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APPLICATION NOTE

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Forensic analysis of paper currency with FTIR microscopy

Key words
iN10 FTIR microscope, counterfeit, forensic science, FTIR microscopy, questioned documents

Nicolet iN10 FTIR Microscope

Confirming the authenticity of documents is so important to commercial trade, border security and law enforcement groups that these investigations represent a distinct branch of Forensic Science. Questioned document specialists use a wide array of analytical techniques to assist in their investigations ranging from first-line visual inspection tools to advanced chemical-specific analytical instrumentation. Visible light microscopy techniques are well suited for characterizing the printing techniques of individual characters and to look for evidence of alteration. Imaging methods, often using various light sources and filter combinations, complement direct visual inspection to enhance comparisons to genuine articles.

The need for advanced chemical analysis to support forensic casework has become more important because of the complexity and sophistication of the fraudulent items. Counterfeiting money is one of the oldest-known criminal activities and, as police are witnessing, criminals no longer need access to complex offset printing techniques to produce quality counterfeit notes. A reasonably high-quality photographic copier can produce very realistic counterfeit currency. For example, the European Central Bank reported that approximately 600,000 individual Euro notes were detected and removed from circulation in each of the last three years.[1] Not only do merchants and consumers need to stay alert for suspicious bills, but research and development continue to improve detection methods for automated cash handling machines (e.g., vending, ATM – automated teller machine, bill counters, etc.).

High-performance laboratory instruments enable inspection of Questioned Documents, such as banknotes, to progress into the chemical domain, allowing detection and study of anomalies not observable by visual inspection alone. The Fourier Transform Infrared (FTIR) microscope, a mainstay of the forensic laboratory, is exceptionally well suited for study of the inks, toners, and papers of fraudulent documents because it combines standard visible light microscopy with non-destructive molecular spectroscopy analysis. One instrument that combines several forensic-relevant techniques with excellent analysis software is the Thermo Scientific™ Nicolet™ iN10 FTIR Microscope. The Nicolet iN10 Microscope combines standard color video inspection, polarized light, infrared transmission and reflection spectroscopy, and micro-contact-mode sampling using attenuated total reflectance (ATR). Using these various modes of chemical imaging inspection, investigators can undertake in-depth studies of paper currencies.

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The "backbone" of any banknote is, of course, the paper it is printed on. Currency is printed on high cotton-content paper for durability. Figure 1 shows representative spectra of paper specimens. All paper products have a similar carbohydrate chemical structure because of their natural product origins (e.g., wood pulp, cotton or the like), so the main features of the infrared spectra are also similar. However, paper makers use different fiber stock and additives, like mineral or polymeric fills, to provide different properties. These variations affect the patterns seen in the infrared spectra, which can help identify the paper source. In Figure 1, the spectral patterns are similar, but some unique features stand out, generating useful differences for comparisons.

Inks and pigments applied to the paper are generally present at low concentration, just covering the top layer of paper fibers. Using surface-sensitive attenuated total reflectance (ATR), the infrared pattern of the ink alone can be obtained. Figure 2 shows some representative spectra of the inks from printed features on different paper currencies. Because the ink layer is thin, spectral features of the underlying paper often remain (note the carbohydrate signal towards the left end of some spectra in Figure 2), but there are also distinct patterns between 1800 and 700 wavenumbers representing "fingerprints" of the ink. The spectrum in plot (A) is significantly different than the other three due to this particular print containing a grade of calcium carbonate as shown by the strong peaks at 1420 and 875 cm^{-1}. This gives the ink bulk.

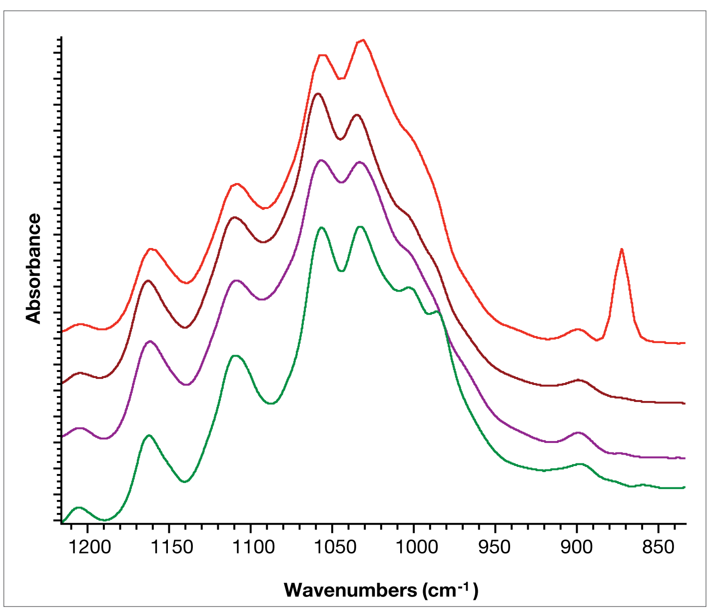

Figure 1: Characteristic spectra of paper products. From top: bright white copy paper; linen business paper; 25% cotton bond paper; natural color cotton paper (€20 note).

Counterfeit currency produced using laser printer technology may look like an excellent reproduction to the naked eye, but the toner used with these printers is easily distinguished from printing inks used on authentic bills. Laser printer toner is composed of pigmented polymer particles that are transferred to the paper in the printing process. Figure 3 shows the infrared spectra of color text produced using a laser printer. The patterns show strong polystyrene bands indicating that this is the polymer used in the toner. Polystyrene is the most common toner material in today's market – it gives the powdery feel anyone who has changed a toner cartridge will remember. The IR features linked to the pigments are also present in the spectrum, as well as bands from the paper base layer.

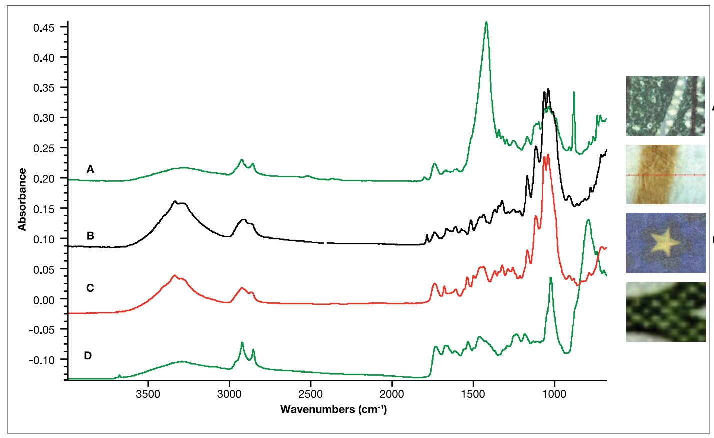

Figure 2: Representative spectra of inks printed on paper currencies. A) Green raised treasury seal (USD); B) Brown printed design (RMB); C) Yellow star (EUR); D) Part of the character "B", (KRW).

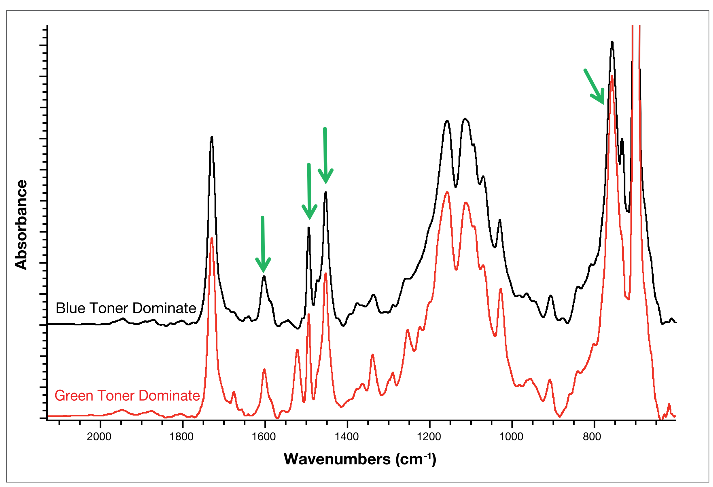

Figure 3: Infrared spectra of text printed with a digital color printer showing strong features of the polystyrene-based toner matrix indicated with arrows.

Infrared microscopy's key value is its ability to target a very specific location for data collection. For this reason, the technique is very popular for studying defects and trace contamination. Figure 4 shows a dark clump, approximately 100 microns in size, located in an unprinted area of a circulated 20 Euro note. The red spectrum is from this embedded particle and includes a peak (signals) from the paper. Comparing this spectrum of just the base paper (purple spectrum), you can clearly see the peak differences. The spectrum of the particle (upper trace of Figure 4) matches a black raised print feature in Figure 2A. We speculate that small pieces of the raised print have been abraded through handling and stuck to this location. Paper currency also collect particles as they pass from hand to hand, including particles that might be useful as trace evidence in law enforcement cases unrelated to counterfeiting.[2]

Advanced FTIR microscopes, such as the Nicolet iN10 Microscope, have imaging modes for studying distributions of chemical features over wider areas. Figure 5 shows an example of an infrared image examining different attributes of a pair of banknotes (circulated and new) from the Ukraine. The imaging data set contains a full spectrum at each point. To convert this massive information into a 2D image, we select a pattern known to represent one component (ink or contaminant). Colorizing (red where the pattern is strong, blue where it is weak) leads to the imagery shown. Red will mean that pattern – component – is present there; blue that it is absent. Image (B) was created searching for the spectral pattern of cotton fibers. This image demonstrates how the IR microscope can "see" through the print layer (the fibers are seen basically everywhere, even under the ink). Similarly, image (C) is generated from the IR signature associated with a blue/gray pigment. The dark print on the left (A) does not show in this image because it has a different spectral pattern – hence a different chemical composition. Under the microscope, it is easy to see that the circulated bill's surface is rough, making it easy for particles to get trapped on the surface. Image (D) highlights materials with a polyamide spectral pattern – shown by the arrow. The red "hot spots" in image (D) are most likely small skin flakes (which are polyamides) from people handling the bill.

Treasury departments continue to deploy new security features on paper currencies, but it seems criminal attempts to defeat the new features soon follow. Law enforcement is responding by adding new analytical tools, like FTIR microscopy, to study the chemical nature of suspicious articles. Until recently, these tools were found only in central laboratories with expert operators. Fortunately, the easy-to-use Nicolet iN10 Microscope with its intelligent software and sampling options makes FTIR microscopy much more widely accessible. As the skills of criminals improve, placing powerful tools like the Nicolet iN10 Microscope in the hands of more investigators will help keep law enforcement a few steps ahead.

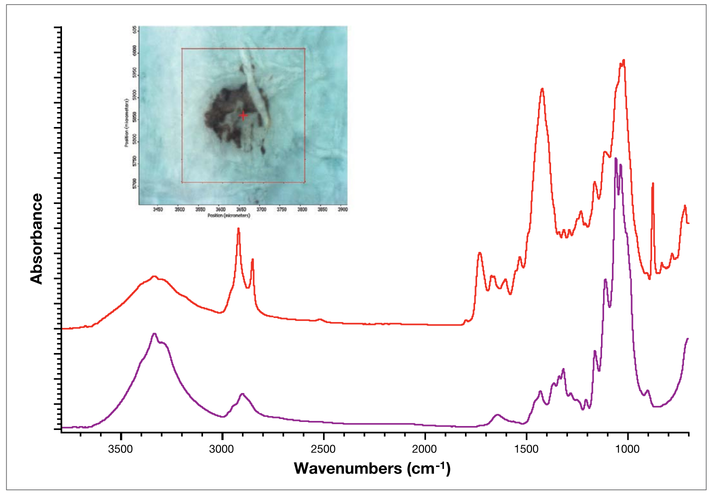

Figure 4: Using micro-ATR to investigate possible contaminants and particles in a unprinted area of 20 Euro note. Upper trace is the spectrum of an embedded particle in the paper matrix; lower trace is paper region just adjacent to the particle.

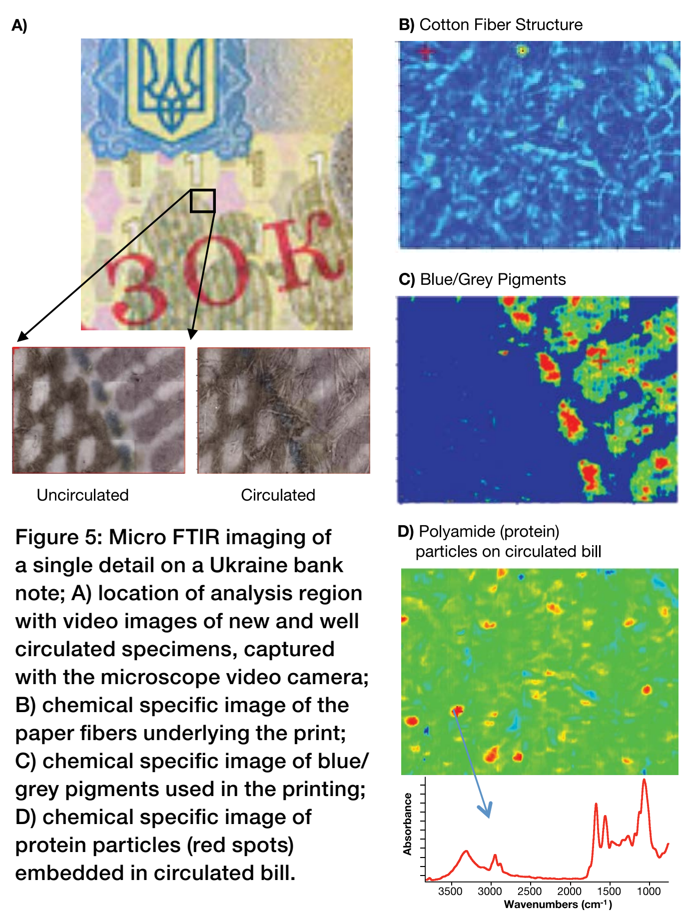

Figure 5: Micro FTIR imaging of a single detail on a Ukraine bank note; A) location of analysis region with video images of new and well circulated specimens, captured with the microscope video camera; B) chemical specific image of the paper fibers underlying the print; C) chemical specific image of blue/grey pigments used in the printing; D) chemical specific image of protein particles (red spots) embedded in circulated bill.

References

1. European Central Bank News Release, 10 January 2013 - Biannual information on euro banknote counterfeiting.
2. Jenkins, A. J. Forensic Sci Int. 2001 Vol 121:189-93.

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