

Investigation of emission capability of reduced graphene oxide film cathode for terahertz vacuum electron devices

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Abstract-Terahertz vacuum sources with high power are in immediate need for several applications like medical, security, communication, etc. The power and performance of these devices mainly depends on cathode. As structure become smaller, it is very much difficult to obtain high power at terahertz frequency, using conventional low current density thermionic cathodes. As a result development of non-conventional field emission cathode is in progress, which may produce a very high current density with comparatively high current and can help in terahertz research and application. In this work our main aim is to develop and analyze high current density ($>10^3 \text{ A/cm}^2$) sheet beam film cathode using reduced graphene oxide (rGO)-nano particle composite.

I. INTRODUCTION

PHYSICAL dimension of terahertz range devices are practically very small. Producing higher power at terahertz range nowadays became very necessary as many applications depend on high frequency with high power. But with frequency, required current density also goes up drastically. Also many modern devices require sheet electron beam. It is becoming very difficult for conventional thermionic cathode to fulfill those requirements. Also, increasing the operating temperature can drastically reduce the life of the cathode.

Recent reports showed that scandium doped tungsten nano-particle cathode can produce $\sim 120 \text{ A/cm}^2$ current densities [1, 2], but this is still far below to the requirement ($>10^3 \text{ A/cm}^2$). Among the several alternatives, field emission cathodes are one of the promising candidates. Due to the very thin yet comparatively strong structure, rGO films [3,4] can produce relatively very high field emission current with high current density, which gives it a strong possibility to be used as a cathode for terahertz range vacuum electron devices (VEDs). The field emission current can numerically be estimated using the Fowler-Nordheim (F-N) equation [5].

However, the practical applications are still in experimental stage and also, field emission experiment reports[6,7] has shown that rGO films get degraded after a few milli-ampere of field emission current. The phenomena has been considered as a result of chemical impurities [8,9] (contaminations etc) integrated inside the film during the synthesis process. For these reasons, better understandings of these characteristics are necessary. In this research work our main goal is to develop an rGO film sheet beam cathode which can produce very high current. Among several approaches to improve the properties, adding metal composite shows a better prospect. Silver [10] and gold [11] metal has been the most common choices among others, but due to low melting temperature, they are restricted within low temperature applications.

II. RESULTS

In our first approach, an rGO film (fig 1.) synthesized using modified hummer method has been tested in vacuum chamber. The film dimension is $4 \text{ mm} \times 5 \text{ mm}$ of length and height respectively. A dc power supply (5kV) has been used as the voltage source. A stainless steel block and a molybdenum bar have been used as the film holder and the anode respectively. The vacuum level was kept at $\sim 10^{-7}$ torr with the help of a turbo and an ion pump.

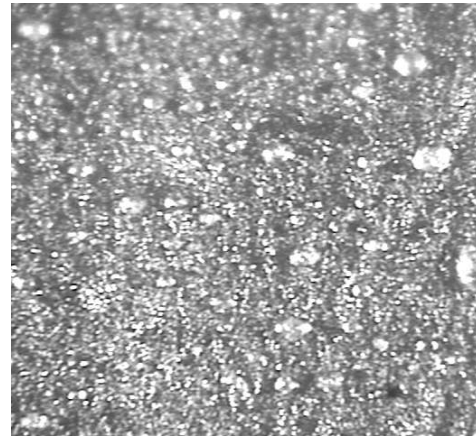


Fig. 1. Optical microscope image of rGO film

The I-V characteristics (Fig. 2) show that the emission current at the first cycle reaches up to 40mA at an applied voltage of 3.5 kV. At this peak value, some burnout at the tip has been observed and the current drops drastically. During the measurement of the 2nd cycle, it has been observed that the emission current is reduced by more than 70%.

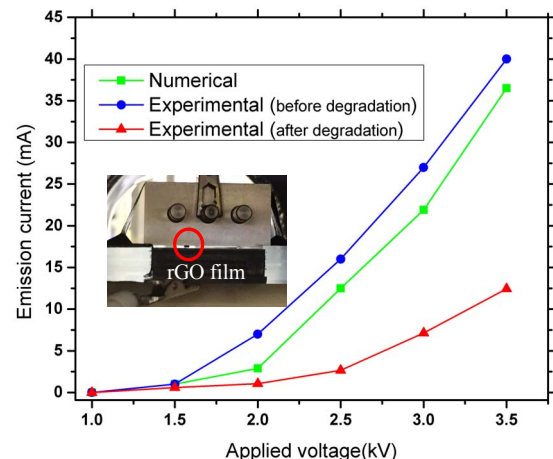


Fig. 2. I-V characteristics of rGO film as cathode.

After the experiment cycles, the film under test was removed and examined with an optical microscope. It has been observed that the tip was degraded severely (Fig.3). This phenomenon has been occurred due the overheating of the tip. During the high current emission, the tip gets heated by joule heating and the temperature on the film rose to a very high value. This may be the result of poor electrical conductivity and poor heat conduction between the film and the substrate.

During the chemical synthesis process, oxygen functional groups are created, which are reduced during the thermal annealing process. But still a lot of impurities and oxygen functional groups remained inside the film even after the thermal reduction process. This impurities and oxygen group causes the degradation of thermal and electrical conductivities, thus reducing the load handling capability.

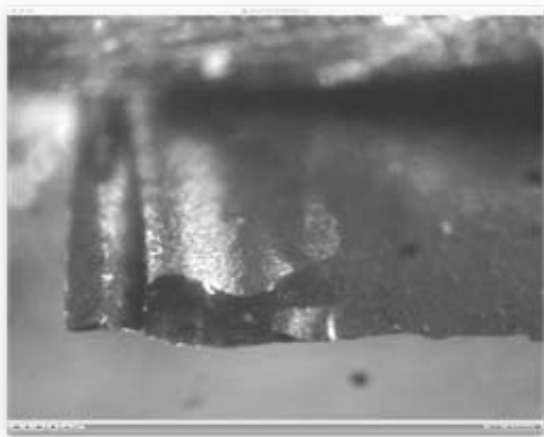


Fig. 3. Optical microscope image of the degraded film

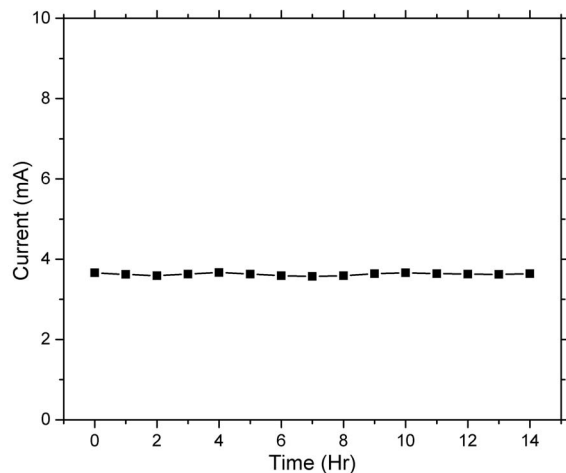


Fig. 4. Life time curve at 3kV

To check the stability during long run, a life time test also conducted at a low emission current. During the test, the film has shown a prospective life time characteristics. The applied voltage was kept at 3 kV with an emission current of 3.8 mA. Only 0.5% deviation has been observed during a 14 Hr. life time test (Fig.4), which implies a good stability during continuous experiment.

III. CONCLUSION

With very high field emission current from very thin edge and a good stability over time, reduced graphene oxide films show a good prospect to be used as a high current density field emitter. However, to use these films as cathode, a lot of improvement has to be made to the physical properties of the film material.

Our second approach will be to develop rGO-nanometal composite films with such a composite material that can withstand electrical and thermal load to a higher extend. After considering several composite materials, tungsten has been chosen as the nano-particle material due to its high thermal stability and electrical conductivity. A novel synthesis process also is in need to be devolved to integrate the tungsten composite inside the rGO film. A complete understanding of the field emission mechanism and film synthesis process will lead to an improved and compatible field emission cathode and will enable us to study further with compact terahertz vacuum electron devices.

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