Digital Transformation of High Voltage Isolation Control and Monitoring System for HVE-400 Ion Implanter

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Abstract

The HVE-400 ion implanter is a specialized ion implantation system designed for boron and phosphorus doping of semiconductor materials. The ion source and extraction deflection system operate on a high-voltage platform, whereas the corresponding control system is maintained at ground potential. Control and measurement signals for various parameters at the high-voltage terminal must be transmitted between ground and high voltage via optical fibers to achieve electrical isolation. An upgrade has been implemented due to aging of the fiber-optic transmission control and monitoring system, which had become unstable. The modernization replaces the original distributed single-point control architecture with an advanced distributed centralized control approach, integrating all control and monitoring functions into an industrial control computer for digital operation and display. The software incorporates two distinct automatic calculation methods for ion mass number. Following the upgrade, the implanter's high-voltage platform control and monitoring system exhibits characteristics of digitization, centralized control, high reliability, robust anti-interference capability, rapid communication speed, and user-friendly operation.

Full Text

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Abstract: The HVE-400 ion implanter is specialized equipment for boron and phosphorus doping of semiconductor materials via ion implantation. The ion source and extraction deflection system operate at high voltage, while the corresponding control system resides at ground potential. Control and measurement signals for various parameters at the high-voltage end must be transmitted between ground and high voltage through optical fibers to achieve electrical isolation.

An upgrade was necessitated by the aging of the original fiber-optic transmission control and monitoring system, which could no longer operate stably. The transformation replaces the conventional distributed single-point control method with an advanced distributed centralized control architecture, integrating all control and monitoring functions into an industrial computer for digital operation and display. The software implements two independent methods for automatic calculation of ion mass number. Following the upgrade, the implanter's high-voltage platform control and monitoring system features digitization, centralized control, high reliability, strong anti-interference capability, fast communication speed, and simplified operation.

Key words: High voltage isolation; Optical fiber communication; Control signal; Feedback signal; Decentralized centralized model; Digital graphical interface.

1. Background Introduction

The HVE-400 ion implanter, manufactured by High Voltage Engineering Europa B.V. (HVE) in the 1980s, is specialized equipment for semiconductor ion implantation processes. The system comprises an ion source, analyzing magnet, acceleration tube, focusing and deflection system, scanning system, target chamber, and control system. The ion source operates at a high voltage potential of 30 kV (extraction voltage) plus 400 kV (acceleration voltage), while the extraction system, initial focusing components, and analysis deflection magnets are located on the 400 kV high-voltage platform. The corresponding control system platform remains at ground potential.

Control signals for the ion source—including filament, anode, source magnetic field, heating oven, and gas inlet flow control—are 0–10 V continuously adjustable DC voltage signals transmitted from ground potential. These signals undergo conversion and are sent via optical fiber to the high-voltage terminal to control the ion source. Measurement parameters at the high-voltage platform include filament voltage, filament current, anode voltage, anode current, source magnetic field current, and heating oven current. Voltage signals are modulated into 0–10 V DC signals, while current signals are modulated into 0–60 mV DC signals. All measurement signals are converted and transmitted from the high-voltage terminal to the ground-level monitoring console through optical fiber.

The principle block diagram of the original fiber-optic transmission control and monitoring system is shown in Figure 1 [Figure 1: see original paper]. This system employed a decentralized single-point control method, with each data point set manually via adjustment knobs and displayed on independent instrument panels, requiring a dedicated fiber and conversion system for each signal.

After decades of operation, many components of the original control and monitoring system have aged, resulting in reduced reliability of both control and acquisition signals and creating potential safety hazards and operational inconveniences. Consequently, a comprehensive upgrade of the implanter's high-voltage platform fiber transmission control and monitoring system was undertaken.

2. System Architecture

Based on comprehensive analysis of relevant literature [2–20], this upgrade employs multi-mode optical fiber for high-voltage isolation and modular components including Advantech photoelectric conversion modules and A/D and D/A conversion modules [5,8,14,15,16,21] to construct the system framework. All data transmission and reception utilize an advanced distributed centralized fiber communication mode, replacing the original distributed single-point approach. All control and monitoring functions are consolidated in an industrial computer for digital graphical display and operation.

The implanter control and monitoring system utilizes two optical fiber communication loops. The first loop controls and monitors all high-voltage-end ion source components (at 400 kV + 30 kV potential), including control signal transmission for filament, anode, source magnetic field, heating furnace, and inlet gas flow, as well as feedback of current and voltage measurement signals. The second loop controls and monitors various components at the 400 kV high-voltage platform, including transmission of control signals for extraction voltage, analysis magnet, and focusing power supply, along with feedback of corresponding voltage, current, and status signals. The overall scheme is illustrated in Figure 2 [Figure 2: see original paper].

The control and monitoring system primarily consists of an industrial computer (with GUI control interface), two USB data conversion interfaces (E15-485 USB-to-RS485 converters), two sets of photoelectric signal conversion modules (ADAM-4541, enabling bidirectional conversion between RS485 and optical signals), several D/A conversion modules (ADAM-4024, 4-channel analog output modules that convert RS485 digital signals to analog voltage signals), several A/D conversion modules (ADAM-4017, 8-channel A/D converters that acquire analog voltage signals and convert them to RS485 digital signals), a relay module (ADAM-4060, implementing switch control for coarse adjustment of the analysis magnet), and other ancillary components.

In the computer control software, the values of control signals along with their corresponding port addresses and channel numbers are configured. Control information is output from the USB port to the E15-485 conversion module, which transforms it into RS-485 signals. These electrical signals are then converted to optical signals via the ADAM-4541 photoelectric conversion module and transmitted through long-distance optical fiber to the receiving end of another ADAM-4541 module at the high-voltage platform. The optical signals are converted back to RS-485 electrical signals and sent to the ADAM-4024 module, where the control value in the RS-485 signal is transformed into an analog voltage signal and delivered to the controlled device at the preset port address and channel. By presetting module addresses and channels, control signals for multiple devices can be transmitted through a single optical fiber.

Monitoring data collected from various instruments at the high-voltage platform consists of analog voltage signals. These signals are converted to digital information through the multi-channel ADAM-4017 analog-to-digital conversion module, combined with address and channel information into RS-485 signals, converted to optical signals by the ADAM-4541 module, transmitted to ground potential through optical fiber, converted back to electrical signals, and finally sent to the computer via the USB interface module for display on the graphical software interface. Similarly, multiple high-voltage monitoring signals can be transmitted through a single optical fiber.

3. Graphical Software Interface

The graphical software interface for the implanter high-voltage platform control and monitoring system is developed using the Delphi programming language and runs on the Windows 7 operating system, as shown in Figure 3 [Figure 3: see original paper]. All control and monitoring functions are centralized on this graphical interface for display and operation. The main interface is divided into two panels: the ion source control panel and the high-voltage platform control panel, and includes "Start," "Initialize," "Pause," and "Exit" buttons for straightforward operation.

Upon launching the main GUI, users must verify that software configuration matches hardware settings before clicking "Start." In the "Setup" menu, the communication settings item allows checking of USB port numbers to ensure consistency between software settings and the physical positions of the two USB conversion cards, with port communication parameters configured as "9600, n, 8, 1." The addresses and channel numbers of D/A, A/D, and I/O modules can also be modified and configured through the program options. In the "Setup" menu, the module settings item opens a configuration tab where correct values are set according to the hardware module addresses and the channel numbers corresponding to different signals, ensuring software-hardware consistency. Additionally, to align control signals and measured feedback values with the actual ranges of physical quantities, linear calibration of each signal can be performed using the calibration setting menu item in the "Setup" menu.

Once initial setup is complete, all configured parameters in the setup menu are automatically saved and loaded automatically during subsequent experiment runs. The "Init" command resets all control signal input values (displayed in white text boxes with up/down fine-adjustment arrows) to zero, preventing automatic loading of previous experiment's control values at the start of a new run. The initialization command does not affect parameter values set in the "Setup" menu. After completing setup and resetting control parameters to zero with "Init," a new experiment can be initiated by pressing "Start."

Control signals can be entered manually in the text box or adjusted incrementally using the up/down arrows. Feedback signals are displayed in real-time on corresponding status monitoring bars after range calibration. When experimental conditions are stable, the "Pause" button can be pressed to temporarily lock the control signal input boxes, preventing accidental adjustments from affecting the experiment. When parameter adjustments are needed, pressing "Start" again restores normal operation. Upon experiment completion, control signals should generally be returned to zero before pressing "Exit" to terminate the session.

4. Improvement of Mass Number Calculation

In ion implantation experiments, ions extracted from the ion source typically contain mixed components of various species. The analyzing magnet selects the target ion AX^{n+} for implantation. Under fixed extraction voltage, varying the magnet current generates a magnetic field that deflects ions with different mass-to-charge ratios through a 90-degree magnet into the acceleration tube and ultimately into the target chamber.

The mass-to-charge ratio of ions passing through the deflection magnet is determined by the equation:

$M/q = k$

where M is the ion mass number, q is the ion charge number, V is the extraction voltage, B is the magnetic field strength, and k is the calibration coefficient. In the original implanter, M/q calculation was implemented in hardware. The mass number calculation box collected extraction voltage signal V and magnetic field signal B measured by the HALL probe, performed hardware calculation using two LH0094CD calculation modules, adjustment potentiometers, and associated circuits, then converted the resulting M/q voltage signal to an optical signal for transmission to the control console via optical fiber, where it was converted back to a voltage signal and decoded for digital display.

Experimental observations revealed faults in the mass number calculation box circuitry, resulting in inaccurate mass number display. Therefore, we abandoned the M/q signal from the calculation box and instead directly transmit extraction voltage V, magnetic field strength B, and feedback magnet current I to the computer via optical fiber, performing mass number M calculation in software.

To verify HALL probe signal integrity and enable cross-validation, an alternative mass number calculation method was implemented. When the magnetic field is uniform, the relationship B $_0$I holds, allowing mass number calculation via:

$M/q = k_1 \cdot V/B^2$ or $M/q = k_2 \cdot V/I^2$

The calibration coefficients k_1 and k_2 can be determined experimentally using known ions such as $^{40}Ar^+$ and $^{14}N^+$. Since k_1 and k_2 can be calibrated at any time during experiments, this approach is significantly more convenient than adjusting the k parameter potentiometer inside the high-voltage chamber's mass number calculation box. In the software GUI, q can be set as an independent parameter, making M more intuitive to display than M/q.

During experiments, HALL probe signal issues were confirmed. Figure 4 [Figure 4: see original paper] shows a mass spectrum obtained using magnet current scanning (with M_2), where the X-coordinate represents M/q (u/e) and the Y-coordinate represents ion beam current I (A) measured in the target chamber using BF_3 gas as the ion source. The spectrum clearly identifies ions of different species, charge states, and residual impurity gases. When HALL probe failure occurs, mass number can still be calculated using current signals, providing greater operational convenience. After HALL probe repair, mass numbers M_1 and M_2 show good consistency following k_1 and k_2 calibration using $^{40}Ar^+$ and $^{14}N^+$ ions.

5. Summary

Due to aging of the fiber transmission control and monitoring system for the implanter's high-voltage platform, which compromised stable operation, an upgrade was performed to replace the original distributed single-point control mode with an advanced distributed centralized control architecture. All monitoring and control functions were consolidated on a computer for display and operation, incorporating dual-method ion mass number calculation capabilities. The graphical interface is simple, configurable, and easy to operate. The upgraded system offers high reliability, strong anti-interference capability, fast communication speed, and simplified operation, making it suitable for high-voltage, strong electric field, and strong magnetic field applications. A comparison of the control and monitoring system before and after renovation is presented in Table 1 .

Table 1. Comparison of the control and monitoring system before and after renovation

Comparison Item	Before Renovation	After Renovation
Control Mode	Decentralized single-point control	Decentralized centralized control
Structure	Discrete component circuit board	Functional module
Operation Interface	Mechanical panel	PC GUI

Comparison Item	Before Renovation	After Renovation
Number of Optical Fibers	Multiple (one per signal)	Few (shared)
Signal Processing	Hardware implementation	Software implementation
Operational Stability	Unstable (aging)	Stable
Maintenance Convenience	Complex	Simple

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Note: Figure translations are in progress. See original paper for figures.