Laser Cleaning Cylindrical Cells for Optimum Wire Bondability

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Abstract

Wire bonding has been used as an interconnection method in microelectronics since the 1960s and continues to migrate into new applications over time. In the last two decades, it has been utilized to interconnect cylindrical battery cells for modules for electric vehicles, airplanes, energy storage, and many other applications. It is known that cleaning the surface of the battery cells is essential for successful wire bonding. This paper will outline the influence of laser cleaning to the surface of the battery cells to achieve optimum wire bonding onto cylindrical battery cells.

Key words

Cylindrical battery cell, laser cleaning, wire bonding.

Figure 1: Aluminum wire bonded battery module.

I. Introduction

Ultrasonic heavy aluminum (Al) wire bonding was one of the first interconnection methods for cylindrical battery cells. [1] This process consists of ultrasonically attaching an aluminum wire onto two or more bondable surfaces to permit electrical current to flow. [2] It is used in numerous industries applications including military, medical, semiconductor, power electronics, automotive, etc. For cylindrical battery cells in a module, Al wire is used to interconnect a battery cell to a common busbar. A photo of an Al wire bonded battery module is shown in Figure 1.

The wire bonding process is completed with a combination of voltage (or current), time, and force. An ultrasonic waveform is generated from a transducer via an electric signal applied to a piezo-ceramic stack. This sinusoidal waveform has a set frequency, usually in the Kilohertz (kHz) range, and is normally set to 60 kHz for heavy Al wire. [3] The waveform travels along a bonding tool, or wedge, and the voltage, time, and force are exerted onto the wire and makes the necessary deformation for the bond to be made. [3]

There are numerous methods of interconnecting battery cells to a busbar. The more common methods are wire bonding, ultrasonic welding, resistance welding, and laser welding. [4] The BMWi3 utilized laser welding while the Tesla Model S used wire bonding and the Nissan Leaf used ultrasonic welding. [4] Das et al. listed wire bonding with the highest score on their Pugh matrix for comparing these interconnection technologies. [4] Each interconnection method has its advantages and disadvantages depending on the battery application. Wire bonding is an easy to repair room temperature process, which is capable of joining dissimilar metals, while it has a relatively low cost of equipment, and can easily be automated. [4] Two concerns with wire bonding are fixturing and contamination. The part being wire bonded needs to be rigidly held and the surface(s) need to be clean of contaminants and other foreign materials. This study focusses on the influence of laser cleaning on the surfaces which are to be wire bonded.

II. Cleaning and wire bonding

The manufacturing, packaging, and shipment of cylindrical cells can influence the wire bond ability of the battery terminals. There are instances of oils used in stamping processes that are often not completely removed, and the nickel coating is easily oxidized. While some companies use a manual cleaning process, others have utilized CO_2 cleaning and others have decided not to clean the surface at all, but instead use aggressive wire bond parameters. Wire bonding is a self-cleaning process as the Al oxide of the wire and the bonding surfaces are displaced during the excitation of the ultrasonic energy. However, oils and other solvents might not be fully removed and could cause reliability issues. [2] The purpose of this study is to determine if a laser cleaning process can be completed without damaging the nickel plating layer or the aluminum layer of the positive and negative terminals of the cylindrical battery cell. A variety of cylindrical Li-Ion battery cells was evaluated in this study.

Laser cleaning is a precise thermal process that removes surface layers through ablation with a pulsed laser beam. [5] Initial attempts to wire bond the as-delivered battery cells without cleaning led to numerous failed connections. A subsequent manual cleaning step using a fiberglass brush also proved ineffective, as aluminum oxides and other contaminants rapidly accumulated on the brush. Consequently, laser ablation was selected as the primary cleaning method prior to wire bonding.

The laser cleaning was performed with a Keyence Laser Cleaner MD-X2520A with Worx ME3-Max system. The laser cleaning was performed with 15.25 W power at 120 kHz pulse frequency and a scan speed of 1500 mm/s with 75 µm line spacing. All battery cell wire bonding was performed with a Hesse Mechatronics BJ959 Heavy Wire Bonder. The details of the wire bonding parameters and influence of laser cleaning on the success rate of wire bonding will be shown in a future study.

III. Characterization of battery cells before and after laser cleaning

Methods

To investigate the effects of laser cleaning on the metallic casing of battery cells, complementary analytical techniques were employed. X-ray fluorescence (XRF) was used to quantify changes in surface composition, particularly the removal of contaminants such as oxides, coatings, or residues, and to monitor possible surface enrichment of the base metal. XRF provides a semi-bulk measurement with a typical penetration depth of 10–100 µm, depending on the element and material. Scanning electron microscopy with energy-dispersive X-ray spectroscopy (SEM-EDX) provided high-resolution imaging of the cleaned surfaces, enabling detailed assessment of morphological alterations such as melting, roughening, or micro-cracking, while localized elemental mapping allowed evaluation of oxide removal and surface homogenization. SEM-EDX is more surface-sensitive, with a typical penetration depth of 1–5 µm, making it ideal for near-surface compositional analysis. Together, these methods offered a comprehensive characterization of both the physical and chemical modifications induced by laser cleaning of the metal casings.

For this study, commercially available lithium-ion cells from different manufacturers were evaluated in the as-delivered state to capture a representative range of designs and production methods. The investigated cells included Samsung 50E and Samsung 50G, Molicel P42A (all 21700 format), and Panasonic NCR18650B (18650 format). These cells were selected due to their widespread use in electric mobility and stationary storage applications, as well as their differences in capacity, electrode formulation, and power-performance balance. Comparative analysis of these cell types allowed for assessing how laser cleaning interacts with varying casing materials, surface treatments, and manufacturing practices. Key specifications of the evaluated cells are summarized in Table 1.

Table 1: Key specifications of the evaluated lithium-ion cells.

Supplier	Model	Format	Chemistry	Nominal Capacity	Nominal Voltage	Casing Material	Typical Application
Samsung	50E	21700	NMC	5000 mAh	3.6 V	Nickel plated stainless steel	Electric vehicles, power tools
Samsung	50G	21700	NMC	5000 mAh	3.6 V	Nickel plated stainless steel	EVs, high-power applications
Molicel	P42A	21700	NCA	4200 mAh	3.6 V	Nickel plated stainless steel	EVs, energy storage
Panasonic	NCR18650B	18650	NCA	3400 mAh	3.6 V	Aluminum	Laptops, e-bikes

X-ray fluorescence (XRF) measurements of the cells were performed before and after laser cleaning with a Horiba XGT9000 instrument under vacuum to minimize air absorption and improve detection sensitivity. Full-surface scans of the battery cell tops were conducted with a pixel size of 88 µm, while detailed scans of three selected spots on each cell were acquired with a pixel size of 8 µm. This approach allowed both an overview of elemental distribution across the surface and high-resolution analysis of localized areas to understand the effect of laser cleaning.

SEM analysis was performed before and after laser cleaning of the battery cells with a FEI Megaellan 400 XHR SEM with EDS capabilities, the analysis was performed with 20 kV and 64 pA. To accommodate space constraints in the chamber of the SEM, the battery cells were opened and only the top part of the cells was analyzed, the bottom part of the case as well as the battery electrodes and separator were discarded, as these parts of the battery cells are not relevant for the analysis presented in this study.

Results

Battery cells were received directly from the manufacturers and handled with care to preserve their original condition. To avoid introducing external contamination, the tops of the cells were never touched and no contact with foreign materials was allowed. All analyses were therefore conducted on cells in their as-delivered state, ensuring that the results reflect only intrinsic surface and material characteristics, and then after the laser cleaning step.

1. Before laser cleaning

The following summarizes the XRF and SEM-EDX, analyses performed on the cells prior to laser cleaning:

a) X-Ray Fluorescence (XRF)

XRF analysis of the battery cell tops revealed the presence of a nickel coating on the stainless steel surface in the full-surface scans (shown in Figure 2 for the Molicel battery). This was observed on both the positive and negative terminals of the Samsung and Molicel batteries, as well as on the negative terminal of the Panasonic cell. In contrast, the positive terminal of the Panasonic cell showed signals corresponding to aluminum and manganese. The manganese peak may result either from manganese alloying in aluminum (commonly in Al3xxx series alloys) or from spectral interference between Mn and Al. Overall, the XRF results confirm the manufacturer-applied surface treatments.

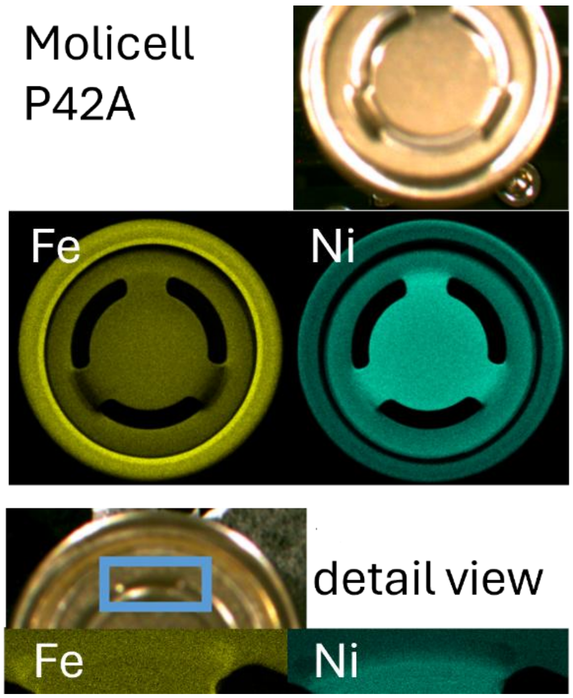

Figure 2: Results of XRF analysis of the Molicel P42A before laser cleaning, which has Ni coated stainless steel terminals in the top of the cell. A result of the detailed analysis of one spot with 8 µm resultion of the analyzed cell is shown in the bottom.

Detailed spot scans with an 8 µm pixel size were performed at three selected locations on each cell. The results showed that the nickel coating on the stainless-steel parts was uniform across the analyzed areas, with no significant local depletion or contamination detected. An example of one of the analyzed spots is presented in Figure 2 in the bottom. These findings establish a clear baseline for evaluating possible damages of laser cleaning to the Ni coating and its impact on the surface composition.

b) Scanning Electron Microscopy with Energy Dispersive X-Ray Spectroscopy (SEM-EDX)

SEM-EDX analysis was performed on all cell types both before and after laser cleaning. Due to space limitations, only the results for the Samsung 50E cell are presented here in Figure 3; results for all other cells are available upon request. Analyses were conducted at the center of the positive terminal as well as at the edge of the cell, corresponding to the negative terminal.

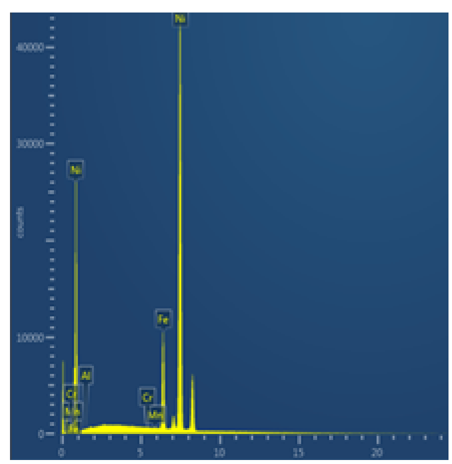

Figure 3: SEM-EDX analysis of the positive terminal of the Samsung 50E battery cell. The elemental analysis shows 96.7% Ni and 3.1% Fe content on the surface.

Analysis of the center of the positive terminal revealed 96.7% ± 0.1% Ni and 3.1% ± 0.1% Fe. Detailed examination confirmed complete coverage of the terminal with a nickel coating and a surface of very low roughness. Similar results were observed for the negative terminal of this cell.

High-resolution SEM-EDX analysis demonstrates full coverage of both terminals with a nickel coating and a smooth surface structure. Multiple spots with a total area of 40 × 60 µm were analyzed for each terminal, which are used as representative areas of the entire top surface of the cell.

2. After laser cleaning

a) X-Ray Fluorescence (XRF)

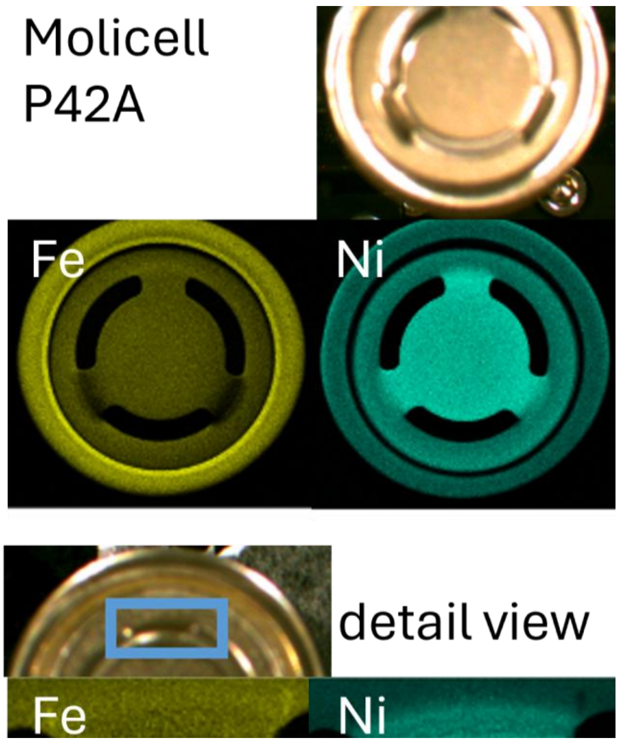

Figure 4: Results of XRF analysis of the Molicell P42A after laser cleaning, and the detailed analysis of one spot with 8 µm resultion of shown in the bottom. It can be seen that the metallic surfaces of the battery cells are not damaged by the laser cleaning process.

XRF analysis of the battery cell parts after laser cleaning is presented in Figure 4 for the same cell as shown before laser cleaningError! Reference source not found.. No c hanges in the elemental composition of the parts were observed, indicating that the laser cleaning process did not alter the bulk surface composition or damage the nickel coating. Maintaining the integrity of the coating is critical to ensure successful wire bonding and to prevent damage to the battery cell casing.

b) Scanning Electron Microscopy with Energy Dispersive X-Ray Spectroscopy

SEM-EDX analysis of the Samsung 50E battery cell after laser cleaning showed that the nickel coating on the positive terminal remained intact. The measured elemental composition - 96.5% Ni and 3.2% Fe - remained essentially unchanged compared to the pre-cleaning measurements shown in Figure 3, confirming that the laser cleaning did not damage the coating of the positive terminal of the battery cell.

SEM surface analysis and SEM-EDX analysis of the negative terminal of the same battery cell is presented in Figure 5. The results indicate that laser cleaning did not damage the nickel coating or the surface of the negative terminal, which is consistent with the results of the XRF analysis. Maintaining a complete Ni coating is essential for ensuring successful wire bonding. [6]

For the negative terminal, the elemental composition of the surface after laser cleaning remained unchanged

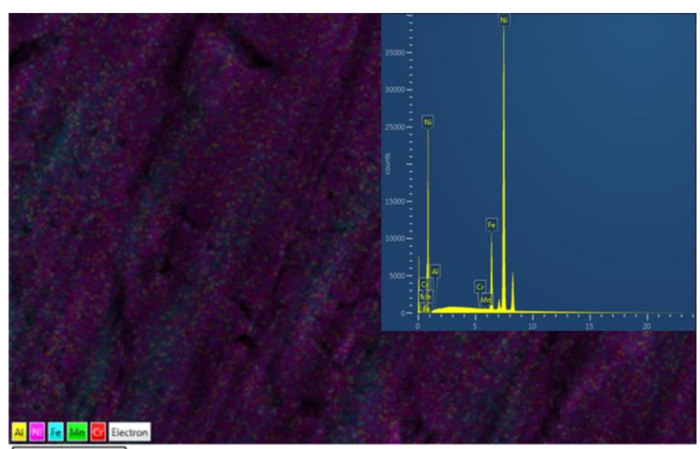

Figure 5: SEM-EDX analysis of the negative terminal of the Samsung 50E battery cell after laser cleaning. Different colors represent different elements on the surface of the metal, which is shown to be Ni coated. The elemental analysis shown in the top right shows 86.5% Ni and 13.3% Fe content on the surface.

compared to pre-cleaning measurements, confirming that the process did not damage the battery cell surface. Analysis of the surface roughness (shown also in Figure 5 for the negative terminal) showed for both the positive and negative terminals no differences, further demonstrating that the metal surface remained unaltered after the laser cleaning step.

IV. Conclusion

It was found that laser cleaning can be performed successfully on the battery cell without damaging the top metallization layer of all the cylindrical battery cells. It was shown that Ni-coatings on the battery terminals stay fully intact while being cleaned with 15.25 W laser power and that no changes of the microscopic surface structure of the battery terminals occurred due to the laser cleaning. It was also shown that the elemental composition of the battery terminals remains unchanged. The effectiveness of the laser cleaning will be evaluated in future studies.

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