4 Technical specifications

4.1 *Range*

In practice the range of this type of specific resistivity meter is restricted for the following reasons.

(i) The maximum current supply cannot be much higher than 1 A without requiring transformers too large for this kind of instrument.

(ii) The input impedance at the preamplifier is in the region of 10 MΩ due to the capacitive connections at the measuring frequency.

(iii) 10 mV is the smallest detectable voltage signal able to be handled by the AC-logarithmic circuits.

Conditions (i) and (iii) indicate that the lowest measurable resistances of the sample between the potential contacts could be of the order of 10 mΩ. Condition (ii) implies that the highest measurable resistances could be of the order of 10 MΩ. Thus with these simple assumptions the range of the device would be nine decades. With special arrangements it is possible to extend the range of the meter by a few decades (Andersson *et al* 1975).

Because the difference between the signal levels of u_0 and u cannot be much higher than three decades in practice, one reference resistance is not enough to cover the whole range. For simplicity it was decided that two reference resistances with a manual scale-changing selector would be used.

4.2 *Calibration*

Calibration of the instrument is performed easily and accounts for the k factor outlined in equation (1) and table 1. The measuring circuit is made compatible with all sample holders by choosing R_0 so that k is equal for all sample holders. Calibration can also be done experimentally by replacing the sample with suitably selected resistor chains.

4.3 *Accuracy*

Because of the purpose of the measurement the meter was not designed to be a high-accuracy instrument. Through the nine decades the accuracy is better than $\pm\frac{1}{4}$ decade. The main reasons for this inaccuracy are the non-ideal logarithmic amplifier and the various stray currents, especially capacitive ones, in the sample holder. However, it is possible to increase the accuracy and extend the range of the meter easily by eliminating stray currents and by enlarging the signal levels.

Acknowledgments

The work has been done in cooperation with Outokumpu Oy 1973–7. The authors are very grateful to Professor E Laurila, member of the Academy of Finland, and to Mr M Laurila for all the support they have given us during the work.

References

Andersson T, Yström L and Persson B 1975 A wide-range resistance meter with logarithmic output for continuous measurements over several decades *J. Phys. E: Sci. Instrum.* **8** 398–402

Keller F C and Frichknecht F C 1966 *Electrical Methods in Geophysical Prospecting* (New York: Pergamon)

Niininen H 1973 Measurement of electrical conductivity: an application in geophysics *Dipl. Engng Thesis* Helsinki University of Technology, Espoo (in Finnish)

van der Pauw L J 1958 A method of measuring specific resistivity and Hall effect of discs of arbitrary shape *Philips Res. Rep.* **13** 1–9

J. Phys. E: Sci. Instrum., Vol. 12, 1979. Printed in Great Britain

System for the measurement of fast response times under fast electromagnetic irradiation

Ivan Schuller,†§ M Clark,† J Berman† and K E Gray‡

† Department of Physics, University of California, Los Angeles, California 90024, USA

‡ Solid State Science Division, Argonne National Laboratory, Argonne, Illinois 60439, USA

Received 1 February 1978, in final form 30 October 1978

Abstract We describe a system that has been used successfully for the measurement of relaxation times of superconducting tunnel junctions under light irradiation. The system allows the measurement of 2 μV signals of less tha 10 ns rise time, with a signal-to-noise ratio of better than 4. We also describe, for the first time, the behaviour of a commercial GaAs solid state laser at cryogenic temperatures.

1 Introduction

Recently there has been considerable interest in the time-dependent properties of solids, particularly in the field of non-equilibrium superconductivity. The basic parameters being studied are the various relaxation times involved. We describe a system that allowed the measurement (Schuller and Gray 1976, 1977) of 2 μV signals with a signal-to-noise ratio of 4 and rise times of less than 10 ns, generated by a superconducting tunnel junction that was irradiated with a fast laser pulse.

We also describe, we believe for the first time, the behaviour of a commercial GaAs solid state laser (904 nm) at cryogenic temperatures. In any laboratory that has cryogenic facilities, the use of a GaAs laser can save a considerable amount of money where a high-power pulsed laser is required.

2 Apparatus

The irradiation system consisted of a GaAs injection laser (RCA, SG2012) pulsed by a fast pulser (HP214A) of about 10 ns rise time. The detection system used fast amplifiers and a signal averager. The tunnel junction and the laser were encased in separate superconducting niobium shields to avoid direct electromagnetic pick-up (seen as a ringing at the beginning and end of the pulse), and they were located either in the same ^{4}He Dewar (Schuller and Gray 1976) or in two separate Dewars (Schuller and Gray 1977). To improve the screening still further, 50 Ω solid coaxial lines (UT-141SS, available from Blake Assoc., Medford, Massachusetts) were used for the electrical pulses to the laser and for the biasing and detecting channels. The 115 V supplies for the amplifiers, oscilloscopes, etc were floated to eliminate all possible ground loops. The total pick-up at the junction was less than 15 μV peak-to-peak. A block diagram of the experimental set-up is shown in figure 1. The junction was optically connected to the laser by a fibre optic bundle that had a loss of less than $\frac{1}{2}$ dB. The junction was biased with a battery-operated power supply, and the high-frequency pulses were blocked from this supply with a low-pass RC filter.

§ Present address: Solid State Science Division, Argonne National Laboratory, Argonne, Illinois 60439, USA.

0022-3735/79/040263+03 $01.00

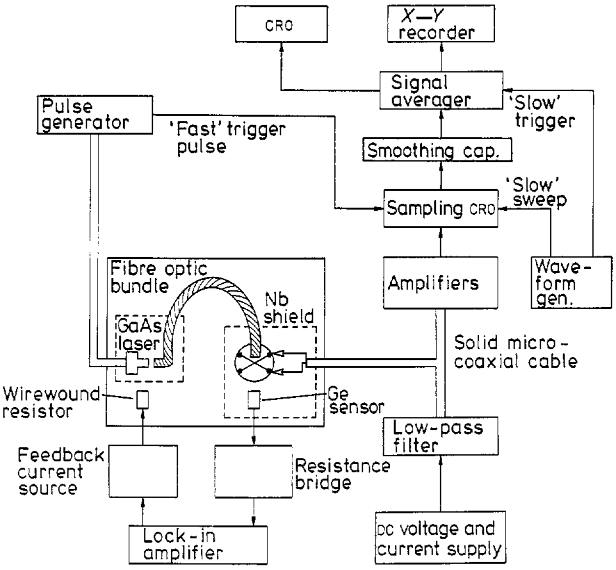

Figure 1 Experimental set-up for the measurement of the relaxation time of the superconducting order parameter.

The output pulse from the junction was first amplified by two low-noise amplifiers (HP162A, HP8447A) which had a fast rise time of the order of 4 ns and a total gain of 80 dB. The circuits of an oscilloscope (Lumatron 120A) sampled the amplified pulse at a time τ after the arrival of a 'fast' trigger pulse from the laser pulse generator (HP214A) and produced an output which at any instant was proportional to the most recent sample. This output was smoothed by a smoothing capacitor. At this stage the system equivalent noise referred to the input was about 20 μV peak-to-peak. To explore the pulse shape and reduce the noise further, a sawtooth ramp from a Tektronix 162 waveform generator was used to sweep slowly (about 10 s) through the pulse in the sampling oscilloscope circuits, while the smoothed output was recorded in a digital memory and signal averager (Varian TAC C-1024) which was triggered at the start of the 'slow' sweep. The sweep was slow enough to avoid distortion of the pulse by the smoothing capacitor. The output from the signal averager could be displayed on an oscilloscope or *X–Y* recorder (Honeywell 560A), and the system equivalent input noise was at that stage less than $\frac{1}{4}$ μV. An alternate detection system in use at present consists of two 130 ps amplifiers (AC-3020LN and AC-1200H from B and H Electronics, Box 490, Chester, New York 10918) with a total gain of about 70 dB, a Tektronix sampling oscilloscope (7S14), and a Northern Tracor (NS-544) signal averager.

Although this arrangement adequately reduced the noise, it was also necessary to compensate for the 10–15 μV pick-up (ringing) at the beginning and end of the laser pulse. This was accomplished as part of the averaging process in the following way. For exactly one-half of the sweeps the polarity of the battery supplying the DC junction bias was reversed and the waveform from the sampling scope was subtracted from the memory. In this way the relaxation time signal (which reverses polarity with DC bias) was added and the pick-up (which remained unchanged, since neither any physical part of the pulse circuit nor the impedance was changed) subtracted. As a result, the pick-up could be compensated to better than $\frac{1}{4}$ μV. A typical signal taken directly from the *X–Y* recorder is shown in figure 2. The signal averaging and subtraction have clearly greatly reduced the noise as well as the pick-up. The rise time of the pulse shown is limited by the relaxation time of the superconductor and not by the detection system; this was checked by measuring a fast pulse (5 ns, 10 μV) with the detection system. The decay signal shows a slight undershoot, caused by the low-frequency threshold of one amplifier (0·1 MHz). The B and H amplifiers have a lower threshold (2 kHz) and do not show the undershoot.

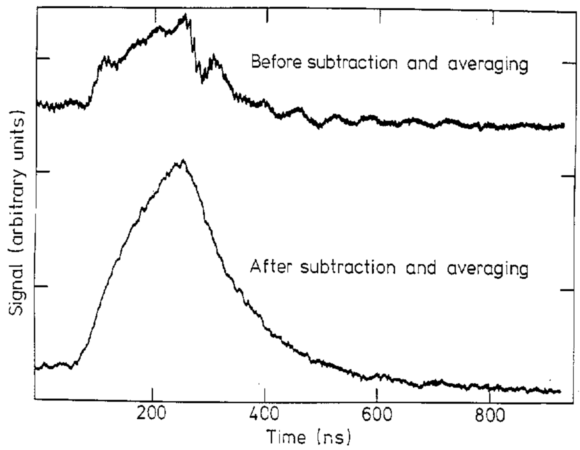

Figure 2 Typical signal obtained from a tunnel junction.

A GaAs laser was used in the temperature range 1·3–4·2 K. It was thermally anchored to a copper holder without any precautions taken to avoid thermal shock. The plot of light output as a function of current through the laser has the form shown in figure 3. There is first a linear region up to the 'lasing threshold', then there is a sharp break in the curve where the laser starts emitting coherent radiation. Deterioration has been observed in its performance (the change in the derivative of the light output against current at the lasing threshold decreases) after several months of use (curve B). This is possibly due to thermal recycling and self-induced damage due to heating. For comparison, we show the performance of an unused laser at 4·2 K (curve A).

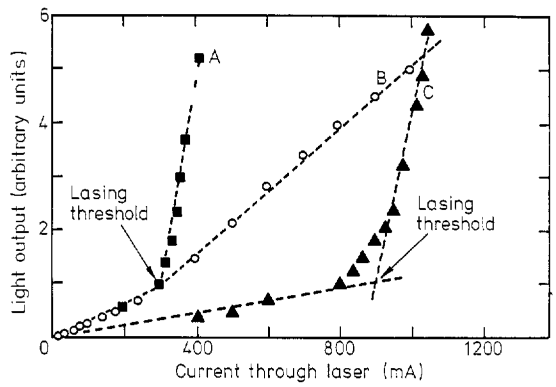

Figure 3 Light output against current for a solid state GaAs laser (RCA SG2012). The break point in the curve is the point at which the laser starts to emit coherent radiation. Curve A: the light output of an unused laser at 4·2 K; B: the light output of a laser at 4·2 K after 4 months of use; C: the light output of an unused laser at 77 K. The lasing threshold is much larger at higher temperatures and the 'performance' of the laser deteriorates with time.

In general the performance improves at lower temperatures, particularly below the λ point of helium. This is probably due to the fact that at helium temperatures the heat is conducted away from the laser more efficiently than at higher temperatures. A comparison of the performance of one of the lasers at different temperatures is given in table 1. A systematic study of the operation of this laser at helium temperatures can provide more information (Ciftan and Debye 1965, Keyes 1970, Chakravarti and Parui 1971, Eliseev 1973, Litvinov *et al* 1974) in problems relating to the operation and degradation due to thermal processes in semiconductor lasers.

Table 1 Comparison of laser parameters at different temperatures.

	77 K	4·2 K	1·3 K
Maximum pulse width (μs)	0·7	30	150
Lasing threshold (mA)	600	300	200
Forward voltage (V)	2·0	1·5	0·7
Maximum duty factor (%)	5	12	25

One of us (I S) is presently studying the behaviour of superconductors under microwave irradiation. The detection system is essentially the same. The microwaves are pulsed using an SPST pin diode switch (Narda Microwave Corp., Plainview, Long Island, New York 11803) with a bandwidth of 0·2–18 GHz. The results will be published elsewhere (Schuller and Dahlberg 1979).

In summary, we describe a system capable of detecting microvolt signals with nanosecond rise time using signal-averaging techniques.

Acknowledgments
One of us (I S) would like to thank the Solid State Division of the Argonne National Laboratory where part of this work was performed, and Professors R Orbach and P M Chaikin, and Dr Charles Falco for innumerable discussions. Our special thanks to Casey Kot from Northwestern University for doing such an excellent job with the fibre optics. The work was supported in part by the US Office of Naval Research, Contract no. N00014–75–C–0245 and by the National Science Foundation, Grant no. NSF DMR 76–82347.

References

Chakravarti A N and Parui D P 1971 Time dependence of the shift of the energy of peak emission in GaAs junction lasers operated with a flat-topped current pulse at 77 K
Int. J. Electron. **30** 589

Ciftan M and Debye P P 1965 On the parameters which affect the cw output of GaAs lasers
Appl. Phys. Lett. **6** 120

Eliseev P G 1973 Degradation of injection lasers
J. Lumin. **7** 338

Keyes R V 1970 Thermal problems of the pulsed injection laser
IBM J. Res. Dev. **17** 158

Litvinov, V F Molochev V I, Morozov V N, Nikitin V V and Semenov A S 1974 Dynamic instability of semiconductor laser at low temperatures
Sov. Phys. – JETP Lett. **19** 384

Schuller I and Dahlberg E D 1979 Microwave effects in superconductors
J. Low Temp. Phys. to be published

Schuller I and Gray K E 1976 Experimental observation of the relaxation time of the order parameter in superconductors
Phys. Rev. Lett. **36** 429.

Schuller I and Gray K E 1977 Temperature dependence of the relaxation time of the superconducting order parameter
Solid St. Commun. **23** 337