A low stray light, high current, low energy electron source

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A design of an electron gun system is presented whose stray light emission is reduced by about three orders of magnitude compared to a regular low-energy electron diffraction gun. This is achieved by a combination of a BaO cathode run at rather low temperature and a 30° tandem parallel-plate analyzer used as an optical baffle. The system provides a high beam current of several microampers at 50 eV beam energy. The system can be used down to ~10 eV. © *1999 American Institute of Physics.* [S0034-6748(99)03510-8]

I. INTRODUCTION

We present the design of an electron gun system that delivers a high current of low-energy electrons of variable energy and almost completely eliminates the emission of stray light. This system is especially suitable for cathodoluminescence experiments of surface regions. Weak luminescent light emission in the visible range can easily be obscured by a strong background of stray light from the electron gun. High beam currents increase luminescence signals while a low kinetic energy of the electrons enhances surface sensitivity. Since electron guns that provide all three features are neither commercially available nor found in the literature an electron gun system had to be built for this purpose.[1] Its design is rather compact, the whole system can be mounted on a CF 40 flange.

II. DESIGN

A. Electron gun

The electron gun is based on a design introduced by P.W. Erdman and E.C. Zipf that provides a high current of low-energy electrons. We will only give a short description of the principal ideas and our implementation. For further details the reader is referred to their work.[2] The electron gun consists of a BaO cathode placed just in front of an aperture in the anode. An electrostatic einzel lens collimates the electron beam before it leaves the gun through a grounded exit aperture. The energy of the electrons is determined by the potential of the cathode with respect to ground. The design allows for energies of a few volts up to several hundred volts. The beam is collimated and the current is in the range of several tens of microampers at 50 eV electron energy.

Special attention is paid to the choice of nonmagnetic materials and, in addition, the complete system is encapsulated in a μ-metal tube which also reduces stray light emission. Oxygen-free copper and bronze are the main materials. The aperture disk of the anode is made of molybdenum and can easily be exchanged. Commercially available screws of copper nickel alloy are used. For the gun we chose polyimide (kapton, vespel) insulation elements over ceramic ones because this material can easily be machined in small dimensions with high precision. Ceramic tubes and washers are used for the optical baffle. The elements of the gun are gold plated without the usual magnetic diffusion-barrier layer of nickel. Since the BaO cathode is sensitive to both copper and gold vapor a small heat shield of tantalum is placed around the cathode. P.W. Erdman and E.C. Zipf found for their design that the electron current is very sensitive to the distance between the cathode and the anode aperture. Other authors found similar behavior for guns of a similar design.[3] In order to allow for optimizing this distance during operation we mounted the cathode holder on a miniature linear motion drive. A simulation[4] of the electron trajectories with recommended voltages for this gun design given by P.W. Erdman and E.C. Zipf is shown in Fig. 1. The simulation nicely reproduces the experimental results.

B. Optical baffle

Light emission must be suppressed not only in the direction of the electron beam but in all directions. We follow a two-fold strategy. First, we use a thermionic BaO cathode (STD 134 cathode with base, HeatWave) that is operated at a low temperature of about 1000 °C. It has a large emitter disk of 3.4 mm diameter and gives a high current density. The heater wire is completely encapsulated and therefore light emission is already reduced. Second, we designed an optical baffle (Fig. 1). It is made of two 30° parallel-plate charged particle analyzers. Their apertures were chosen large enough (3 mm) to allow all electrons to pass through them, that is, they do not work as energy analyzers. Although parallel-plate analyzers show several disadvantages over other energy analyzers,[5] they have properties that suit our needs very well. They are compact and easily manufactured. The electron beam is only translated parallel by a small distance if a tandem analyzer is used. The focus of a 30° parallel analyzers lies well away from the exit aperture. As can be seen from Fig. 1 there are four guarding plates between the top plate and the base plate. They ensure a uniform electric field gradient between the top and the base plate and also suppress stray light emission. All plates are graphite coated to reduce reflectivity and enhance light absorption. The distance of the centers between the first two apertures on the top surface of

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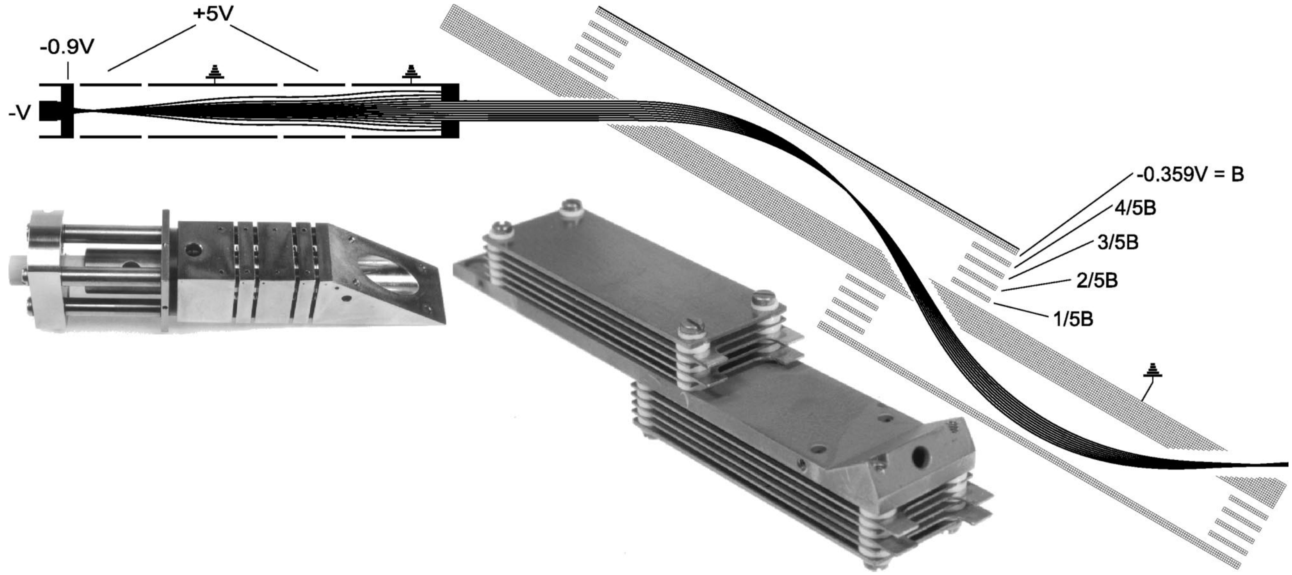

FIG. 1. Sketch and photograph of the electron gun with the optical baffle and simulation of the electron trajectories. V denotes the voltage applied to the cathode with respect to ground that determines the kinetic energy of the electrons.

the base plate (thickness 3 mm) is 33.5 mm. The distance between the second and third one measured on the opposite face of the plate is $33.5+3\sqrt{3}$ mm. The distance between the reflecting electrode and the base plate is 7 mm. The voltage necessary to pass the electron beam through the apertures is determined to $\frac{1}{2}*(d/g)*E/e$ with E the kinetic energy of the electrons, and d the distance between the base plate and the reflecting electrode.[6] g is the sum of the distances between the base plate and the exit aperture of the gun and the image, respectively.

In Fig. 1 the simulated electron trajectories through the optical baffle are shown. The system is designed to image the exit aperture of the e gun into the center of the exit aperture of the first analyzer which is at the same time the entrance aperture of the second stage. Field inhomogenities around the apertures lead to an slightly distorted beam. Meshes over the holes would have eliminated this problem, but would also reduce the beam current.

III. PERFORMANCE

A test of the electron gun without the optical baffle confirmed the performance characteristics reported by P.W. Erdman and E.C. Zipf.

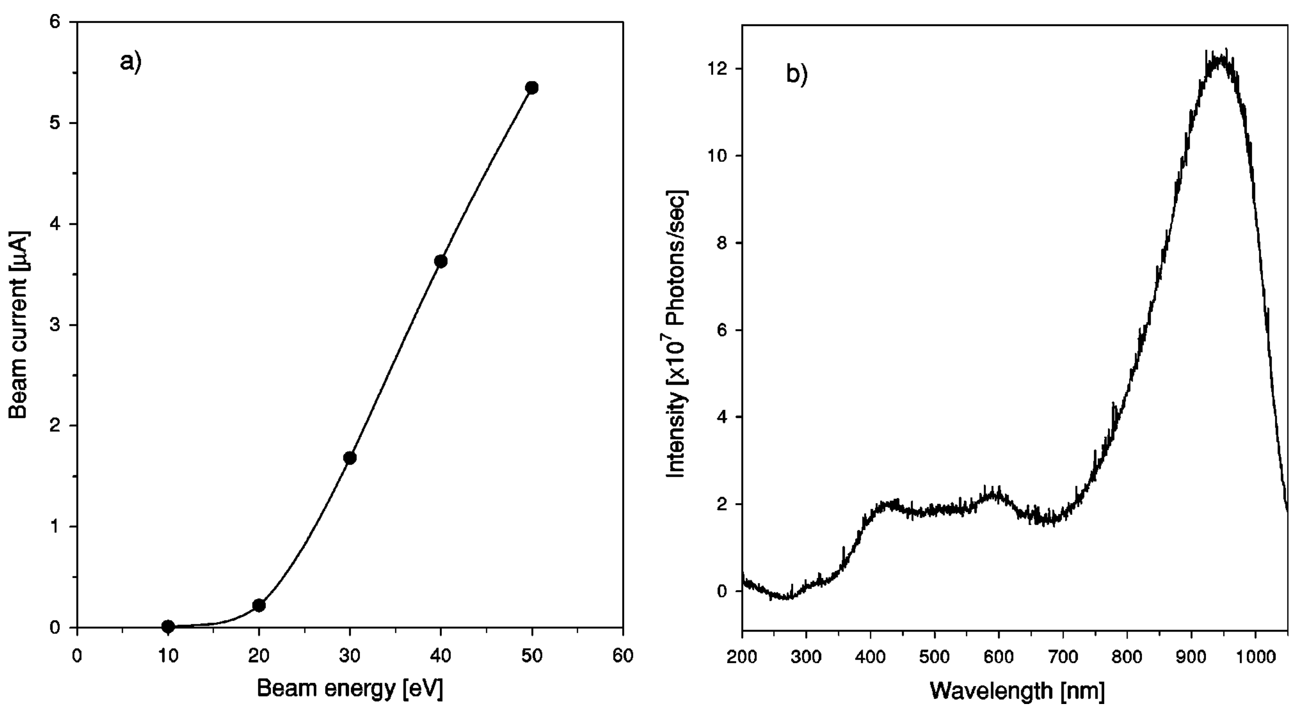

FIG. 2. (a) Beam current as a function of beam energy. (b) Transition radiation spectrum of a NiAl(110) crystal. The bands at 420 and 590 nm are transition radiation bands while the band at 940 nm is due to the remaining stray light of the electron source. (40 eV beam energy, 1.8 μA beam current).

The fraction of electrons passing through the optical baffle was determined by comparing two measurements. First, by measuring the electron current hitting the grounded first reflection plate. The second measurement consisted of setting the reflection voltage for maximum throughput and measuring the current impinging on a metallic target placed in front of the exit aperture. The transmission of the optical baffle was in the range of 20%.

Figure 2(a) shows the typical beam current for various electron energies. The current decreases with the decreasing energy. The voltages for the einzel lens as well as the baffle have to be slightly adjusted for different kinetic energies. The diameter of the electron beam is about 1 mm in a distance of roughly 6 cm.

Attached to our ultrahigh vacuum chamber is a ultraviolet-visible (UV–VIS) spectrometer with a liquid nitrogen-cooled charge coupled device (CCD) detector. The chamber is equipped with an Er low-energy electron diffraction (LEED) system with a LaB_6 filament from VSI. The position of the LEED gun with respect to the UV–VIS spectrometer is similar to that of the electron gun system. Only stray light can be detected for both electron sources. Comparing the integral light intensity we find that our system emits three orders of magnitude less light. In addition, the maximum of the light emission lies with over 900 nm well in the infrared region which makes it easy to subtract the residual background from measurements.

We built the electron gun system for cathodoluminescence experiments of very small metal clusters on a supported, ultrathin Al_2O_3 film on NiAl(110).[7] Our light detection system consists of a collector lens and an UV–VIS spectrograph with a liquid nitrogen-cooled CCD detector. Initial experiments show that the remaining stray light in our spectra is of the same order of magnitude as our signal which allows for easy separation [Fig. 2(b)].

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