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Original Research Article

Latent fingerprint detection using graphitic carbon nitride (g-C_3N_4) and FTIR analysis

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ABSTRACT
The latent fingerprints are important physical evidence; their appearance is also a factor of the donors. In this paper, the chemically inert (g-C_3N_4) graphitic carbon nitride was used as a fluorescent powder to create prints on glass surfaces under different conditions. The ridge clarity, contrast and continuity of samples were viewed under UV light. The chemical characteristics of the compound were determined through the use of FT-IR. FT-IR identified the presence of amines and other functional groups, which have a greater attraction towards the fingerprint residue. Findings show that g-C_3N_4 allows visualisation of latent fingerprints, and evaluation after visualisation should be followed by instrumental examination.

1. Introduction

Latent fingerprints are a crucial part of trace evidence in forensics because of their unique character, singularity and identification usefulness in human identification. In addition to features of the ridge patterns, latent fingerprints consist of complicated chemical deposits that result from eccrine and lipid secretions, such as sweat, lipids and proteins [1]. Such residues are usually invisible and need to be developed using the correct development methods in order to be seen, especially on non-porous surfaces. Graphitic carbon nitride (gC_3N_4), a chemically stable and fluorescent substance, has recently attracted attention as an effective substance to be used in the enhancement of latent fingerprints because of its optical characteristics [2]. But visualization is not enough to provide a complete forensic interpretation, and additional chemical characteristics are required. Fourier transform infrared (FTIR) spectroscopy is a non-destructive analytical method that is capable of detecting functional groups that help to bind with the fingerprint residues [3].

2. Difficulties in the visualisation of Latent Fingerprints

Latent fingerprint visualisation is a complicated procedure that depends on several factors that impact the quality and dependability of prints developed [4]. Their invisibility is one of the main problems because latent fingerprints consist of transparent secretions like sweat, lipids, and amino acids that cannot be easily observed without any enhancement methods [5]. Surface variability is another important challenge because the various substrates react differently to the deposition of the fingerprints. The residues can be absorbed by the porous surfaces and its yields weak impressions, and the non-porous or textured ones give poor adhesion and lack of clarity [6,7]. Also, background interference may arise whereby development materials stick to the substrate and the fingerprint, thereby reducing the contrast and concealing ridge details [8].

Such environmental factors as temperature, humidity, light exposure and time are also critical factors. These may destroy or distort the residues of fingerprints, and old or exposed prints are hard to visualize. Smudged and incomplete prints also make identification difficult, as it leaves fewer clear ridges. Besides, traditional processes tend to be insensitive, hence can hardly be used to find small fingerprints. Contamination or destruction during handling and processing is also a possibility, and this may compromise forensic evidence [9].

3. Application and requirement of graphitic carbon nitride (gC_3N_4) in latent fingerprint imaging and analysis

Latent fingerprints are still a difficult task to visualize in the field of forensic science because of the shortcomings of traditional methods of developing latent fingerprints. Conventional processes, including power dusting and chemical processes, lack sensitivity and contrast, and background interference, especially when dealing with a complex and multicoloured or non-porous surface [10]. Moreover, humidity, temperature, exposure to light, and time are environmental conditions that can damage fingerprint residues leaving faint, smudged, or even destroyed ridge patterns. The challenges have necessitated the development of superior materials that can demonstrate high sensitivity and non-destructive visualization [11].

The g-C_3N_4 (graphitic carbon nitride) has become one of the materials that can solve these problems because of its distinctive optical and structural characteristics. G-C_3N_4 is a metal-free polymeric semiconductor that has strong intrinsic fluorescence in the ultraviolet (UV) light and can be used to visualize the latent fingerprints with high contrast [12]. The source of this fluorescence greatly increases the visibility of a ridge and reduces the level of background noise, which is especially beneficial in the detection of fingerprints. Residues of sweat, lipids and amino acids are made possible by its nanoscale structure and create selective adhesion to the ridge patterns, producing clear and continuous images [13].

Application of g-C_3N_4 also satisfies an increasing demand for better methods of analysis in latent fingerprint investigation. Traditional techniques mainly concentrate on visualization of patterns, yet they fail to be effective in situations of weak or old prints [14]. Such innovative materials as g-C_3N_4 improve the detection sensitivity and reliability to guarantee the improvement of the recovery of usable ridge details [15]. Hence, its use is a valuable development in forensic science that would help in the analysis of latent fingerprints more accurately, efficiently and reliably [16,17].

4. Principles and uses of FTIR in compound detection

Principle of FTIR: Fourier Transform Infrared (FTIR) spectroscopy is the analysis method that is employed in identifying chemical compounds on the basis of their interactions with infrared light. The general concept of FTIR is that molecules absorb the infrared light at certain wavelengths, which are proportional to the vibrational frequencies of chemical bonds of the molecule [18]. As infrared radiation goes through a sample, some frequencies are absorbed, and others are transmitted, and a characteristic spectrum is obtained. The infrared radiation of a molecule is absorbed by each of its functional groups (-OH, -CH, -NH, and -CO) at a different frequency, forming a molecular fingerprint of the compound. The FTIR instruments operate on the principle that all wavelengths are collected by the interferometer at once, and a mathematical Fourier Transform the unprocessed data to produce a spectrum of intensities vs wavenumber (cm^{-1}). This spectrum is compared with the reference spectra to identify the compounds [19,20].

5. FTIR and functional group interaction in the analysis of latent fingerprint

FTIR spectroscopy is a popular analytical method that is applicable in identifying as well as quantifying chemical substances. It makes it possible to detect organic, inorganic and polymeric substances quickly with minimum sample preparation. FTIR finds significance in the analysis of traces of drugs, fibres, paints and explosive residues used in forensic science [21]. Latent fingerprints are complicated composite mixtures that mostly consist of water, lipids, amino acids, proteins and contaminants. These groups have functional groups, which include hydroxyl (-OH), carboxyl (-COOH), amine (-NH_2), and alkyl (-CH) that interact in the chemical reaction during development of the fingerprint [22].

The functional groups are considered to be active sites because they are chemically reactive. As an example, the -OH and -COOH groups can form hydrogen bonds, whereas the -NH_2 groups engage in the electrostatic interaction. When such substances as g-C3N4 are used, the nitrogen-based surface of these substances reacts with them due to hydrogen bonding, van der Waals forces, and electrostatic attractions [23]. This causes discrimination in sticking to the ridges of fingerprints, creating enhanced visibility and obtainability. The study of such interactions is vital to enhancing the sensitivity, selectivity, and reliability of the visualization and forensic examination of latent fingerprints [24, 25].

Materials: Graphitic carbon nitride (gc3n4) employed in this research was prepared by melamine or urea as sources of nitrogen as precursors or purchased commercially. Fingerprint deposition was done on glass slides, paper, and plastic sheets. Fluorescent fingerprints were observed under a UV light source. To determine functional groups, FTIR spectroscopy was conducted [26, 27].

6. Preparation and characterisation of the g-C_3N_4

Graphitic carbon nitride (g-C_3N_4) is a metal-free fluorescent nanomaterial compound synthesised through a simple thermal polycondensation reaction with analytics-grade urea as the only precursor. The weight of urea was calculated to be 10g, and it was placed on a 0.1 mg accuracy analytical balance and then transferred to a semi-covered alumina crucible (50 ml capacity, lid slightly open to allow the gases to escape). The crucible was placed at the centre of a programmable muffle furnace and heated at a constant ramp rate of 5 Degree/C min from room temperature to 550°C [28]. The resulting pale-yellow flaky product was scraped out, then ground into a fine homogeneous powder with an agate mortar and pestle for 10-15 minutes (taking caution not to grind too hard to destroy nanosheet morphology). The ultimate yield was about 1.5-2.0 g. The fluorescent yellow powder was placed in a sealed glass vial to avoid moisture, which was stored in a desiccator. The N-rich functional groups (-NH, -C=N) of the powder allow H-bonding/electrostatic interactions with fingerprint residues to visualise forensic LFPs [28].

7. Fingerprint samples collection and development procedure

In this study, 15 latent fingerprint samples were assembled by voluntary donors after being informed of a structured Google consent form. The form contained the information like age, gender, contact number, and any history of skin allergies, disorders or amputation of fingers for the reliability of the sample. All donors were asked to give a thumb impression on a clean glass under controlled conditions of latent fingerprints. The fingerprints were deposited at moderate pressure in the absence of any pretreatment. The conventional powder dusting technique was used to treat the developed samples with the synthesised graphitic carbon nitride (g-C3n4) powder. Special care was used in putting the powder on to prevent distortion of ridge patterns. The visualized fingerprints were observed in ultraviolet (UV) light by using a UV torch. The latent fingerprints were visualized under UV light in dark room with a digital camera (Canon, model EOS R100). For normal photography, all five sample were photographed with shutter speed 1/3s, aperture f/4.5, and ISO 6400 under controlled conditions. For UV photography, images were photographed with a shutter speed 1/80, an aperture of f/5.6, and ISO 12,800 with the help of UV torch. All the procedures were done under the standard forensic procedures to be consistent, reproducible and maintain the fingerprint characteristics.

8. Results and discussion

The prepared powder of graphitic carbon nitride (g-C3N4) successfully developed latent fingerprints on glass surfaces. The light-yellow fluorescent powder, obtained through the thermal polycondensation of urea, exhibited high fluorescence under 365 nm UV light illumination. Fingerprints exhibited good contrast under visible light but were much clearer and sharper under UV light. The powder showed good selectivity towards fingerprint residues, allowing clear undisturbed ridge patterns to be developed.

The fingerprints displayed visible level 1 and level 2 features such as a whorl pattern, ridge endings, bifurcations and enclosures. These are crucial for individual identification in forensic practices. These findings demonstrate that g-C3N4 powder is a suitable fluorescent material for latent fingerprint detection with high contrast, good level of ridge details and forensic utility. The grading scale is also adopted based on fluorescence intensity and ridge clarity up to level 1, 2 and level 3 [29].

A) Showing level 1 detail under normal light. B) Showing level 2 detail under UV light.

Ridge details

Fig. c. Core Fig. d. Delta

Level 1 Details

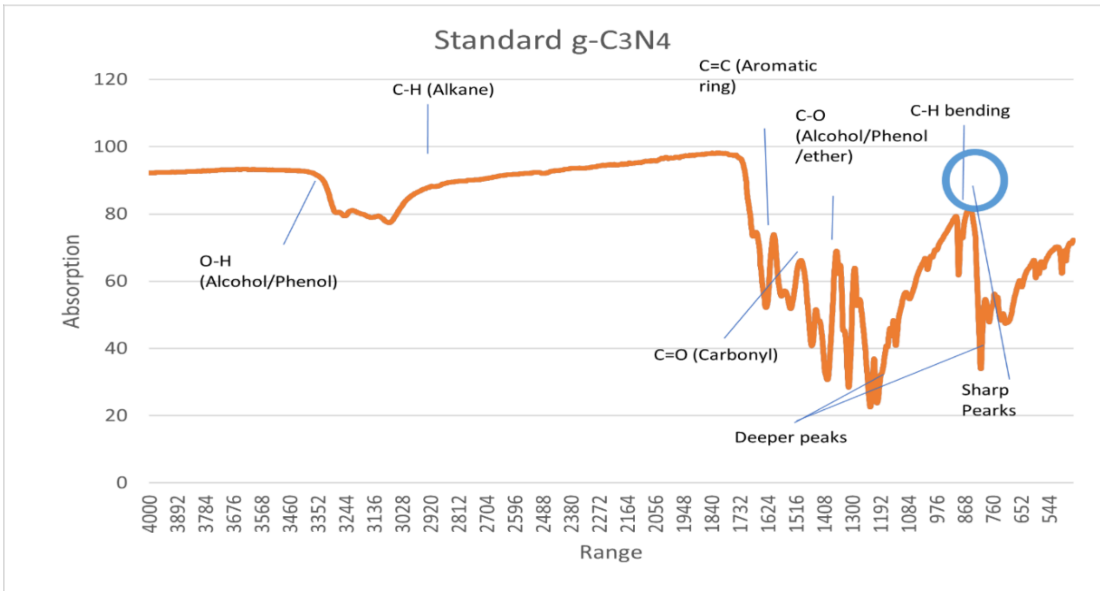
Fig. e. Enclosure Fig. f. spur Fig. g. Bifurcation

Fig. h. Bridge Fig. i. Tri-bifurcation Fig. j. Dot

Level 2 Ridge Details

9. Findings of the compound by FTIR

FTIR analysis of the compound indicated that the peaks show functional groups of doped g-C_3N_4. It has been found that there is a binding between the material and fingerprint residues, which means that doped g-C_3N_4 is good at binding organic compounds found in fingerprints. It is claimed that doped g-C_3N_4 has improved functional groups, which leads to efficient binding between the doped g-C_3N_4 and fingerprint residues, leading to an improved detection.



- The broad peak at 3200-3400 cm^{-1} is due to -O-H (due to moisture/ surface hydroxyls).
- The peaks at 2850-2950 cm^{-1} are showing -C-H alkanes, which show the presence of organic residual components.
- Peaks around 1200-1400 cm^{-1} showing C-N stretching, which is unique to carbon nitride.
- Peaks at around 1700 cm^{-1} to the C=O group, which shows a surface oxidation.
- Sharp peaks around 800-900 cm^{-1} showing triazine/heptazine ring, which confirms the compound is g-C_3N_4.

10. Conclusion

Graphitic carbon nitride (g-C_3N_4) has been successfully used to develop fluorescent latent fingerprints on glass. The powder exhi8bited intense fluorescence under 365 nm UV light, revealing patterns with improved contrast, resolution, and continuity compared to visible light. Key level 1, level 2 fingerprint features, such as whorls, ridge endings, bifurcations, enclosure, core and delta were observed, proving the potential of g-C_3N_4 for forensic identification. The superior performance of g-C_3N_4 is attributed to the nitrogen-rich surface and fine powder particles that selectively adhere to fingerprint residues (sweat, oil and amino acids). The FTIR spectrum showed the presence of O-H, C-H, C-N, C=O bonds and triazine/heptazine rings, indicating successful synthesis and interaction with latent fingerprint residues. In conclusion, g-C_3N_4 is a cost-effective, sustainable, stable and sensitive alternative powder to current commercial powders, and has the potential to be applied in future forensic latent fingerprint development and analysis.

11. Future directions

Graphitic carbon nitride (g-C_3N_4) should be further studied on various porous, non-porous, and semi-porous substrates, including metal, plastic, paper, wood and banknotes. The effectiveness of the material on aged, dilute, superposed and weathered fingerprints should also be tested at various temperatures, humidity and light levels. Additional research can be carried out with doped or modified g-C_3N_4 nanocomposites to enhance fluorescence, selectivity and sensitivity. Benchmarking with commercial powders and other nanoparticles may demonstrate its effectiveness. Combinations with other detection methods, ridge enhancement using AI, and its incorporation in forensic toolkits could enhance practical applications. Toxicity, storage stability, and large-scale cost-effectiveness should also be assessed before routine forensic implementation.

Authors' contributions

All authors contributed equally to the conception, design, experimental work, data analysis, interpretation of results, and preparation of the manuscript. All authors reviewed and approved the final version of the manuscript for publication.

Conflicts of interest

The author declares no conflict of interest.

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Data availability

No new data were created.

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