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Repurposing electronic waste: unveiling hidden gratings in discarded projectors for innovative x-ray diffraction simulations

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Abstract

This study introduces a novel approach to enhancing physics education by repurposing discarded projectors as educational tools for simulating x-ray diffraction. The focus is on exploring malfunctioning projectors, particularly the 3 liquid crystal displays technology EPSON model EB-X36, to extract high-temperature poly-silicon thin film transistor-liquid crystal displays for use as two-dimensional gratings. Through a systematic disassembly process, malfunctioning projectors were transformed into educational resources, aligning with the objective of addressing both educational and environmental challenges posed by electronic waste. Additionally, the study investigated the utilization of JD 850 laser pointers for safe and efficient simulation of x-ray diffraction, employing Fraunhofer diffraction principles. Experimental setups were designed to demonstrate practical applications of diffraction concepts, providing students with hands-on experience and enhancing their understanding of diffraction phenomena.

Keywords: x-ray diffraction simulation, HTPS TFT-LCD gratings, electronic waste repurposing, Fraunhofer principles

1. Introduction

In 1912, Max von Laue proposed the idea that the ordered arrangement of atoms in a crystal could serve as a natural diffraction grating for x-rays. Since then, x-ray diffraction has be-come a valuable technique for studying the crystal structure, enabling the determination of lattice spacing and structure through diffraction pattern analysis [1]. However, universities with a curricula that mandate students to engage in experiments on crystal diffraction using x-rays can readily conduct optically analogous experiments inspired by Laue diffraction. In these experiments, the x-ray beam is substituted with a laser beam, and crystal pieces are replaced with two-dimensional gratings [2, 3]. In principle, a mere piece of cloth can serve as a two-dimensional grating in an analogue experiment [1]. Additionally, two-dimensional gratings with aperture arrays printed on slides can be obtained from online scientific equipment suppliers [2, 3].

However, our objective is not to utilize pre-made gratings like those, Instead, we aim to uncover two-dimensional gratings within discarded and neglected electronic devices found in electronic waste piles. Considering the widespread use of projectors in universities, we have accounted for this. However, over time, projectors become prone to damage, often caused by issues such as damaged, swollen, or exploded image bulbs, malfunctioning motherboards or image signal generators, and damaged power supply units. The difficulty intensifies when locating substitute spare parts, as numerous manufacturing firms have discontinued the production of components for older projector models. Alternatively, if we opt to find spare parts, their high cost nearly justifies purchasing a new projector instead. As a result, dysfunctional projectors remain scattered and unused in storage, contributing to the growing issue of electronic waste, often referred to as the 'graveyard problem' [4]. As a physics teacher at the university level, conducting experiments with advanced equipment such as x-ray diffraction using a crystal is typically unattainable, even in well-equipped laboratories, due to the financial constraints of the university. In light of these budgetary limitations and in response to the need to restore damaged projectors for teaching. The idea emerged that repurposing damaged projectors could provide a cost-effective solution for instructing physics courses, particularly for simulating x-ray diffraction. Returning to the earlier concept, our intention was to identify a malfunctioning component within the projector that could potentially serve as a two-dimensional grating for simulating x-ray diffraction. However, we needed to review projection technology in malfunctioning projectors to deter-mine what would be suitable for use as a two-dimensional grating.

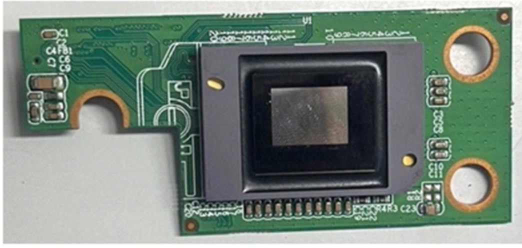


Figure 1. Due to a hermetic seal encompassing the DMD and its control circuits in the malfunctioning ViewSonic projector model PJD5123, we en-countered difficulty in attempting to dismantle it.

We explored two prominent projector technologies, digital light processing (DLP) and 3 liquid crystal displays (3LCD), to investigate the technology employed by the malfunctioning projector for image projection. In 1987, Larry Hornbeck pioneered DLP technology at Texas Instruments, leveraging a digital micromirror device (DMD) for image projection [5, 6]. The key feature of DLP technology is its use of micromirror arrays, and in the context of single-chip DLP systems, a single DMD chip is used [7]. While DMD inherently possesses the property of diffraction [8, 9], the DMD in DLP projectors is enclosed in a hermetic seal with its control circuits. Consequently, the DMD cannot be detached from the control circuit board, as evidenced during the disassembly of the faulty ViewSonic projector model PJD5123 [10] (see figure 1). The distinctive external features of this projector, based on DLP technology, are easily discernible, with symbols or letters prominently marking its surface, including the identifier 'DLP' (see figure 2), as seen in the damaged ViewSonic model PJD5123 [10] and Mitsubishi model XD460U [11]. Subsequently, 3LCD technology was developed by the Japanese imaging company Epson in 1989 [12]. A projector employing 3LCD technology operated by initially separating the white light emitted from the lamp into its three primary colours—red, green, and blue. This division was achieved by directing the lamp light through specialized dichroic filter/reflector assemblies known as 'dichroic prisms', as seen during dismantling in figure 8. Each dichroic prism permitted only specific wavelengths corresponding to particular colours to pass through, reflecting the remaining wavelengths away [13].

Figure 2. The symbols 'DLP' present on the malfunctioning projector are a trademark of the Texas Instruments Company.

In this process, the white light was separated into its three primary colour beams, with each one directed toward its respective LCD panel before passing through. The image was formed on the LCD screen through the following process: The three LCD panels in the projector received electronic signals, generating the image for projection. Each pixel on the LCD was coated with liquid crystal, and the alteration of the electrical charge supplied to the liquid crystal contributed to image formation [14]. Known as high-temperature polysilicon thin film transistor-liquid crystal display (HTPS TFT-LCD), the primary role of this LCD was to function as a light valve for the projector [15]. Due to its nature as a light valve, the HTPS TFT-LCD enabled light transmission and could display diffraction. In contrast, removing this LCD from the control circuits was straightforward, unlike the DMD chip employed in DLP technology projectors. Ultimately, we opted for the HTPS TFT-LCD, sourced from a malfunctioning EPSON model EB-X36 [16], to serve as a two-dimensional grating in our teaching. The distinct external characteristics of projectors based on 3LCD technology, such as the damaged EPSON models EB-X36 [16], EB-X05 [17], EB-W10 [18], and Hitachi projector model CP X445W [19], were readily noticeable. Symbols

Figure 3. A symbol featuring red, green, blue, and the letters '3LCD' is prominently displayed on projectors using 3LCD technology that are experiencing defects.

Figure 4. The outward appearance of the malfunctioning EPSON model EB-X36 before the dismantling process.

or letters, including the identifier '3LCD', were prominently featured on their surfaces, as shown in figure 3.

2. Materials and methods

In preparing for the instructional activity, we disassembled a discarded projector from the electronic waste graveyard, specifically the EPSON model EB-X36 (see figure 4), which utilizes 3LCD technology. The goal was to ex-tract an HTPS TFT-LCD, though similar methods could have been applied to malfunctioning projectors from other brands using 3LCD technology.

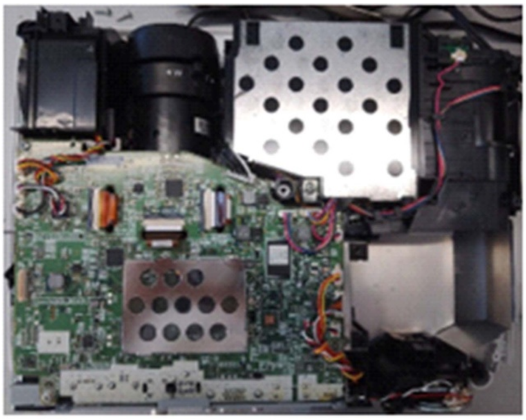


Figure 5. Upon lifting the lid, the green circuit board became visible. Three channels, each with rectangular shapes and rounded edges, were observed, each accompanied by a ribbon cable extending from it; the letters 'EPSON' were written near each. Beneath this region, three HTPS TFT-LCDs were located.

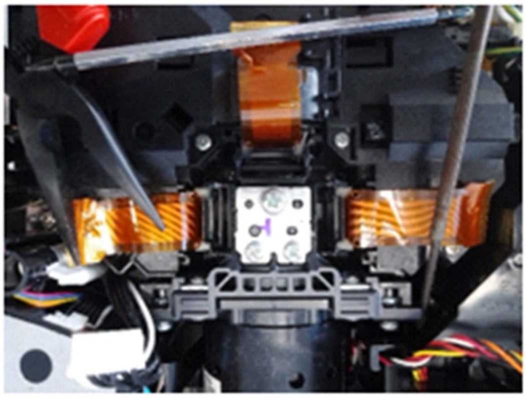


Figure 6. Upon removing the small coloured wires, ribbon cables, and loosening the screws, followed by detaching the green circuit board, we observed three HTPS TFT-LCD contact block adapters, each connected to a ribbon cable.

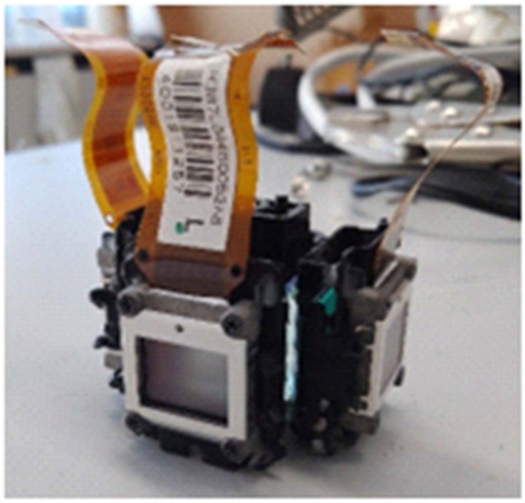


Figure 7. After loosening all the screws, we successfully pulled out three HTPS TFT-LCDs contact block adapter.

The disassembly began with gathering the necessary tools, including a screwdriver, flat-nose pliers, and scissors, along with an instructional dismantling video of the EPSON projector, which was made available on the website [20]. Using screwdrivers, we loosened the nuts and removed the cover, revealing the green circuit board. We identified three channels, each with rectangular shapes and rounded edges, and observed a ribbon cable extending from them with the letters 'EPSON' written on it. Beneath this section, we found three HTPS TFT-LCDs (see figure 5). After disconnecting the small coloured wires and ribbon cables and loosening the screws, we detached the green circuit board. Upon further inspection, we noted that the three HTPS TFT-LCDs were connected to a contact block adapter through three ribbon cables (see figure 6). Once all screws had been removed, we successfully extracted the contact block adapter containing the three HTPS TFT-LCDs (see figure 7). Using flat-nose pliers, we carefully removed the contact block adapter, which was attached to the dichroic prism with adhesive (see figure 8). The three HTPS TFT-LCDs, each with its corresponding contact block adapter, were then obtained for use in disassembling the malfunctioning 3LCD technology projector (see figure 9). We then used a screwdriver to loosen the nuts securing the contact block adapter on all four sides, after which we cut the ribbon cable to fashion an HTPS TFT-LCD that could be used as a two-dimensional grating in educational simulations of x-ray diffraction (see figure 10).

For safety, we selected the cost-effective JD 850 (diode) laser pointer [21], classified as a Type 3 device [22], with an output power not exceeding 100 mW. Students were advised that the laser

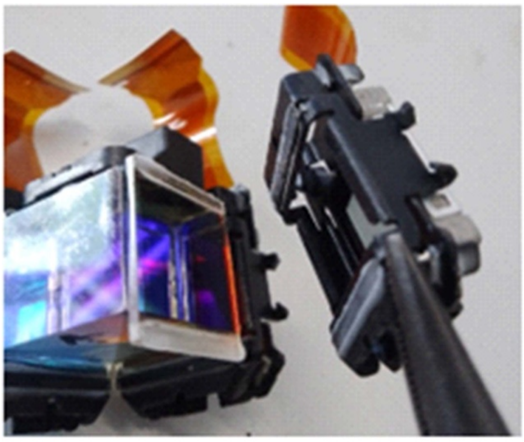


Figure 8. Used pliers to carefully extract the LCD contact block adapter from the dichroic prism, to which it was adhered with glue.

Figure 9. We acquired three HTPS TFT-LCDs, each accompanied by a corresponding contact block adapter, from dismantling one 3LCD technology projector.

pointer should never be shine or reflect directly into anyone’s eyes.

The collimated diode laser beam from the JD 850 had a minimal divergence angle, ranging from 1.2 to 2.4 mRad [21], making the laser beam effectively parallel. This feature made the laser an ideal source for Fraunhofer diffraction [3, 23], as shown in the schematic in figure 11. The Fraunhofer diffraction equation provided the theoretical basis for understanding and predicting diffraction patterns from crystal lattices, similar to Bragg’s equation [2, 3], and operated on shared geometric principles [24], which were essential in x-ray diffraction experiments with crystals—a field pioneered by Laue.

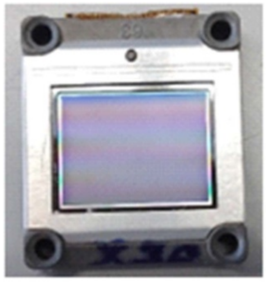


Figure 10. Used a screwdriver to loosen the nuts securing the contact block adapter on all four sides, then severed the ribbon cable to fashion an HTPS TFT-LCD suitable for serving as a two-dimensional grating, which can be utilized in teaching simulations of x-rays.

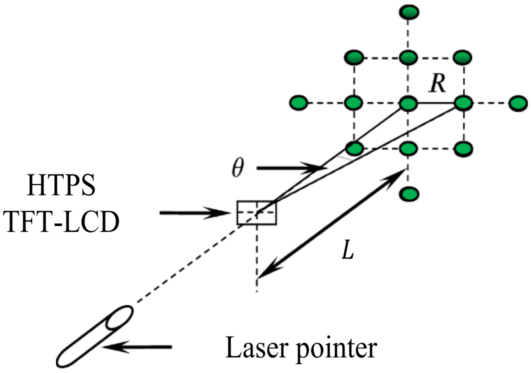


Figure 11. Diagram illustrating the Fraunhofer diffracttion setup installed by the students.

Through hands-on experience with laser diffraction and the Fraunhofer equation, students gained insights that enhanced their understanding of Bragg’s law. The mathematical similarities between Fraunhofer diffraction and Bragg diffraction were emphasized, as documented in [24]. Students were tasked with setting up the experimental arrangement with a sufficiently large distance (L), as shown in figure 11, to ensure that the conditions for Fraunhofer diffraction were met between the wall and the HTPS TFT-LCD grating.

After the setup, students measured the distance (R) between the centre of the laser beam and the first diffraction point ($n = 1$), corresponding to first-order diffraction, and by measuring R as the distance between the central line and the second diffraction spot, they identified $n = 2$, representing second-order diffraction. The same approach was applied to analyse higher diffraction orders, following the Fraunhofer equation:

$$n\lambda = d\sin\theta. \tag{1}$$

We conveyed to students that this equation served as a tool for calculating the grating spacing (d) within the HTPS TFT-LCD grating, where λ was the wavelength of the laser light, and θ was the diffracted angle between the central beam line and the diffraction spots of each order.

Given that the central line of the incident laser beam was perpendicular to the wall surface, we explained to students how to apply their trigonometric knowledge, specifically the properties of right triangles, to deduce that

$$\sin\theta = \frac{R}{\sqrt{R^2 + L^2}}, \tag{2}$$

and then showed them how equation (1) could be rewritten as

$$d = n\lambda\frac{\sqrt{R^2 + L^2}}{R}. \tag{3}$$

Thus, equation (1) was simplified into equation (3), allowing students to calculate the spacing of the HTPS TFT-LCD grating using JD 850 red, green, and blue laser pointers with wavelengths of 650 ± 10 nm, 532 ± 10 nm, and 405 ± 10 nm, respectively. Although the beam diameter of the laser pointers was typically less than 13 mm at a distance of 10 m [21], the limitations of the darkroom width required setting the distance L at 1.60 ± 0.003 m, resulting in a beam diameter of approximately 2–3 mm on the wall. This minimized beam divergence and satisfied the Fraunhofer condition.

After completing the setup, we directed the laser onto the HTPS TFT-LCD, generating diffraction patterns. Figures 12–14 display the diffraction patterns produced by red, green, and blue lasers, respectively, on the darkroom wall. These patterns were captured using a smart phone camera positioned approximately 82 ± 0.5 cm from the wall. Diffraction orders were marked on the darkroom wall, and we measured the distances $R(s)$ for first- through fifth-order diffraction. Additionally, the R spacing was measured both vertically and horizontally for each diffraction order and laser colour. For each diffraction order, the measured R spacing had a discrepancy of 0.1–0.2 cm; however, the laser colour had no effect on this discrepancy. Using these measurements, the HTPS TFT-LCD grating spacings, $d(s)$, and their average values ($\bar{d}$) were calculated, as detailed in table 1.

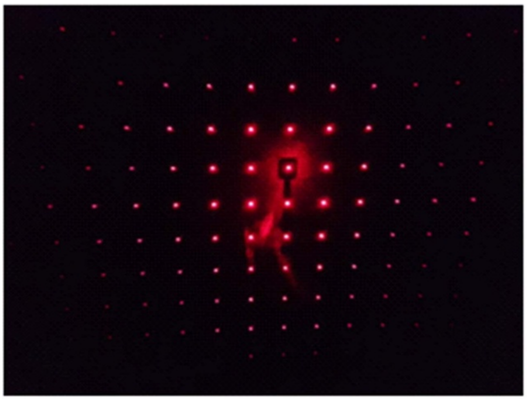


Figure 12. The diffraction patterns generated by the red laser (650 ± 10 nm) were displayed on the darkroom wall.

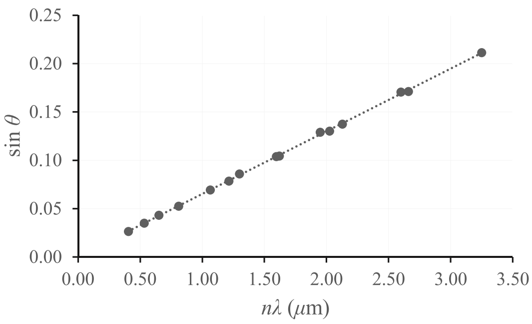
3. Results and discussion

From equations (2) and (3), together with the data in table 1, we plotted a graph with sin θ as the dependent variable and $n\lambda$ (a composite independent variable) on the x-axis. This produced a well-defined straight line with the equation $y = 64{,}840x + 0.0003$ and a coefficient of determination $R^2 = 0.9996$, leading to a calculated grating spacing d of 15.4 μm, as shown in graph 1.

However, while practicing, students raised questions about why the diffraction pattern obtained from the red laser (figure 12) was larger than those from the green (figure 13) and blue (figure 14) lasers. We clarified that, according to equation (1), when the grating distance (d) of the HTPS TFT-LCD remains constant, the angle θ in sinθ is directly proportional to the laser wavelength (λ). Consequently, the red laser, with a wavelength of 650 nm, produced a visibly larger diffraction pattern compared to the green and blue lasers, respectively. When we set the same approximate area on the darkroom wall by tracing a rectangular region of approximately 50.8 cm in width and 41.0 cm in height for all three

Table 1. Results of students' testing include calculations of the HTPS TFT-LCD grating spacing $d(s)$ for each order of diffraction, determined from measured $R(s)$ and $L = 1.60 \pm 0.003$ m including their average, $\bar{d}$, for each laser colour.

Laser colour	n	R (cm)	d (μm)	$\bar{d}$(μm)
Red	1	6.9 ± 0.1	15.1 ± 0.32	15.1 ± 0.26
	2	13.8 ± 0.1	15.1 ± 0.26	
	3	20.8 ± 0.1	15.1 ± 0.25	
	4	27.7 ± 0.1	15.1 ± 0.24	
	5	34.6 ± 0.1	15.1 ± 0.24	
Green	1	5.6 ± 0.1	15.2 ± 0.40	15.4 ± 0.32
	2	11.1 ± 0.1	15.4 ± 0.32	
	3	16.7 ± 0.1	15.4 ± 0.30	
	4	22.2 ± 0.1	15.5 ± 0.30	
	5	27.8 ± 0.1	15.5 ± 0.30	
Blue	1	4.2 ± 0.1	15.4 ± 0.53	15.5 ± 0.43
	2	8.4 ± 0.1	15.4 ± 0.42	
	3	12.6 ± 0.1	15.5 ± 0.40	
	4	16.8 ± 0.1	15.5 ± 0.40	
	5	21.0 ± 0.1	15.6 ± 0.39	



Graph 1. Sin θ is expressed as a function of $n\lambda$ with a slope of $1/d$.

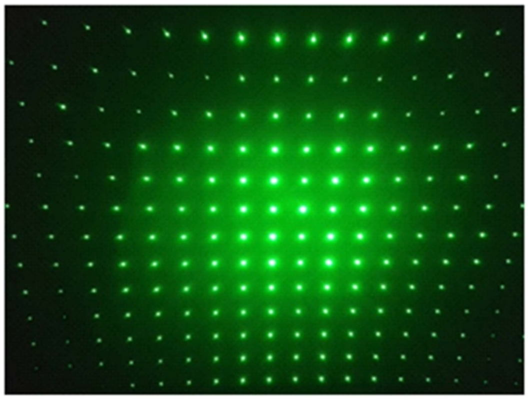


Figure 13. The diffraction patterns created by the green laser (532 ± 10 nm) were visible on the darkroom wall.

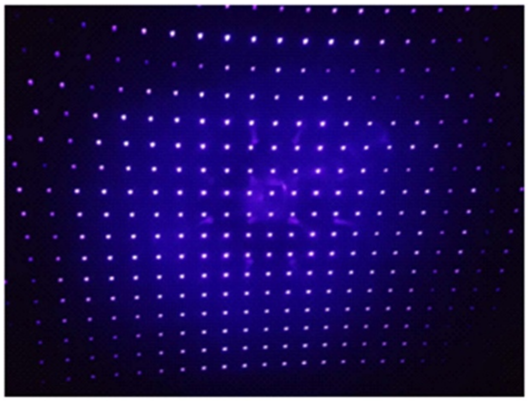


Figure 14. The diffraction patterns generated by the blue laser (405 ± 10 nm) were projected onto the darkroom wall.

laser colours, the blue laser, with the shortest wavelength, illuminated the most cells per unit area (approximately 374), followed by the green laser (221) and the red laser (120). This observation aligned with equation (1), which showed that shorter wavelengths produced higher-density diffraction patterns, resulting in more illuminated cells within a given area.

We further explained that the symmetry observed in the diffraction pattern corresponded to the symmetry of a square grating printed on slides [1], similar to square gratings fashioned from plastic [2], and resembling grating patterns printed on paper [24]. This symmetry was com-parable to a plate derived from optical analogues used to interpret perturbed x-ray diffraction pat-terns of real crystal lattice structures [25], as illustrated in plate 20 of that study. Moreover, it aligned with the x-ray diffraction pattern observed in Laue's experimental findings [26], where the luminous spots surrounding the central peak formed an approximate square lattice [27].

We referred back to table 1 to examine the spacings of the HTPS TFT-LCD for each diffraction order and across various laser colours. At this point, students understood that the grating

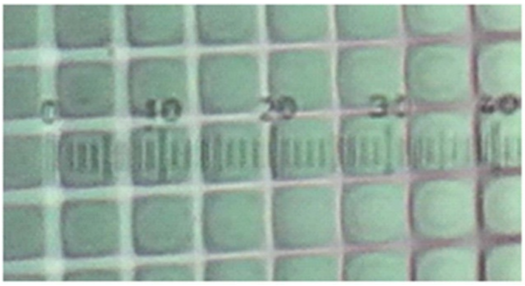


Figure 15. Light micrograph of the HTPS TFT-LCD. The location of the ocular scales was indicated, and the photograph was captured using a student's smart-phone aimed at the eyepiece of the microscope.

within the HTPS TFT-LCD likely exhibited a square configuration. With several calculated spacing values, we asked what aspects could be confirmed or compared. Prompted by our guidance, students proposed additional experiments, and two suggestions emerged from the class. The first idea involved researching the dimensions, specifically the spacing, of an HTPS TFT-LCD online, presuming it to be a square. Unfortunately, this search yielded no relevant information. We clarified that obtaining such information might be restricted or confidential due to the policies of the projector company. The second idea was to borrow a binocular light micro-scope from the Department of Biology. This tool would enable a closer examination of the internal structure of the HTPS TFT-LCD, facilitating a direct comparison with the spacings calculated from table 1.

To validate our hypothesis, we employed a Nikon Eclipse E400 binocular microscope [28] to investigate the internal structure of the HTPS TFT-LCD. With a magnification of 100× for the objective lens and 10× for the eyepiece, the microscope, as depicted in figure 15, revealed a distinct square grid. Utilizing the ocular micrometer, where one pitch measured 2.5 μm (as indicated in the figure), we determined the average grating spacing for the HTPS TFT-LCD to be 15.9 $\pm$ 1 μm. We also observed that the grating (sieve) wire thickness was approximately 2.4 $\pm$ 1 μm. The measured spacings aligned closely with the calculated averages for the blue, green, and red lasers, respectively, and converged as the diffraction order increased, as shown in table 1.

We demonstrated to students the correlation between the spacings, symmetry, and systematicity of a diffraction pattern with the lattice from which the pattern originated. Despite representing two-dimensional lattices, these observations mirrored those seen in diffraction patterns from actual three-dimensional structures. From the diffraction pattern and the inspection of the HT-PS TFT-LCD grating under the light microscope, we concluded that it represented arrays of atoms in a simple cubic structure, where atoms are positioned solely at the cube corners [29, 30].

After calibrating our grating using known wavelengths from the JD 850 laser pointers (red, green, and blue), we recognized the potential to utilize this setup for determining the unknown wavelengths of various light sources. We suggest using common laboratory light sources such as LEDs, which can serve as sources with relatively well-defined wavelengths. Students can measure the diffraction patterns produced by these LEDs and calculate the corresponding wavelengths. Additionally, lasers of unknown wavelength can be tested if available; students can analyse the resulting diffraction patterns and use their measurements to estimate the wavelength based on the established relationship between known grating spacing and diffraction angles.

During the dismantling of the projector, we found some dichroic prisms that were very interesting. We are considering using them for experiments on light refraction in the near future.

4. Conclusions

This study repurposed malfunctioning projectors, specifically those employing 3LCD technologies, for educational use in simulating x-ray diffraction experiments. By salvaging components, particularly the HTPS TFT-LCDs, from discarded projectors, we demonstrated a cost-effective approach to uncovering diffraction gratings within defective projectors. Detailed procedures for disassembling projectors and preparing components for experimentation were provided. Using Fraunhofer diffraction principles, we analysed diffraction patterns generated by laser illumination, which revealed the square lattice configuration of the HTPS TFT-LCD grating. Further validation through microscopy confirmed the lattice structure. This work provides practical insights into utilizing electronic waste for educational purposes, offering a hands-on approach to enhancing physics education through experimentation.

Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

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