New Concept of a Scanning Laser Microscope Integrated Inside an Encapsulated Cryogenic Sample Stage

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We introduce a compact scanning laser microscope that is applicable for direct visualization of dissipative electric structures in solid state systems. In order to overcome the disturbing influence of any background radiation, the shielded sample cryostage incorporates the complete microscope consisting of a laser diode, the deflection unit, and the focussing optics. Our imaging method provides access to a class of nonlinear transport phenomena that so far have eluded unperturbed observation.

Key words: Scanning laser microscopy; Cryogenics; Nonlinear transport phenomena.

The scanning laser microscope has been established a few decades ago in various fields of science and technology. Some general advantages over conventional optical methods are discussed already to a large extent [1]. The basic idea behind the imaging process is similar to that of scanning electron microscopy. A laser beam is focussed on the surface of the sample to be investigated. As a result of the interaction, one can obtain local information on such physical quantities as the reflection, the fluorescence, or the change in conductivity. By scanning the laser spot over the whole surface, the quantity of interest can be mapped as a function of the beam position. Upon transcribing to a gray scale presentation, we also take the brightness-modulated image to illustrate the local distribution of the system response.

Our interest concentrates on a scanning laser microscope that can be operated in the range extending from liquid-helium to room temperature. A further demand is to avoid penetration of any background radiation disturbing the sensitive phenomena of structure formation to be looked at. Hereto, we have designed an adapted solution where the laser diode together with the deflection unit and the focussing optics are mounted *inside* the shielded sample stage. The latter can be immersed into liquid helium of a conventional bath cryostat. Such an integrated sample-imaging unit excels the well-established scanning techniques of laser and electron microscopy where the whole apparatus is located *outside* an optical cryostat [2, 3].

The motivation for constructing the present imaging technique derives from previous low-temperature experiments where we have visualized the spatial and (to some extent) the temporal current flow during impact ionization semiconductor breakdown by means of scanning electron microscopy [4, 5]. In case of those materials which even are sensitive against low-energy radiation (e.g., p-type germanium), there remain severe shielding problems as a consequence of the window left for penetration of the beam probe. The external optical components, like lenses and mirrors, also deliver an unwanted source of room-temperature irradiation into the sample cryostage. These findings exemplarily demonstrate that low-temperature scanning electron microscopy and, accordingly, analog methods utilizing an optical cryostat are not applicable to radiation-sensitive systems. Our integrated concept has the potential to overcome such difficulties.

The present apparatus consists of an evacuable cylinder (that is, a tube sealed by a top and a bottom flange all made from stainless steel with 200 mm height and 50 mm diameter) immersed into a conventional bath cryostat. The complete scanning laser microscope is mounted on a base plate arranged in upright position inside the cylinder. Thermal coupling between the base plate and the liquid-helium bath occurs via the bottom flange which also carries the sample. Figure 1 shows the scheme of the scanning laser unit. The base plate (1) at the top contains a set of drill holes (2) that enable thermal coupling of the electric wiring. Below, we have arranged the laser diode including the collimator optics (3) together with a polarisation filter (4) and the deflection unit. The latter embraces the fixing (5), the bimorphous piezoelectric element (6), and the mirror (7) for beam deflection in the x-direction as well as of the corresponding fixing (8), piezo (9), and mirror (10) in the y-direction. At the bottom of the base plate, a focussing lens (11) completes the "flying spot" part of the

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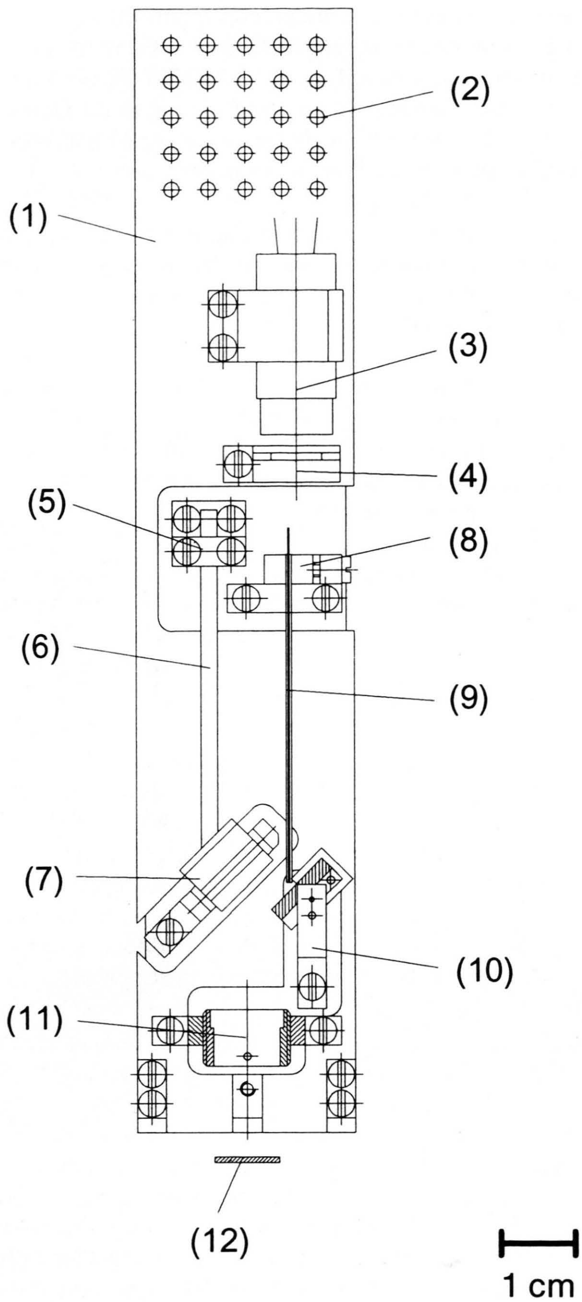

Fig. 1. Scheme of the scanning laser microscope: (1) base plate, (2) drill holes for thermal coupling of the electric wiring, (3) laser diode with collimator optics, (4) polarisation filter, (5) fixing of the x-direction piezo, (6) x-direction piezo, (7) x-direction mirror, (8) fixing of the y-direction piezo, (9) y-direction piezo, (10) y-direction mirror, (11) focussing lens, (12) sample position. For simplicity, the surrounding metal cylinder has been omitted. The length scale is indicated at the bottom right.

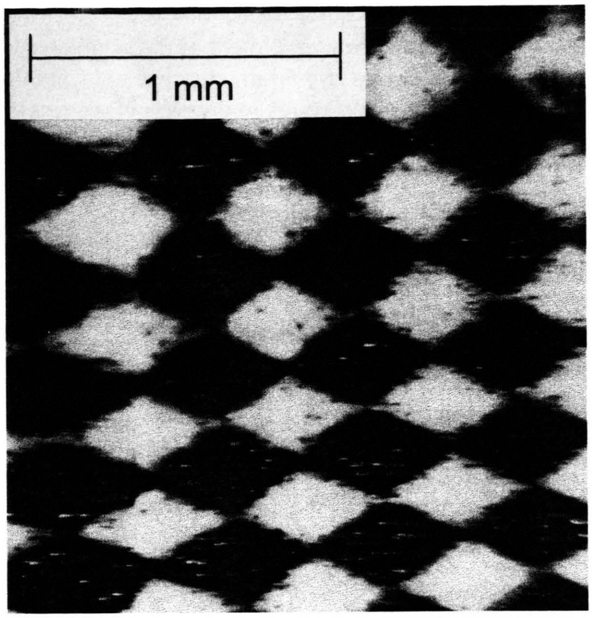

Fig. 2. Picture of a chequer-board-like pattern taken with the scanning laser microscope by detecting the scattered light. The length scale is indicated at the top left.

scanning laser microscope. The position of the sample to be investigated is marked by (12). In practice, we have glued the sample onto a sapphire disk by using two-component epoxy resin. If desired, the disk is in direct contact with the liquid-helium bath. Optimum thermal coupling can be reached in the temperature range of superfluid helium. Finally, imaging of the physical quantities one is interested in proceeds as follows. On the one hand, we measure the reflection or fluorescence of the sample by means of a pin-diode properly arranged next to the focussing lens. On the other hand, the change in electric conductivity of the sample is recorded as a function of the beam position.

For completeness, we present some technical data. The wavelength of the laser diode at room temperature is 670 nm, the emitted light power 1 mW. The focus of the light is adjusted to infinity, the diameter of the beam limited to about 3 mm. The focal length of the focussing lens amounts to 20 mm. We achieve in x- and y-direction a scan range of about 3 mm down to a temperature of 2 K. So far, the spot size of the laser focus on the surface of the sample has been determined to about 15 μm. The resolution strongly depends on the quantity to be measured. As an example of a reflection image taken at room temperature, Fig. 2 gives a scanned picture of a chequer-board-like pattern, the archetype of which was generated by a conventional laser printer. Note that the small (bright and dark) speckles were already present on the archetype. They give a rough impression of the resolution. Preliminary performance data have been outlined elsewhere [6].

To conclude, we have introduced a novel type of an integrated scanning laser microscope that can be used for imaging structure formation processes in radiation-sensitive solid state systems and is particularly well adapted for liquid-helium temperature applications. As a further advantage, our apparatus still operates in a strong magnetic field. First experiments, starting from impact ionization breakdown phenomena in bulk semiconductors and aiming to the Quantum Hall Effect in low-dimensional semiconductors, will be subject of forthcoming publications.

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