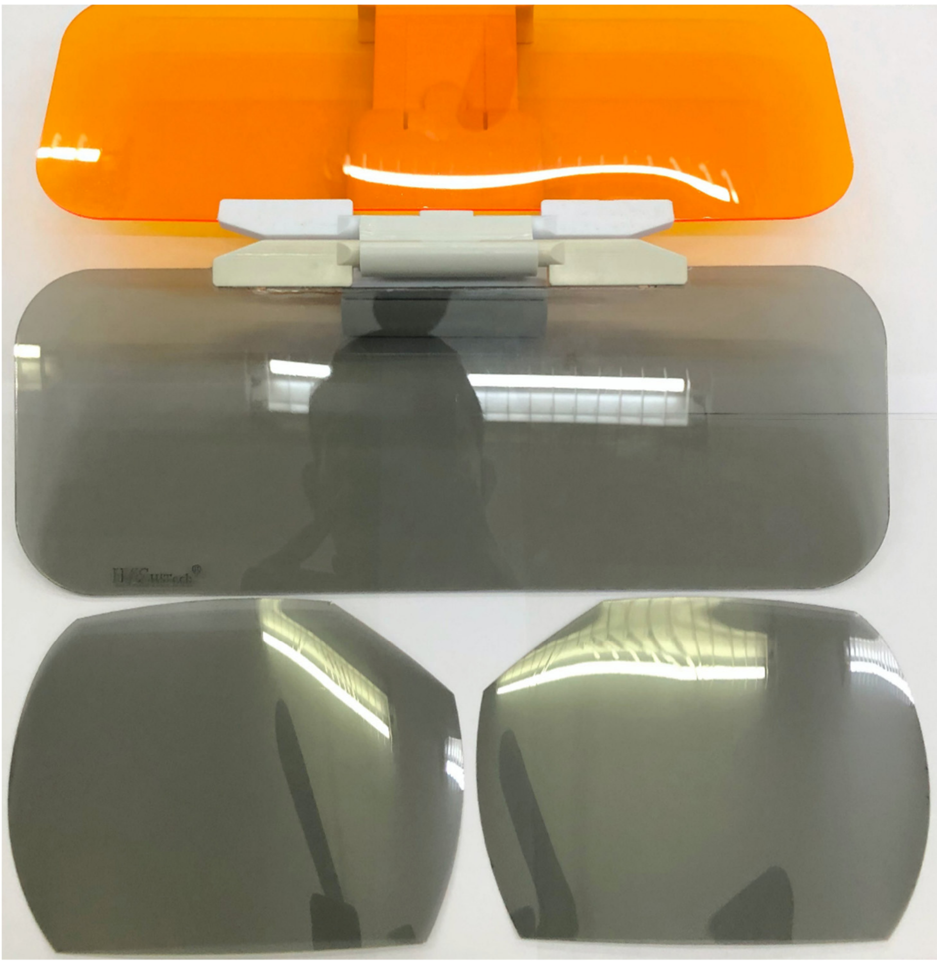

Figure 1. The polarizing flip plate (**top**) and headlight filters (**bottom**) used in our experiment.

Figure 2. Pictures of LED headlights with (**right**) and without (**left**) polarizing filters.

Figure 3. Pictures of polarizing filter-equipped LED headlights, observed with (**right**) and without (**left**) the polarizing flip plate.

To quantify the effectiveness of our polarized system, we sought to measure its illuminance and luminance in comparison to conventional headlights. Figure 4 includes the illuminance measurements from four different types of lamps: 25 W (LED), 28 W (LED), 30 W (LED), and 60 W (Halogen). The results of our experiments demonstrate that the polarized 30 W LED headlight could provide the same illuminance (approximately 32,000 lux) as the 60 W halogen bulb. This means that our polarized LED system could replace the standard 60 W halogen headlights while providing adequate illumination for the driver.

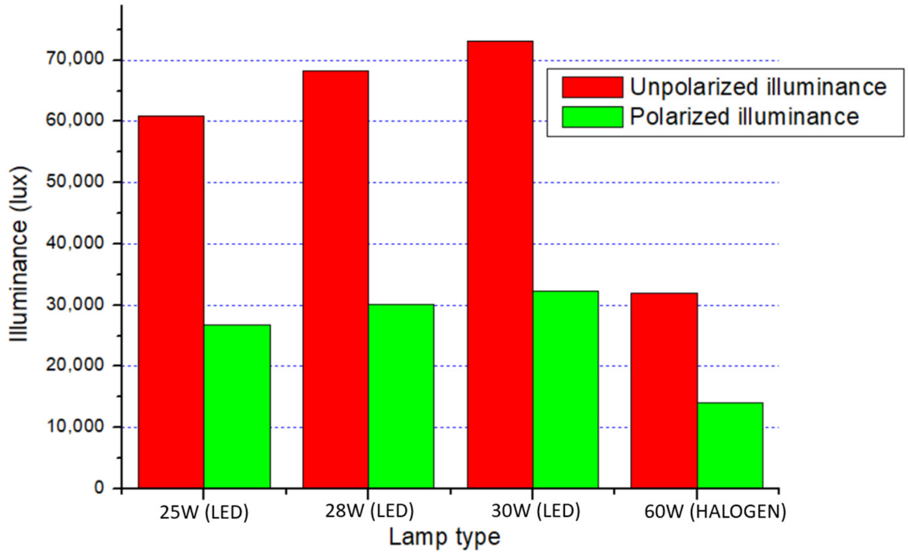

Figure 4. Illuminance measurements of LED (25 W, 28 W, and 30 W) and halogen headlights (60 W).

Figure 5 illustrates our illuminance measurements through two polarizing filters (the filters attached to both the headlights and flip plate). In all three cases of LEDs, the illuminance was reduced by approximately 97.5%, meaning that a driver using our proposed system only receives 2.5% of the illuminance from a car moving in the opposite direction. This reduction in illuminance corresponds with the near elimination of glare observed in Figure 3.

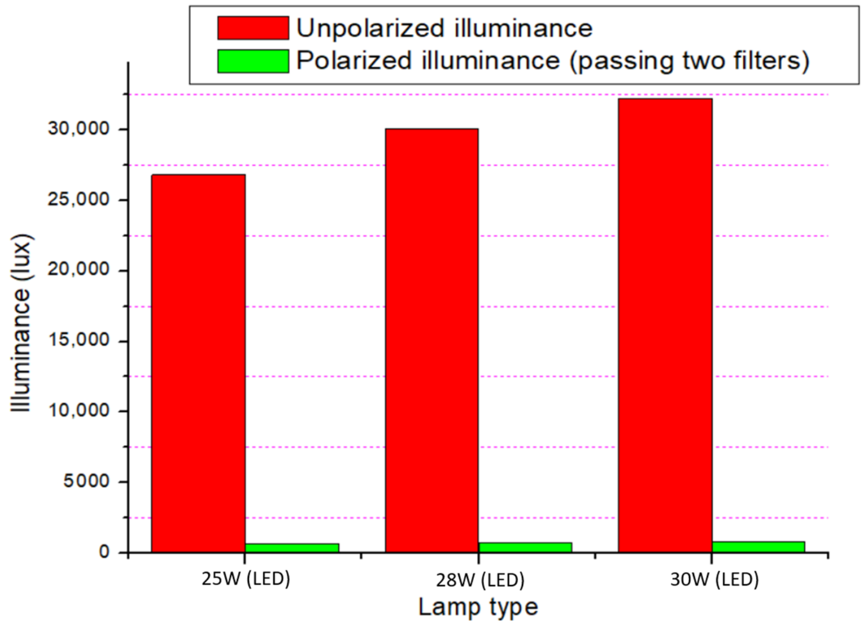

Figure 5. Illuminance measurements of LED headlights with different powers (25 W, 28 W, and 30 W). Polarized measurements are taken after light passed through both the polarized headlights' filter and flip plate.

Figure 6 shows our illuminance measurements after the light passed through only the headlight's polarizing filter. We measured a luminance reduction of approximately 56%, which is consistent with our illuminance findings for light passing through one polarizing filter in Figure 4.

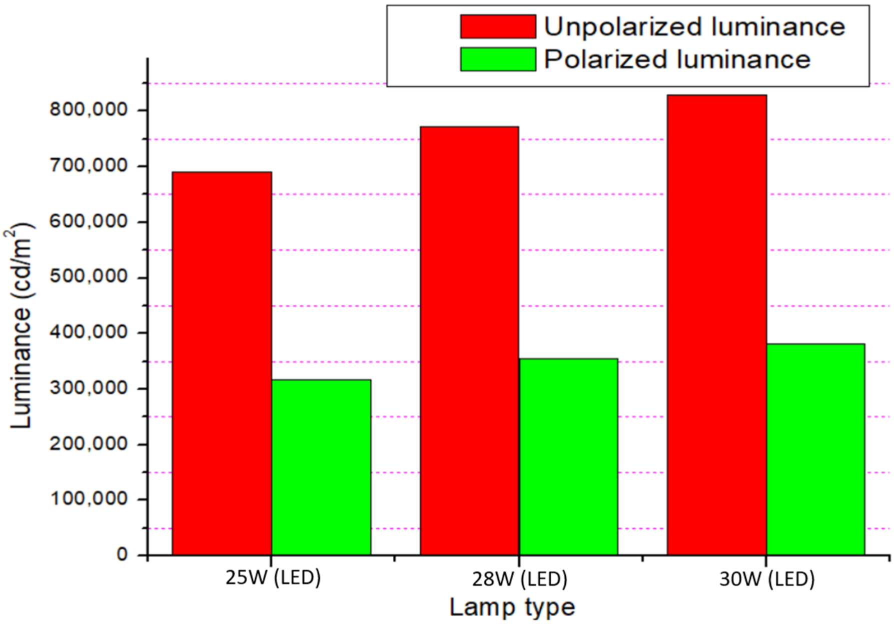

Figure 6. Luminance measurements of LED headlights with different powers (25 W, 28 W, and 30 W). Polarized luminance measurements were taken after light passed through only the headlights' polarizing filter.

Figure 7 is our luminance measurements after light passed through both the polarized headlight filter and the flip plate. The results depict a net luminance reduction of about 97.5%, which is consistent with the values recorded for the illuminance of light passing through two polarizing filters in Figure 5.

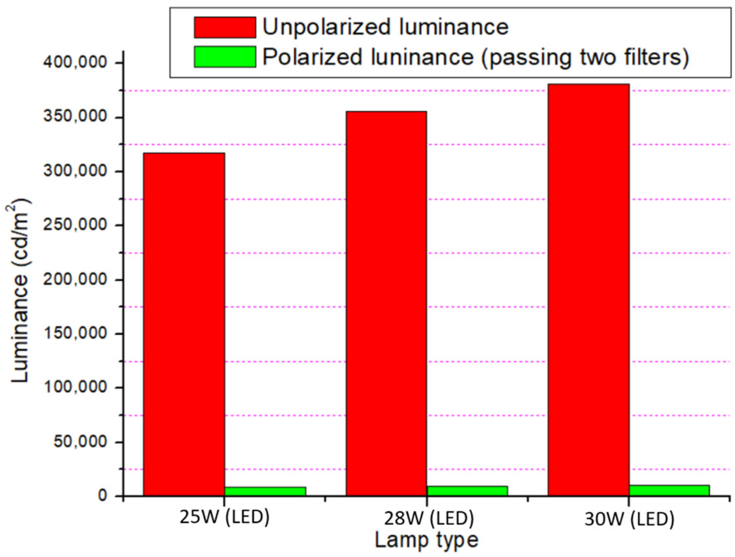

Figure 7. Luminance measurements of LED headlights with different powers (25 W, 28 W, and 30 W) after the light passed through both the polarizing filter and polarizing flip plate.

Figure 8 shows the temperature measurements of the polarizing filters in the halogen and LED lighting systems. According to this figure, it is apparent that the filter's temperature in the halogen system increased by nearly 30 °C, whereas the LED filter only experienced a 5 °C increase over the same period. Because of lower temperatures, the polarizing filters in the LED lighting system will have a significantly higher operating lifespan. To approximate the lifespan improvements of our LED system, we utilized Arrhenius' equation [31]:

$$k = k(T) = Ae^{-\frac{E_a}{RT}}$$

where k is the rate of degradation, A is the frequency factor, E_a is the activation energy, R is the gas constant, and T is the saturation temperature of the filter.

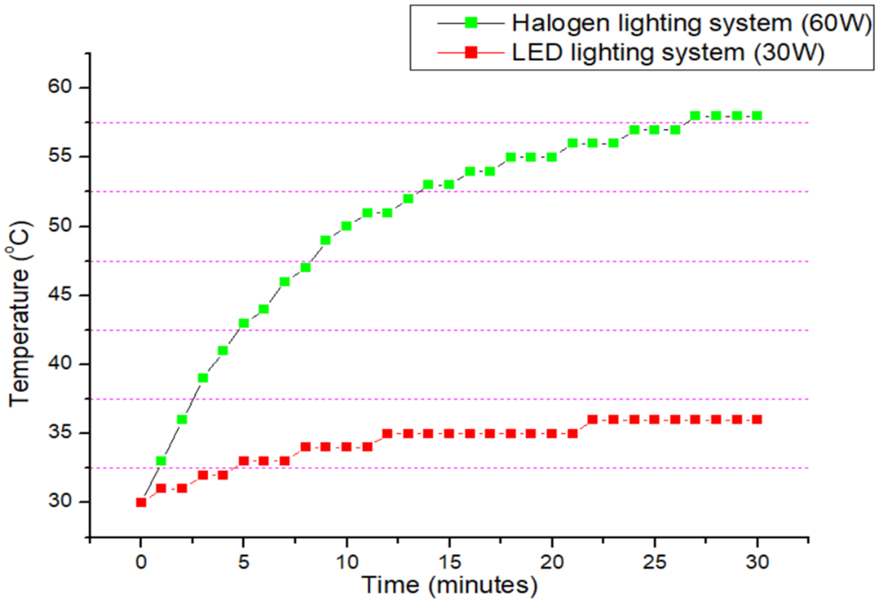

Figure 8. Temperature measurements of the polarizing filters in the halogen and LED lighting systems after 30 min.

In our experiment, the polarizing filters are made of PVA, with an activation energy of 185 kJ/mol [32]. The gas constant (R) is 8.31446 J·K^{-1}·mol^{-1}. Additionally, the saturation temperatures after 30 min in the two cases are T_H = 58 °C (331 K, halogen system) and T_L = 36 °C (309 K, LED system), as shown in Figure 8.

From the above equation, the degradation ratio of the halogen and LED headlight filters were calculated as follows:

$$AF = \frac{Ae^{\frac{-E_a}{RT_H}}}{Ae^{\frac{-E_a}{RT_L}}} = e^{\frac{-E_a}{R}\left(\frac{1}{T_H} - \frac{1}{T_L}\right)} = e^{-\frac{E_a}{R}\left(\frac{T_L - T_H}{T_H T_L}\right)}$$

where AF is the degradation ratio of the halogen and LED headlight systems, A is the frequency factor, E_a is the activation energy, R is the gas constant, and T_H and T_L are the saturation temperatures of the halogen and LED filters, respectively.

The degradation ratio is calculated to be approximately 120, meaning that the polarizing filter attached to the LED headlight system will have a lifespan roughly 120 times higher than that of the halogen system.

3.2. Feasibility of Implementation

While promising, we realize that other avenues of this system need further discussion before adoption. In particular, glare reduction could lead to drivers failing to recognize incoming vehicles due to their familiarity with conventional lighting systems. Furthermore, we did not investigate the impact of dust and grime accumulation on headlights and windscreens, which could potentially reduce the brightness of incoming light, thereby abating the perception of nearby vehicles. The latter issue is especially important since dust, grime, and other pollutants tend to accumulate on headlights and windshields in polluted or heavily trafficked areas, which could pose a safety hazard for cars using this lighting system.

Regarding the accumulation of dust, grime, and other particulates, it was discovered that detection distances were reduced due to their build-up on the windshield [23]. However, despite depolarization due to light striking the particulates, the degradation of detection distance was found to be less in the polarized system than in regular headlights. Nevertheless, regular cleaning of the windshield and headlamps are recommended for optimal performance.

As discussed by Land, the use of polarized headlights increases a driver's visibility of pedestrians [20]. Furthermore, according to a study by Hemion [23], the use of polarized headlights also increases the detection distances compared to the traditional system. It should be noted that the headlights used by Land and Hemion were halogen lamps. In this study, we determined that unpolarized LED headlights have a lighting distance of 155 m and 115 m when polarized. The halogen system's lighting distance was similar at 110 m. It is also worth mentioning that these measurements are taken from headlights in high-beam mode. Additionally, we believe that our polarized system's low-beam performance is akin to that of the halogen system, judging from their similar high-beam lighting distances. Regardless, further study into beam configurations is needed to quantify their impact on illumination distances. Since our modern polarized LED system possesses superior illuminance, a lower power rating, and comparable high-beam illumination distances to halogen lamps, this combination makes them well-suited for automotive lighting.

Another glaring issue of this system is that its benefits might only be realized once it has been widely adopted. In our previous and most promising research [17,21,24], it is apparent that this system will only work if both vehicles are equipped with polarized headlights and windshields or flip plates. This fact also brings up the issue of glare reduction when multiple vehicles are present. For example, a third vehicle approaching from behind will shine its headlights through the back of a car, potentially blinding the driver due to the reflection in their mirrors. Further study is needed to determine whether the windows and mirrors need to be polarized as well.

Despite some challenges and uncertainty, we believe that the widespread adoption of this system is prudent. As discussed by Hemion [19], the benefits of reducing accidents vastly outweigh the cost of installing polarized filters in cars. We also believe that further studies into the use of modern LEDs in Land's polarized lighting system would remove all doubt in its capabilities. Therefore, additional research is needed for the incorporation of our automotive lighting system.

4. Conclusions

We have successfully constructed a new polarized lighting system that almost entirely removes glare while providing adequate visibility by using polarizing filters. Our experimental results demonstrated that a combination of polarized headlight filters and flip plate blocks up to 97.5% of the total incoming light, leading to a near elimination of observed glare. Additionally, the polarized LEDs demonstrated comparable lighting to conventional headlights both in terms of brightness and illumination distance. The LED headlight filters also have a theoretical lifespan 120 times greater than the halogen headlight system due to lower operating temperatures. Further research into the effects of particulate accumulation on both headlights and windscreens and the interaction of conventional and polarized lighting systems are needed to determine the viability of our system for mass adoption.

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